Forest Research Information Paper 160

The Thin Green Line:

A Symposium on the State-of-the-Art in Reforestation

Ontario

Ontario Forest Research Institute
OFRI • IRFO

Forest Research Information Paper No. 160

The Thin Green Line

A Symposium on the State-of-the-Art in Reforestation

Proceedings

Compiled by
S.J. Colombo

July 26-28, 2005
Thunder Bay, Ontario, Canada

Ontario Forest Research Institute
Ontario Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, Ontario
Canada P6A 2E5

2005

APPLIED RESEARCH AND DEVELOPMENT • ONTARIO MINISTRY OF NATURAL RESOURCES

Library and Archives Canada Cataloguing in Publication Data

Thin Green Line Symposium (2005 : Thunder Bay, Ont.)
The Thin Green Line : a symposium on the state-of-the-art in reforestation : proceedings

(Forest research information paper, ISSN 0319-9118; no. 160)
Includes bibliographical references.
ISBN 0-7794-9195-5

1. Reforestation—Congresses.
2. Afforestation—Congresses.
I. Colombo, S.J. (Stephen John)
II. Ontario Forest Research Insitute.
III. Title.
IV. Series.

SD409 T54 2005 634.9’56 C2005-964012-X

Printed in Ontario, Canada

Single copies of this publication are available from:

Ontario Forest Research Institute
Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

Telephone: (705) 946-2981
Fax: (705) 946-2030
E-mail: information.ofri@mnr.gov.on.ca

Cette publication hautement spécialisée *The Thin Green Line: a symposium on the state-of-the-art in reforestation* n’est disponible qu’en anglais en vertu du Règlement 411/97, qui en exempte l’application de la Loi sur les services en français. Pour obtenir de l’aide en français, veuillez communiquer avec le ministère des Richesses naturelles au information.ofri@mnr.gov.on.ca.

This paper contains recycled materials.

Summary

The Thin Green Line symposium was attended by nearly 200 professionals, mainly from across Canada and the United States but also included participants from Europe and Asia. The symposium continued Ontario's long and rich tradition in reforestation. Forest regeneration is a cornerstone of managing forests sustainably. Prompt and efficient regeneration gives society the benefits of wood products, as well as the economic wealth that obtaining and processing wood creates. Good reforestation habits provide more wood from less land and increased timber productivity means that demand for wood products can be met with less impact on non-wood uses of the forest.

This document is a compendium of invited and volunteer papers and posters presented at the symposium. (Where papers were not submitted, abstracts are provided.) Papers by invited speakers are first, followed by volunteer presentations organized by symposium themes as follows: status of reforestation and afforestation around the world, nursery methods to produce target seedlings, planting and planting site treatments to optimize regeneration, and enhancing timber production and non-timber values through stand establishment. Papers are printed as received and content is the responsibility of the authors.

Résumé

Le colloque ***The Thin Green Line (Le Front Vert)*** a accueilli près de 200 professionnels provenant pour la plupart du Canada et des États-Unis mais également d'Europe et d'Asie. Le colloque s'inscrit dans cette longue et riche tradition qu'entretient l'Ontario à l'égard du reboisement. La régénération forestière est la pierre angulaire de la gestion durable des forêts. Une régénération efficace et rapide permet à la société de tirer avantage des produits du bois, de même que de la richesse économique qui accompagne la récolte et le traitement du bois d'œuvre. L'adoption de bonnes habitudes en matière de reboisement permet également de produire davantage de bois à partir de superficies territoriales moins importantes, et donc de continuer à répondre à la demande en réduisant du même coup les conflits avec d'autres usages qu'on pourrait faire de la forêt.

Le présent document est un recueil de résumés tirés des articles et affiches présentés par les conférenciers invités et volontaires à l'occasion de ce colloque. (Lorsque les articles ne sont pas présentés, des résumés sont fournis.) Les articles répertoriés ci-dessous sont d'abord ceux des conférenciers invités, ils sont suivis par les présentations des conférenciers volontaires, lesquelles sont classées selon les thèmes suivants : état de la forêt et du reboisement à l'échelle mondiale, méthodes visant à produire des semis « cibles » en pépinière, traitement des plantations et des terrains en vue d'optimiser la régénération du milieu et augmentation de la production de bois d'œuvre et des ressources non ligneuses par l'établissement de nouveaux peuplements.

Acknowledgements

The Thin Green Line symposium was made possible by the contributions of many individuals and organizations. Generous financial support was received from the Ontario Ministry of Natural Resources, Thunder Bay Ventures, the National Research Council's Industrial Research Assistance Program (NRC-IRAP), Tembec, Hill's Greenhouses, Bowater, KBM Forestry Consultants, A&R Greenhouses, Weyerhaeuser, Beaver Plastics, Monsanto, Jellien Tree Nursery, Jiffy Products, and the Sustainable Forest Management Network. **The Thin Green Line** symposium also received goods and services support from The Working Forest Newspaper, Valhalla Inn, Lakehead University, Jiffy Products, La Maison Verte Tree Nursery, Weyerhaeuser, Abitibi, Outland Reforestation, KBM Forestry Consultants, Cheadle Johnson Shanks MacIvor LLP, Norlink, and Fukushima Enstrom LLP.

The organizing committee is grateful to **Trudy Vaittinen** of the Ontario Ministry of Natural Resources for providing a range of excellent graphics. We are also grateful for the assistance of OMNR's **Rob Mackereth**, **Abby Obenchain,** and **Heather Wreggit,** and Lakehead University's **Abby Anderson**. The Forest Renewal Coop maintained the symposium website and their staff, **David Challen**, **Rachel Parks**, and **Scott Weibe**, provided valuable support. We are indebted to Bowater and Hill's Greenhouses for providing staff and tours of their sites. The conscientious hard work of our conference coordinator, **Sonia Gellert** of KBM Forestry Consultants, was a tremendous help.

The organizing committee for **The Thin Green Line** was **Laura Betts** (Forest Renewal Coop), **Grant Brodeur** (Broland Wilderness Reforestation), **Dan Corbett** (MNR), **Qinglai Dang** (Lakehead University), **Shelagh Duckett** (MNR), **Sonia Gellert** (KBM), **Bill Klages** (Bowater), **Joan Lee** (Lakehead University), **Thom McDonough** (MNR), **Kevin Van Duyn** (Hill's Greenhouses), **Jian Wang** (Lakehead University), and **Mike Wood** (PRT). These people and their organizations devoted many hours of their time to making the symposium a success. As co-chairs of the symposium and on behalf of all the members of the organizing committee, we thank participants of **The Thin Green Line** for an enjoyable and educational week.

Steve Colombo
Ontario Forest Research Institute
Ontario Ministry of Natural Resources

Bill Murphy
Forest Renewal Coop

Contents

The Thin Green Line

Invited Papers

Note: Papers and abstracts are reproduced as submitted.
Content is the responsibility of individual authors.

Challenges and Successes in Regeneration Practices in The Northern Mediterranean Basin

L. Ciccarese

Italy's Agency for Environmental Protection and Technical Services,
Nature Conservation, Via Curtatone 3, 00185 Rome, Italy

Introduction

The objective of this paper is to portray the nature and character of regeneration practices in the northern Mediterranean basin, a region comprising 13 countries: Portugal, Spain, France, Italy, Slovenia, Croatia, Serbia-Montenegro, Albania, Greece, Bulgaria, Cyprus, Malta and Turkey. Oversimplification is a risk when trying to describe forest regeneration in the region, as it is as varied as are forest resources, site conditions, ownership structures, population density, and the general socio-economic and political conditions of respective countries.

In the first part of the paper a general ecological description of the area will be given, as well as of the socio-economic context. The central part of the paper discusses regeneration practices, focusing on forest reproductive material production and stand establishment, considering uniformity and diversity among countries. Subsequently, hot topics surrounding forest regeneration and new issues in the political agenda will be pointed out. Case studies will be presented regarding regeneration.

The Context

The main features of Mediterranean climate are seasonal and daily photoperiodism and rainfall that is concentrated in the cold and relatively cold seasons, with a dry warmer summer season. Of course, this is a gross overgeneralization, as different local conditions generate subtypes of diverse climate: in fact, rainfall ranges from about 100 mm in pre-desertic zones to more than 2,500 mm on some mountains exposed to moist winds; and drought may last from two to six months. Such a climate and other natural factors, as well as human activities, have produced significant impacts on Mediterranean ecosystems, their fragility, instability and degradation (Barbero et al. 1990).

It has been estimated that forest cover was about 82% before the first anthropic settlements in the region, while now it ranges between 15 and 20%.

The Mediterranean basin is a site of exceptional biodiversity. The wealth of vegetation types and tree species located in Mediterranean forests has been recognized as one of the main features that distinguishes them from those in other parts of Europe (Quézel and Médail 2003). In the region forest covers about 66,8 million hectares, about 25% of the total land area and it has been increasing remarkably, even though deforestation in some countries is still significant. During the last decade, the average annual increase of forest cover has been about 2% per year. Main causes for such change are large-scale plantation programs, active conversion of agricultural land and meadow and other wooded lands, and natural expansion of forest into agricultural lands, grasslands and pastures, abandoned as a consequence of the decline of the primary sector's importance (Pettenella and Piussi 2000) after the blast-off of industrial development and the socio-economic growth. Timber harvesting on private and public forest of the region has dramatically decreased since the 1950s, mostly because of the conservation measures put in place in these countries and the weakened ability to compete with foreign wood producers.

As a consequence, growing stock and forest density are increasing, as forests become older. Also, the capacity to provide services may weaken, while risks of fire may increase. In contrast, riparian belts and suburban spaces are increasingly jeopardized by land development for housing, industry or tourism, by transportation infrastructures and by extensive degradation.

Forest degradation because of wars, climate change and desertification, and fires need to be mentioned. Fire has been the dominant disturbance that has shaped the character of the forests in Southern Europe, mostly because of a combination of high temperatures and water deficit during summer. Currently, fires are one of the biggest concerns for the protection of forests and safety of people and property in Southern Europe. The number of fires and area burned fluctuate annually in the Mediterranean region. During the period 1990–2002, an average of 40,000 fires each year destroy around 400,000 hectares of forests and other wooded land in the EU Member States, mostly (95%) concentrated in Southern Europe (Schelhaas et al. 2005), causing huge economic, social and environmental damage. It may be considered that in Spain a large wild fire caused deaths to 14 firemen the 17th of July this year.

Socio-Economic Context of Forest Regeneration

The economic value of Southern European forests is generally low, given the fairly inferior productivity of these ecosystems. In comparison, production of non-wood forest products (cork, resin, fruits, berries, medicinal and aromatic, wild flowers, edible mushrooms, truffles, honey, meat) has great importance. Ultimately, the value of services (biodiversity reservoir, protection of freshwater resources, soil conservation, recreational, historical and cultural values, landscape, climate change mitigation, eco-tourism, etc.) are of major importance in the region (Benoit de Coignac 2001, Weber 2005) and is nowadays even more emphasized in the forest laws of many regional countries.

In this context, afforestation and reforestation (AR) offer scope for a variety of designs, including afforestation to create forests for special purposes, which could also reduce pressure on existing forests. Forests are specifically dedicated for mountain bikers, horsemen, picnic sites, playgrounds, culture and history, etc.

As a consequence, plantation forestry in this area is expanding into a much broader range of species, e.g., broadleaved and wildlife-crop species, diverse species and local provenances, for which more practical information is needed in many aspects of forest nursery production. This trend is backed by EU forest policy (EC 2003).

In Southern Europe, the linkage of afforestation to agriculture is close. Afforestation on arable lands and meadows on a large scale started in the 1950s, covering several million hectares. AR was a way of addressing problems of agriculture overproduction and rural unemployment. AR was dominated by conifers (*Pinus* spp. and *Cedrus* spp., *Douglasia* spp). Many of these plantations were located in areas occupied by other tree species, notably belonging to the genus *Quercus* or other broadleaves (Krstić 1998).

Currently, industrial plantations of fast growing species (*inter alia,* hybrid poplars, eucalyptus, black locust, maritime and radiata pine), cultivated as intensive, industrial plantations, agroforestry systems or linear plantations and windbreaks, are beginning to meet a significant portion of the needs of local communities as well as of the national requirements in terms of timber supply and energy demand. Chestnut also has an important role.

Nowadays, the establishment of monospecific stands of conifers and other species mentioned before are decreasing, as AR for ecological and amenity reasons is increasingly undertaken

Apart from some countries, such as Bulgaria—where forest stand establishment operations are undertaken principally on state-owned lands and particularly on areas destroyed by fire, stands and plantations damaged by drought, clearings and non-forested areas (GGAF 2003)—most afforestation is done by private landowners, subsided by EC grants to participate in afforestation programs. Private landowners require subsidies for establishment and tending costs as well as additional compensation for lost agriculture income.

State and regional administrations participate to create relatively large programmes (such as the “Lombardy 10 large plain forests”), usually located close to urban areas, aimed at recreational activities, reclamation of disturbed areas, erosion avoidance, land biodiversity conservation.

Regeneration Practices

Natural regeneration

Natural regeneration has traditionally been widely used in Northern Mediterranean countries, especially where conditions are generally more favorable. Natural regeneration is appropriate if the provenances and species already growing in the site correspond to the conditions in time and space. Natural regeneration (and ‘assisted natural regeneration’) relies on existing mature trees expected to generate seeds and produce new forests.

In the part of the region where forestry has high standards, the silvicultural systems in use nowadays are based on the principles of a sustainable, "near-to-nature" forestry. Forest operations are cautiously controlled and restricted, aiming to provide timber production through forest natural regeneration.

Coppice is a woody crop raised from shoots produced from the cut stumps of the earlier crop. Coppicing is done for almost all broadleaves to produce small round-wood products, wood for fuel, fencing materials, and wood for paper and particle boards). Coppicing is largely widespread in some countries. In Italy (Pettenella et al. 2005) and Turkey (Makineci 2001) coppice represents a major silvicultural system, especially in privately owned forestlands.

Although still common in the region, coppice is currently considered an outdated silvicultural system. More and more old coppiced stands in the northern Mediterranean basin, from Portugal to Turkey, are subjected to conversion operations leading to high forest.

Artificial regeneration

Although natural regeneration is of historical importance and a prefered option all over the region, AR is also important, as shown by recent rates of planting in EU member countries, as well as EU access countries, Serbia-Montenegro (Dinić et al. 2001) and Bulgaria (Rafailov et al. 2003). Several thousand hectares of AR are established every year in the area, mostly subsided by EU grant.

Because of climate and disturbances, natural regeneration is difficult and demand for artificial AR exists. In fact, for some species, natural regeneration, though desirable, is problematic and insufficient, and at times impossible (Frochot et al. 1986, INRGREF, 1998, Merouani et al. 1998). Afforestation is normally used in former (abandoned) agricultural lands, and highly disturbed lands (after fires, etc.).

As plantation forestry in this area is expanding into a much broader range of species, e.g., broadleaved and wildlife-crop species, diverse species and local provenances, more practical information is needed in many aspects of forest nursery production. “They are not weeds, they are local plants”. These sentences by a US landscape designer, reported by McMullen (2005) expresses the worldwide trend in forestry to expand into a much broader range of species, e.g., broadleaved and wildlife-crop species, and local provenances, for multiple purposes (Colombo 2004).

Seed propagation

The trend of forestry on ‘new’ species is particularly relevant in Europe, where practical information is needed in many aspects of forest nursery production of a large variety of species. The role of research in implementing techniques for seed propagation is crucial. In this regard, outstanding studies have been carried on germination of a number of Mediterranean species. Transfer of know-how and knowledge about germination patterns have still to be improved.

Know-how is still incomplete and in need further development in many fields. A central issue is the study of ‘recalcitrant’ seeds of genera like *Quercus* and *Castanea*, of which natural regeneration is problematic and jeopardized by land fragmentation, especially in coastal areas, and it is something that can be a serious risk for genetic resource management (Piotto 2004).

Lack of investments for storing and pre-treating seeds (chilling, warming, etc.) facilities is a limit in many countries, as well as poor funding of research and extension programs on the issue of seed propagation.

Production of forest planting stock

Currently, two main types of nursery stock are produced in the region: bareroot stock, and container stock; greenhouse transplant stock is very rare. The use of containerized stock has successfully increased in the last decade, at the expense of bareroot stock. In Portugal more than 90% of nursery stock is produced in containers (Neves 2004). In Spain (Pardos et al. 2003, Ribeiro and Marques 2004) and Croatia (Orlić and Perić 2002) bareroot stock prevails.

For bareroot production, nursery beds are formed by hand or with a bed forming machine. In some countries—where undercutting is a routine practice—beds are raised 10-15 cm above the path level, and afterwards go down 2.5 to 5 cm, owing to transplanting operation.

Broadleaves like walnut, oak, chestnut and other species that have large seeds are grown for one season and are sown in the nursery beds at the final density. Sowing normally takes place in spring. Conifers (and broadleaves that have poor and unpredictable germination) are sown at high density, then seedlings are transplanted next season to the final density. Transplanting is done by hand or, in some countries and in some nurseries, by machine.

Final density varies from species to species and depends on the final target wanted by the nurserymen: it ranges from 25 to 100 seeds per m^2. For broadleaved species to be used for protection and environmental purposes adequate spacing to obtain sturdy plants, with a well balanced shoot/root ratio, is 120 cm^2 cm per plant, shaped 15 cm (between rows) by 8 cm (on the row). For species like *Juglans*, *Quercus*, *Celtis*, *Platanus*, *Acer*, spacing ranges from 100 up to 400 cm^2 cm per plant.

Undercutting (once or twice during the growing season), when practiced, is a very important operation in order to promote formation of second-order lateral roots and to make easier final lifting. The timing of root pruning is critical and many authors suggest it be done when the taproot has elongated at least 20 cm (Ciccarese 1997, McCreary and Canellas 2005).

Several studies carried out in many countries of the region show that lifting date (and the way it is done) is really crucial for performance (survival and growth) of the planting stock of certain species. Lifting is done in winter, when plants are dormant. The results of Root Electrolyte Leakage (REL) measurements on elm seedlings, at three different growing steps suggest that the best period for lifting from open nursery beds (for subsequent out-planting in plantations) starts in early November (Ciccarese et al. 2005). Pardos et al. (2003) have demonstrated that the best period for lifting *Pinus halepensis* and *Quercus ilex* is mid-December.

Bareroot stock can be transferred to cold storage (1°C) during winter to be used for spring planting from the middle of March until the early May. Alternatively, it can be heeled-in, in shaded and well-drained soils.

Root Growth Potential (RGP) is a good indicator of plant quality and subsequent field performance, as demonstrated by several studies and, recently, by an EU-funded research project. Research on field performance of planting stock grown with different methods have demonstrated significantly better survival and growth for larger caliper stock, with abundant and fibrous root system.

Containerized forest nursery stock is produced mostly in private nurseries, with use of irrigation systems, peat (sometimes in mixture with soil) and other artificial components. Composted pine bark is sometimes used in place of peat. In many countries, natural soil is now used in tree forest containerized production.

A wide array of containers are used, different in material, size, form, concept. Large containers are used, particularly for producing planting stock to be used on more xeric zones and difficult sites. The standard container is from 200 to 1500 cc (for one growing season) and even larger (Sardin et al. 2001). Marien and Drouin (1977) suggest using seedlings grown in container as big as 700 cm^3. Normally sowing in containers is done by hand; the use of high quality seed-lots is rare. For many reasons, the use of precision sowing machines is still sporadic. Containers are placed in greenhouses or protected areas or located outdoor.

Assessing plant quality

Poor quality planting stock is recognized as one of the main reason for failure of forest tree plantations (Ciccarese 1997b, Louro 1999, Radoglou, 2003, Ribeiro 2003). The focus on planting quality assessment has become more intense after the disappointing performance of a significant part of the forest stands established within the European Commission 2080/92 Regulation, which introduced a grant scheme for AR.

The Council Directive (EEC) No 105/99, entered into force in 2003 in all EU countries, lays down the conditions governing the marketing of forest reproductive materials in the Community (EC 2003). The Directive refers to the certification of genetic quality of reproductive material, as well as of their physical features. However, the Directive mentions morphological parameters to define planting stock quality.

With the aim to improve planting stock quality, private and state owned nurseries have adopted procedures and standards for producing forest reproductive material responding to the requisite asked by the Directive (which only asks for morphological attributes).

Various morphological, physiological and molecular methods have been developed to test the seedlings' condition before planting. It was also the topic of a 1994 IUFRO conference (Making the grade). A EC research project, "European approach for assessing re-growth potential of woody plants: parameters for plant vitality and dormancy of planting stock", studied morphological, physiological and molecular parameters for predicting survival and the rate of growth of tree planting stock. Root electrolyte leakage (REL) and root growth potential (RGP) are two seedling quality assessment methods that have been investigated widely and applied in laboratories: However, their operational use, by nurseries, is inconsistent. Very few nursery have adopted methods and instruments for assessing plant quality through physiological performance tests. In Portugal, since 1997, a process of certification has been approved, which involves assessing the quality of 52 million plants, using morphology attributes (Ribeiro and Marques, 2004) according to the rules introduced by the EC Directive (EC 2000).

Forest reproductive material

An EU scheme was set up in 1999 by Council Directive 1999/105 (EC 2003) on the marketing of forest reproductive material (FRM). The Directive ensures the plentiful supply of high quality FRM of the species concerned within the EU, by stipulating that forest reproductive material may not be marketed unless it is of one of four categories specified by the Directive, and that only approved basic material (the trees from which FRM is harvested) may be used for its production if the material is to be marketed.

Basic material must be approved by an official body as fulfilling the minimum requirements laid down in the legislation. This approval is subject to regular re-inspection. The categories differ in the strictness of the quality criteria which must be fulfilled by material. All information on FRM approved on a Member State's territory is held in a national register, including information about the area(s) in which the material is found or the geographic location (depending upon the category). The Directive introduces the concept of 'region of provenance': for a species or sub-species, the region of provenance is the area or group of areas subject to sufficiently uniform ecological conditions, in which stands or seed sources showing similar phenotypic or genetic characters are found, taking into account altitudinal boundaries where appropriate. The new directive reflects both the modern state of plant breeding and the increased public awareness of nature conservation.

Establishment

Direct seeding

In Europe, direct seeding—the method of creating or restoring woodlands by sowing tree seed directly into their final growing position—stretches back to the Middle Ages (Willoughby *et al*.). After being neglected for a long time, the method is gaining interest among forest managers as an alternative to planting nursery stock, especially when seeds are available in large quantities and at low costs, and when planting seedlings is difficult. Direct seeding can be an economical method for forest restoration, especially for establishing deciduous species (Montero and Caňellas 1999, Nabos and Epaillard 1995, Ciccarese 1997a; McCreary and Canellas 2005). Sardin et al. (2001) and Balandier et al. (2005) have proposed direct seeding for accelerating the establishment of late-successional broadleaved species, for the advantages of direct seeding over planting, such as more rapid establishment, the permanence of a leading shoot, and better root system form.

Seeds may be sown as a single tree species, or as a mixture of species, or occasionally in combination with an annual 'cover crop', such as cereal. The experiences carried out so far on direct seeding advise that some prerequisites need to be met: high germination capacity of seedlots, appropriate sowing technique, and absence of excessively competitive vegetation. Torres (1995) suggests the use of rodent repellent and Sardin et al. (20001) recommend for oak species the use of individual seed protection (metallic grid) and more than one seed per spot. Croizeau and Roget (1986) and Louro (1999) advise that seeding pre-germinated seeds in early spring may be an effective solution to regenerate oak species.

Planting and maintenance

Planting and maintenance depend on species, management objectives and an array of other factors, such as physiography, climate and weather conditions. Guidelines for AR in Southern Europe are available, at regional, national and sub-national levels, providing basic information to landowners and forest managers. Additional information on incentive programs and enrolment procedures is provided at local offices of national and provincial forest offices.

In the region, planting out is made from late winter to early spring. Poor survival and re-growth is associated with later planting. Most forest planting stock is 1-year-old (with exceptions, like poplar).

Site preparation practices are generally minimal, since planting occurs on abandoned agricultural lands. The public favors sound and sustainable management practices and dislikes mechanical and chemical weed control in forest plantations.

In Europe, in general, there is a reluctance to control weeds by herbicides, even though studies have demonstrated the incremental benefit of repeated vegetation control, particularly in the first years after planting.

The establishment of high quality broad-leaved crops is normally achieved by planting at close plantings, in keeping with high-yield objectives and poor seedling survival. High planting densities, such as 3m x 3m spacing, promote apical dominance ('positive competition') and restrict branch development. In this case, with the increasing request for and price of smaller logs, some land owners have adopted commercial thinning (cherry, walnut, oak, willow, elm). Vice versa, negative aspects are high cost for planting, establishment, and tending.

Promising is the establishment of mixed, multi-objectives plantations for production of biomass for industrial or energy use (*Salix*, *Robinia*) and for timber medium (e.g. *Populus*, 10-year rotation) and long rotation (*Juglans*, *Prunus*, *Tilia*, *Fraxinus*, etc.) species (Buresti et al. 2001).

For oak plantations, the minimal initial density should be 625 plants per ha (Montero e Canellas 1999).

Short rotation coppices (wood for energy) are expanding, as the production of energy from biomasss is supported by national energy policies. Willows and black locust, planted at high densities (from 10^3 to 40^3 plants per ha). Establishment occurs in late winter, using high genetic quality stock, at a initial plantation density ranging from 400 to 1100 plants per ha. Protection (fencing, tree shelter) is necessary, even though it raises cost. Growth results of many field trials on stands of noble hardwoods on former agricultural lands in combination with *Leguminosae* and other nitrogen-fixing species have been demonstrated successful (Gavaland et al. 2002). However, if species are not chosen correctly, to meet site environment, success is not guaranteed.

In France, *Quercus petraea* and *Quercus robur* are the major native species used for afforestation and reforestation. Guibert and Généré (2000) suggest using seedlings with a minimum hight of 20 cm. *Quercus ilex* and *Quercus suber* in Portugal, *Juglans regia* and *Prunus avium* in Italy and *Quercus robur* in Croatia are the most common broadleaved species used in AR.

Case studies

The paper will focus on a few case studies and success stories. They are represented by:

- An EU research project aimed at facilitating the creation of partnerships between tree nurseries and forest research agencies from Sweden, Denmark, and Italy, in order to address common technological problems and acquire innovation (Ciccarese et al. 2005)
- A project funded by the Government of Croatia and the World Bank, with the main objective to rehabilitate forests damaged by fires during the last war and to reconstruct a nursery to grow seedlings of species utilized in reforestation of coastal areas (Anonymous 2001)
- In Situ Conservation of Genetic Biodiversity. This is the title of a project funded by GEF and implemented by the World Bank in Turkey, whose main objective was to restore natural resource degradation because of overgrazing, deforestation, and soil erosion caused by inappropriate cultivation
- A project carried by the French CEMAGREF, on cryopreservation of varieties or cultivars of *Ulmus minor*, *Ulmus glabra* and *Ulmus laevis* (Harvengt et al 2004)
- AR projects for the implementation of the Kyoto Protocol
- Nursery production and establishment of plants with Tuber spp., of mycorrhizae for producing truffles

Conclusions

In general, even though important advances have been done in certain European nurseries, the standard of production technology regarding all types of forest regeneration materials has to be elevated in order to improve biological, physiological and genetic quality, as well as cost efficiency. Reports of failed reforestation attempts more often than not mention poor quality as the main cause for these failures (Radoglou 1999, Ciccarese et al. 2005).

Unfortunately, the lack of capital investment in technical developments has created a situation where cost efficiency in the production of forest regeneration materials is low and nurseries are often burdened with environmental problems.

The small size of most forest nurseries and the fact that—normally—forest nurseries are publicly-owned are barriers for implementation for technical development. Fortunately, the call for introducing innovative systems is timely with the existing call for re-organization, modernization, and privatization of forest nurseries occurring in the area.

The use of containerized stock should be enlarged, but in doing so many obstacles have to be overcome The role of research is also important in aspects of seed and vegetative propagation.

In the management of existing forests, one of the first issues is the fact that coniferous stands have started to pose stability problems and regeneration troubles. In these stands a priority is silvicultural treatment to diversify composition and modify structure. In this regard, mixed forests are promoted and the spontaneous recolonization of broadleaved species in coniferous plantations is today strongly encouraged.

An important issue is post-fire management of forest lands. The effects of fire on the ecosystem and its resilience may be very diversified, depending on a multitude of factors, such as fire regime (persistence, frequency, intensity, severity, extent, etc.), vegetation type and site conditions. Artificial restoration may be necessary and much work is to be done, particularly on the aspect of cost of rehabilitation. In this respect, direct seeding is promising.

Since the 1970s, invasion of exotic species, such as *Robinia pseudoacacia* and *Ailanthus altissima*, have become a problem of increasing environmental focus and concern (Tassin and Balent 2004), raising critical questions (which species make good invaders? Which communities are most easily invaded? What will be the rate of spread of invasive species?) that need to be addressed by scientists and land and forest managers.

The role of biotechnology may be helpful to improve regeneration in the region. Research is carried out in all countries of the region, with different objectives. Most public research involving forest biotechnology does not relate to Genetically Modified Plants. Developments and applications of genetic modification technology is carried out mainly on *Populus* and *Salix* with the objective of achieving varieties to be used for bio-remediation and resistance to diseases. (Balestrazzi *et al*. 2000).

The EU policy on rural development and other multilateral environmental agreements (namely the Kyoto Protocol and its mechanisms that allow use of new forest establishment as a mean to fulfill green-house gas emission reduction commitments) now gives incentives for the governments to boost afforestation and reforestation, as well sustainable management of forest resources.

Improving dialogue and exchange of experience on available technology alternatives at the Mediterranean level is essential in order to build capacity in adopting correct plant domestic strategies and nursery programs and use to suitable propagation and regeneration techniques.

References

Anonymous, 2001. Project portfolio in Croatia. The World bank. May 2001. 34 p. Available from (http://www.seerecon.org/croatia/documents/croatia_wb_project_portfolio_may_2001.pdf [cited 12 July 2005]

Barbero, M. Bonin, G., Loisel, R., and Quézel, P. 1990. Changes and disturbances of forest ecosystems caused by human activities in the western part of the Mediterranean basin. Vegetatio 87: 151-173.

Benoit de Coignac G. 2001. Fonctions de la forêt Méditerranéenne et inventaire forestière. Revue forestière française 53 (3-4) : 304-309.

Buresti, E.; Mori, P, Ravagni, S. (2001) - Piantagioni miste con pioppo e noce comune: vantaggi e svantaggi di una scelta complessa. Sherwood – Foreste ed Alberi Oggi 7:(9) 11-17.

Ciccarese L. 1997a. Comportamento in pieno campo di semenzali di Juglans regia allevati a radice nuda, in contenitore e in cassone. Monti e Boschi 2: 35-41.

Ciccarese L. 1997b. La valutazione della qualità del materiale vivaistico forestale. Monti e Boschi 5: 12-25.

Ciccarese, L., Andersen L., Mattssson, A. 2005. A new technology for production of broadleaved forest seedlings to promote sustainable management of European forestry. Final Report of a co-operative research action for technology (CRAFT) project, funded by DG XII (Research Directorate) of the European Commission, within the Fifth Framework Programme, Programme Quality of life, Thematic priority 1.1.1.-5, Project No: QLK5-CT-2001-70315 (acronym BROAD-TECH). APAT, Rapporti 2005. ISBN 88-448-0150-7.

Da Silva R. G. 1971. Eucaliptus cultivation in Portugal (planted areas, ecological zones and afforestation techniques). Timber bulletin for Europe. (FAO/ECE). Papers presented to the symposium of the production and industrial utilisation of Eucaliptus. Vol. 23, Supplement 5. pp. 166-178.

Dinić, A. Pavlović, P., Mitrović, M., Durdević, L., Kostić, O. 2001. The effects of the spruce silvicilture on the beech forest habitat on Maljen Mt., in western Serbia. In Proceedings of the International Conference Forest research: a challenge for an iontegrated European Approach. Volume II. Edited by Kalliopi Radoglou. Thessaloniki, Greece, August 27 – 1 September, 2001. National Agricultural Research Foundation, Thessaloniki, Greece, 559-565.

EC – European Commission, 2000. COUNCIL DIRECTIVE 1999/105/EC of 22 December 1999 on the marketing of forest reproductive material. Official Journal of the European Communities, 15. 1. 2000. pp. 11/17. Available from http://europa.eu.int/eur-lex/pri/en/oj/dat/2000/l_011/l_01120000115en00170040.pdf [cited 12 July 2005]

EC – European Commisison. 2004. COMMISSION DECISION of 29 September 2004 authorising Member States to permit temporarily the marketing of seed of the species *Cedrus libani*, *Pinus brutia* and planting stock produced from this seed not satisfying the requirements of Council

Frochot H., Picard J.F., Dreyfus Ph., La végétation herbacée obstacle aux plantations, Rev. For. Fr. XXXVIII 3 (1986) 271-278.

Gavaland A., Gauvin J., Moreau A., and Bouvarel L. 2002. De l'interet de planter le merisier avec un accompagnement d'aulne : les enseignements de trois essai INRA. Revue forestière française 54(2) : 143-160.

GGAF - Green Gold Alliance Forests. 2003. Our National Wealth, Sustainable Development of the Forest Sector in Bulgaria, National Forest Policy And Strategy, 2003 – 2013, 50 p.

Globevnik L., Kaligaric, M., and Sovinc, A. 2004. Forest cover progression, land-use and socio-economic changes on the edge of the Mediterranean. In Recent dynamics of the Mediterranean vegetation and landscape. Edited edito da: S. Mazzoleni, G. di Pasquale, M. Mulligan, P. di Martino e F. Rego): 13-20. John Wiley & Sons, Ltd. ISBN 0-470-09369-2. Pp. 249-256.

Gracan, J. and Perić, S. 2004. Growth and production of stemwood in 16 provenances of pedunculate oak (*Quercus robur L.*) in Croatia. In Proceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson, 185-190.

Guibert, M. and Généré B. 2000. Evaluation en jeunes plantations de lots melangés del chene sessile (*Quercus petraea*) et pédonculé (*Quercus robur*). Revue forestiére francaise 52(4) : 303-315.

Harvengt L, Dumas E, Meier-Dinkel A and Collin E (2004) Establishment of a cryopreserved gene bank of European Elms. Can J For Res 34:1:43-55.

INRGREF, 1998. Actes du Séminaire Méditerranéen sur la Régénération des Forêts de Chêne Liège, Tabarka, du 22 au 24 Octobre 1996, Annales de l'INRGREF, Numéro spécial, 1998, 253 p.

Krstić. M. 1998. Uporedne karakteristike razvoja I proizvodnosti izdanacke sume buvke I sastojina duglazije I smrce podignutih na bukovom stanistu na područiu istoćne Srbije. Zbornik radova sa V Simpozijuma o flori jugoistocne, 151-150. Zaječar.

Louro G. 1999. Avaliaçaõ da aplicação de programas de apoio à floresta na região do algarve, Direcção Geral das Florestas (DGF-Lisboa), Portugal.

M'Hirit O., 1997. Mediterranean forests: ecological space and economic and community wealth. Unasylva197 (50): 3-14.

Mc Mullen T., 2005. Celebrity landscape designers flourish. Spring garden Special, Personal Journal. Supplement to Wall Street Journal Europe. May 6-8, 2005. pp. 4.

McCreary, D., and Cañellas, I. 2005. Restoration of oak woodlands in Mediterranean ecosystems. In Restoration of boreal and temperate forests. Edited by John Stunturf e Palle Madsen. CRC Press/Lewis Publishers. CRC Press. Boca Raton, USA. 569 p. ISBN 1-56670-635-1. Pp.253-266.

Merouani H. Acherar M., Istanbouli A., 1998. Recherche de quelques contraintes biotiques et abiotiques à la régénération naturelle du chêne liège *Quercus suber* L., Séminaire Méditerranéen sur la Régénération des Forêts de Chêne Liège. Tabarka, du 22 au 24 Octobre 1996, Annales de l'INRGREF, Numéro spécial (1998) 225-243.

Neves, I., and Paiva. V. 2004. Nursery production – a responsible contribution for sustainable forest managemen. In IProceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson. Agenzia per la protezione dell'ambiente e per i servizi tecnici. Rome, Italy. Atti 5/2003. pp. 243-251.

Orlić, S., Perić, S. 2002. Proizvodnja šumskih sadnica u Hrvatskoj 1997. – 2001. godine [Production of forest seedlings in Croatia 1997 – 2001] Rad. Šumar. Inst. 37(2): 211-223.

Pardos M. , Royo A., Gil L., and Pardos J.A. 2003. Effect of nursery location and outplanting date on field performance of *Pinus halepensis* and *Quercus ilex* seedlings. Forestry 76(1): 67-81.

Pettenella, D, Klöhn, S., Brun, F., Carbone, F., Venzi L, Cesaro, L., and Ciccarese, L. 2005. Italy's country report. COST Action E30. Economic integration of urban consumers' demand and rural forestry production. 50 p. Available from http://www.joensuu.fi/coste30/docs/ReportsJan05/Italy_110105.pdf [cited 12 July 2005]

Piotto, B. 2004 Propagation of Mediterranean trees and shrubs by seed. In Proceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson. Rome, Italy. Atti 5/2003, pp. 243-251.

Piussi, P., and Pettenella, D. 2000. Spontaneous afforestation of fallows in Italy. In NEWFOR – New Forests for Europe: Afforestation at the turn of the century. Edited by N. Weber. EFI Proceedings N. 35. European Forest Institute, Joensuu, 151.

Preuhsler, T., and Pinto da Costa, M.E. 1994. Growth of mixed species regeneration below *Pine* shelter. In Symposium of Working group S4.01: Mensuration, Growth and Yield: mixed stands – Research plots, measurements and results. Models, IUFRO 25 – 29 April 1994, Lous/Coimbra, Portugal, 207, 1994.

Radoglou K., Raftoyannis Y., and Halivopoulos G. 2003. The effect of planting date on field performance of *Castanea sativa* and *Quercus frainetto* seedlings. In Proceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson. Agenzia per la protezione dell'ambiente e per i servizi tecnici. Rome, Italy. Atti 5/2003. pp. 243-251.

Radoglou, P. 1999. Effect of environmental stress on planting stock and field performance. In Proceedings of the National Forestry Conference: Planting stock of woody species Thessaloniky, Greece, 28–29 January 1999. Edited by Poppi Radoglou, and Yoannis Raftoyannis. Apat , pp. 21-36.

Rafailov G., Stoyanov N., Belev T., Bardarov D., Tinchev G., Simeonov, K. 2003. NATIONAL FOREST POLICY AND STRATEGY FOREST SECTOR ANALYSIS. PART I. 30 p.

Ribeiro D., and Marques, H. 2004. *Quercus suber* L. and *Quercus ilex* l. Nursery production in Portugal. In Proceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson. Agenzia per la potezione dell'ambiente e per i servizi tecnici. Rome, Italy. Atti 5/2003. pp. 127-135.

Robin, B., and Combot, P. 2004. Large scale production of mycorrhizal broad-leaved forest seedlings in nursery for the improvement of early field performances. In Proceedings of the IUFRO Conference: Nursery stock production and stand establishment of broadleaves to promote sustainable forest management. Rome, Italy, 7-10 May 2001. Edited by Lorenzo Ciccarese, Stefano Lucci and Anders Mattsson. Agenzia per la protezione dell'ambiente e per i servizi tecnici. Rome, Italy. Atti 5/2003. pp. 133-135

Sardin, T., Bourdenet, P., and Argillier, C. 2001. Amelioration des techniques de reconstitution en espéces feuilles de la foret méditérranéenne. Rev. For. Fr. 53(5): 542-556

Schelhaas, M.J., Varis, S., Schuck, A. 2005. Database on Forest disturbances in Europe (DFDE), European Forest Institute, Joensuu, Finland, http://www.efi.fi/projects/dfde/ [cited 13 July 2005].

Tassin J. and Balent G. 2004. Le diagnostic d'invasion d'une essence forestière en milieu rural: example of *Acacia mearnsii* à la reunion. Revue forestière française 56 (2) : 132-142.

Weber, N. 2005. Afforestation in Europe: lessons learned, challanges remaining.. In Restoration of temperate and boreal forests. Edited by John Stunturf e Palle Madsen. CRC Press/ Lewis Publishers. CRC Press. Boca Raton, USA. 569 p. ISBN 1-56670-635-1. Pp.121-128

Applying an Understanding of Stand and Competition Dynamics For Natural Regeneration and Achievement of Alternative End Products: Examples From Western Canadian Mixedwood Forests

P. Comeau

Department of Renewable Resources, 442 Earth Sciences Building
University of Alberta, Edmonton, AB T6G 2E3

Mixedwood stands, dominated by aspen and white spruce, are a prominent and important component of Canada's western boreal forests. Expanded industrial utilization of aspen during the past 15 years, as well as a strong interest in management that emulates natural disturbance and succession has resulted in heightened interest in management of aspen and of mixedwood stands. These stands provide the opportunity to produce both aspen and spruce from the same stands. Without planned management there is a risk of converting mixedwood stands to either pure conifer or pure deciduous stands. In addition, aspen can serve as a nurse crop for white spruce by reducing frost injury (Pritchard and Comeau 2004), reducing winter injury to white spruce, reducing the level of damage from white pine weevil (Taylor et al. 1996), and reducing the vigour of competing grasses and shrubs (Lieffers and Stadt 1994).

Following fire or clearcutting natural regeneration of aspen occurs primarily from root suckers, with white spruce regenerating from seed and establishing within the first few years after disturbance. When spruce is present it will grow in the understory for 40 years or longer, eventually overtopping the aspen and becoming increasingly dominant in the stand as aspen drops out of the stand over the period between 70 and about 140 years. Spruce may also establish on decaying wood and windthrow mounds under aspen and mixedwood canopies when the aspen canopy begins to open up after age 40. When spruce does not regenerate in the understory or when few spruce are present, new aspen saplings may regenerate in the understory of senescing aspen stands. Bluejoint reedgrass (*Calamagrostis canadensis*) and several shrubs (i.e., beaked hazel (*Corylus cornuta*), willow (Salix spp.), red raspberry (*Rubus idaeus*), wild rose (*Rosa acicularis*), red-osier dogwood (*Cornus sericiea*) and green alder (*Alnus crispa*)) are important components of the mixedwood plant community.

Aspen suckering is inhibited by flooding, soil compaction, root crushing, heavy slash, log decks left over the summer, hot intense burns (eg. slash piles), and cold soils (grass cover) (Frey et al. 2003). Harvesting when soils are dry or frozen is desirable to minimize soil compaction and root crushing. Regeneration is often at very high densities, but self-thinning occurs rapidly and results in stands with densities below 20,000 stems/ha at age 10. Self-thinning continues to occur, resulting in a decline in stand density with age.

When aspen cover fails to develop or when aspen is removed by treatments designed to control only woody vegetation, bluejoint reedgrass may become dominant and can be a serious competition problem for white spruce. Grass, herbs and shrubs compete for light, water and nutrients, with the nature, intensity and importance of competition changing from season to season and from year to year. In young stands substantial aspen cover is required to inhibit development of this grass (understory light levels must be below 20%), while in older stands grass cover is reduced by moderate canopies (Lieffers and Stadt 1994).

Spruce can regenerate from seed provided there is a seed source and seedbed conditions are suitable. The periodicity of white spruce seed crops (with good seed crops every 3 to 7 years), high levels of seed predation, and the short period during which seedbed remains available after disturbance, have made reliance on natural regeneration unattractive in western Canada (Greene et al. 1999). In addition, spruce germinants grow slowly (taking 8 to 10 years to reach 50 cm height).

When present, advance regeneration of white spruce can be protected during harvest and subsequently release well. Since use of advance regeneration can avoid problems with high levels of competition, frost and winter injury encountered following planting in a clearcutt and may shorten the rotation length for white spruce, there is also interest in establishing spruce under aspen canopies (ie. underplanting) at age 40 or later (Comeau et al. 2004). Stands selected for underplanting should have at least 20 m^2/ha basal area of aspen, and be located away from black spruce stands and willow thickets to reduce hare browsing problems. When seed producing white spruce are present in the canopy, blading can create favourable seedbed conditions and lead to establishment of natural regeneration in the understory, (Stewart et. al. 2000) suggesting that seedbed is a primary factor limiting natural regeneration in the understory of aspen stands. However this treatment may lead to mortality of the aspen due to root system and stem damage.

During early stages of stand development, the overtopping aspen canopy reduces light available to the understory white spruce. Aspen canopies can develop rapidly, with light levels in the understory dropping below 20% in the second growing season. Competition for light appears to reach maximum levels during the first 15 to 40 years (Lieffers et al. 2002). Light levels under aspen canopies can be related to aspen basal area (Comeau 2002) and these relationships can be used as a basis for thinning guides designed to maintain light at appropriate levels for understory white spruce. Timely application of thinnings or removal of aspen around a component of spruce (either individuals or clusters of trees) can be used to increase growth of white spruce.

Tending in mixedwood stands generally means reducing the volume of one species in favour of the other (Figure 1). Creating and maintaining mixedwood stands is likely to be more expensive than growing single species stands (Table 1), except when very long rotations are accepted for white spruce.

The role of facilitation relative to competition is highly variable in western boreal mixedwood stands, complex and not well understood. It is easy to overstate role of either competition or facilitation. There are clear advantages to growing spruce in a mixedwood setting in low snowfall and summer dry areas where winter injury and competition for soil moisture by bluejoint reedgrass may be limiting. However, these benefits may be overshadowed by the effects of competition on other sites. Consequently, key limiting factors should be evaluated on a site specific basis.

Continued research is needed to improve our understanding of the interplay between competition and facilitation in these mixtures, to support development of models for estimating outcomes of different stand management practices and to support development of tools to assist with effective decision making. Long-term studies, such as those established by the Western Boreal Growth and Yield Association, which document and examine the dynamics of mixtures are essential for improving our understanding of the benefits of tending mixedwoods.

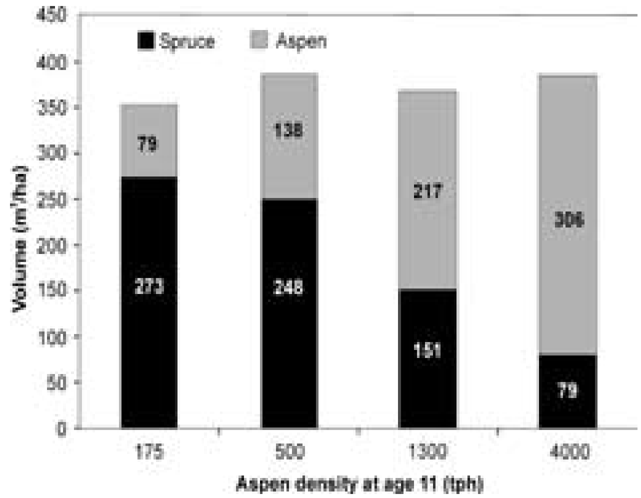

Figure 1. *Estimated effects of aspen density at age 11 on spruce and aspen volume at age 80 based on simulations using MGM2005. [Aspen site index of 20 m and a spruce site index of 16 m at age 50].*

References

Comeau, P.G. 2002. Relationships between stand parameters and understory light in boreal aspen stands. B.C. J. Ecosystems Manage. 1(2):103–110.

Comeau, P.G., Filipescu, C.N., Kabzems, R., and DeLong, C. 2004. Early growth of white spruce underplanted beneath spaced and unspaced aspen stands in northeastern British Columbia. Can. J. For. Res. 34: 2277-2283.

Comeau, P.G., Kabzems, R., McClarnon, J., and Heineman, J.L. 2005. Implications of selected approaches for regenerating and managing western boreal mixedwoods. For. Chron. 81: (in press).

Frey, B.R., Lieffers, V.J., Landhausser, S.M., Comeau, P.G., and Greenway, K.J. 2003. An analysis of sucker regeneration of trembling aspen. Can. J. For. Res. 33: 1169-1179.

Greene, D.F., Zasada, J.C., Sirois, L., Kneeshaw, D., Morin, H., Charron, I., and Simard, M.J. 1999. A review of regeneration dynamics of boreal forest tree species. Can. J. For. Res. 29: 824-839.

Lieffers, V.J., and Stadt, K.J. 1994. Growth of understory *Picea glauca, Calamagrostis canadensis* and *Epilobium augustifolium* in relation to overstory light transmission. Can. J. For. Res. 24: 1193-1198.

Lieffers, V.J., Pinno, B.D., and K.J. Stadt. 2002. Light dynamics and free-to-grow standards in aspen dominated mixedwood forests. For. Chron. 78: 137-145.

Stewart, J.D., Landhausser, S.M., Stadt, K.J., and Lieffers, V.J. 2000. Regeneration of white spruce under aspen canopies: seeding, planting and site preparation. West. J. Appl. For. 15: 177-182.

Taylor, S.P., Alfaro, R.I., DeLong, C., and Rankin, L. 1996. The effects of overstory shading on white pine weevil damage to white spruce and its effect on spruce growth rates. Can. J. For. Res. 26: 306-312.

Table 1. *Estimates of Mean Annual Increment (MAI) and costs for six scenarios estimated using the Mixedwood Growth Model (Version MGM2005A) (after Comeau et al. 2005).[1]*

Scenario	Rotation Length (years)	MAI Spruce	MAI Aspen	MAI Total	Cost ($/ha) MSP & Plant	Cost ($/ha) Herbicide	Cost ($/ha) Spacing	Cost ($/ha) Other	Cost ($/ha) Total
1 Pure aspen.	60	0	3.8	3.8	0	0	0	0	0
2 Pure white spruce with a minor component (200 stems/ha) of aspen.	90	3.2	0.7	3.9	$1100	$300			$1400
3 Mixedwood resulting from the planting of white spruce at 1100 stems/ha and no tending, followed by a single-stage harvest.	90	0.7	2.2	2.9	$1100	0	0	0	$1100
4 Patch mixture of 50% spruce and 50% aspen resulting from the planting of white spruce at 1100 stems/ha, followed by tending spruce in patches 20 to 30 m across, and leaving the remainder of the block untended.	90	1.1	1.0	2.2	$600	$150	0	0	$750
5 Mixedwood resulting from planting white spruce at 1100 stems/ha and thinning aspen to 1100 stems/ha at age 5 years.	90	1.6	2.3	3.9	$1100	0	$600	0	$1700
6 Mixedwood resulting from allowing aspen to regenerate and grow to age 40 years, with white spruce underplanted at 1600 stems/ha in year 40. Aspen are harvested at age 60 with understory protection and a mixture of spruce and aspen are harvested at 120 years (spruce age 80 years).	120	1.8	3.5	5.3	$800	0	0	$200[2]	

[1]Simulations are for a site with white spruce SI50=16 m and aspen SI50=20 m and are started from age 10. In scenarios 1, 3, 5, and 6, aspen density was 10,000 stems/ha at age 10. Scenario 4 is calculated from scenarios 2 and 3, based on the assumption that conifer yield is 45% of the value obtained in scenario 2. Merchantable volumes assume a minimum DBH of 12.5 cm, a minimum top diameter of 7.5 cm, and a stump height of 30 cm. A 20% reduction in volume was included to account for variation in stocking and for other losses.

[2]Extra harvesting costs.

Successful Stock Production for Forest Regeneration: What Foresters Should Ask Nursery Managers About Their Crops

(and Vice Versa)

R.K. Dumroese[1], D.F. Jacobs[2], T.D. Landis[3]

[1] USDA Forest Service, Southern Research Station,1221 South Main Street, Moscow, Idaho 83843 USA
[2] Purdue University, Hardwood Tree Improvement and Regeneration Center, West Lafayette, Indiana USA
[3] USDA Forest Service (retired), Medford, Oregon USA

Introduction

Forest regeneration is a cyclic operation. Seeds are collected from mature trees and planted in nurseries so that the resulting seedlings can be outplanted to the forest after the mature trees are harvested. Similarly, the process of deciding upon, and growing, the best seedlings for that site should be a cyclic process between foresters and nursery managers. The ideal seedling, suitable for all purposes, does not exist. Instead, the ultimate use of the nursery stock controls many aspects of the nursery program. In other words, nursery managers should grow the type of stock that is appropriate rather than the forester having to use whatever the nursery produces. Key to this process is good communication; this facilitates production of seedlings with ever increasing levels of quality for sites for which they are targeted. Thus, target seedlings, grown using the target seedling concept, are the result of foresters' observations and subsequent adjustments in cultural practices by nursery managers.

This is a departure from traditional reforestation seedling production. Nursery management and reforestation in North America have progressed tremendously since the first large scale forest nurseries were established in the early 1900s. In those days, the reforestation process was very simple and linear: nurseries produced seedlings that were then shipped for outplanting. Foresters took what was available and there was little choice. Tree planting was a mechanical process of getting seedlings in the ground in the quickest and least expensive manner. Not much thought was given to seedling quality or the possibility of using alternative stock types.

Since about 1975, however, more science has been infused into the reforestation process. New research into seedling physiology, along with better-educated customers has revolutionized traditional concepts of reforestation and restoration. We now understand much more about how seedlings function—both in the nursery and after outplanting. In particular, the advent of the container seedling showed the importance of nursery cultural practices and vividly demonstrated important concepts like hardiness and dormancy (Tinus and McDonald 1979). Today's seedling customers are very well educated and have high expectations; they know what they want; and they have many choices.

The target seedling concept is relatively new, but the basic idea can be traced back to the late 1970s and early 1980s when new insights into seedling physiology were radically changing nursery management. During this time, several books were published on seedling quality (e.g., Duryea and Brown 1984; Duryea 1985), and these served as precursors to the target seedling concept. In searching the literature, we found nothing published on target seedlings before 1990. In that year, however, a symposium to discuss all aspects of the target seedling was held and the resultant proceedings are still a major source of information on the subject (Rose et al. 1990).

Therefore, successful production of reforestation seedlings for outplanting sites requires that foresters and nursery managers agree on the biological and business parameters associated with seedling production. Although it sounds like these parameters are distinct, they truly overlap and influence each other, illustrating another reason why communication is essential to success.

In this paper, we discuss the business and biological parameters, posed as questions, that foresters and nursery managers must discuss candidly to ensure successful reforestation.

What is the Target Seedling?

A target seedling is a plant that has been cultured to survive and grow on a specific outplanting site. Defining a target seedling requires answers to six questions. Usually, the first five questions should be asked and answered by the forester and then relayed to the nursery manager. Together, the forester and manager can work out the answer to the sixth, and perhaps most important question: What is the ideal stocktype?

1. What is the outplanting objective?

The reason that seedlings are being outplanted will have a critical influence on the characteristics of the target seedling. In traditional reforestation, commercially valuable tree species that have been genetically improved to enhance yield are outplanted with the ultimate objective of producing saw logs or pulp. These objectives and resulting target seedlings should not be confused with seedlings targeted for other restoration projects dealing with riparian enhancement, conservation windbreaks, or ecosystem management purposes. Seedlings grown specifically for those types of projects may not have the characteristics needed on typical reforestation sites. Similarly, seedlings destined for fire restoration projects or for planting under shelterwoods or on obliterated roads may require additional characteristics or modifications not found on typical reforestation target seedlings (Landis 2002).

2. Should you use source-identified or genetically-improved seeds?

Before ordering nursery stock, several genetic concepts should be considered. All nursery managers and reforestation specialists are familiar with the idea of seed source. They know that plant species vary throughout their geographic range because they are adapted to local site conditions. Using a local seed source and collecting from enough individuals to maintain high genetic diversity are basic tenets of reforestation ecology. Proper seed source can be guaranteed through the use of seed zones, and so the location and elevation of seeds must always be recorded and included in the seed source identification code. For species without clearly defined seed zones, seeds should generally be collected as close to the outplanting site as possible.

Genetically improved seeds should be used if the project objective is rapid growth and uniform stand structure, or if disease resistance is needed for restoration. For example, Weyerhaeuser Company grows many of their seedling by genetic family as a way to minimize growth variation in the nursery and obtain faster growth rates in the resulting plantation (Carlson 2003).

3. What factors may limit seedling growth on the outplanting site?

The specifications of the target seedling should be developed by identifying environmental factors that will be most limiting to survival and growth on each particular site. For example, a fire restoration site in eastern Oregon USA might have shallow soils and competition from grasses for moisture and nutrients. In the mountains of northern British Columbia, Canada, however, cold soil temperatures are a limiting factor. In the mountains of Arizona and New Mexico USA, it might be lack of the summer monsoon rains. Other limiting factors might include herbivory, shallow or rocky soil, early or late-season frosts, flooding, vegetative competition (including other trees in a shelterwood), soils with physical properties modified by wildfire, and known root disease pockets.

4. When will seedlings be outplanted?

The outplanting window is the period of time in which environmental conditions on the project site are most favorable for survival and growth. As mentioned in the previous section, soil moisture and soil temperature are the usual constraints. In the Pacific Northwest USA, seedlings are usually outplanted during the rains of winter or early spring. In the mountainous portions of the western USA, stock is normally outplanted as soon as the snow melts; however, a summer outplanting window with specially conditioned “hot planted” nursery stock is recommended on some high-elevation or high latitude sites. In the interior portions of the western USA that are affected by monsoonal moisture, late summer outplanting may be desired. In the southeastern USA, seedlings are planted from late fall through winter. It is important to assure that plants of optimal quality (see below) are timed to be available during the limited outplanting window.

5. How will seedlings be outplanted?

Each outplanting site has an ideal planting tool. All too often, foresters develop a preference for a particular implement because it has worked well in the past. No single tool, however, will work under all site conditions. Special planting hoes called hoedads are popular in the steep terrain of the Pacific Northwest USA, but the level terrain on the Kenai peninsula in Alaska USA or afforestation sites in the Midwest and southeastern USA allow machine planting.

6. What is the ideal stocktype?

Using all of the answers to the first five questions, the nursery manager and forester should candidly discuss stocktype options. Ideally, they decide on the general “look” of the seedling needed. That is, short and stocky for tough sites; small volume containers or 2+0 seedlings for typical, high-quality, low competition sites; tall, stocky, large volume containers or 2+2 seedlings for use under shelterwoods; etc. If only a bareroot facility nursery is nearby, then stocktypes are limited to seedlings (1+0, 2+0, 3+0) or transplants (1+1, 1+2, 2+1, 2+2, etc.). Perhaps 10 or so stocktypes are possible. If only a container nursery is nearby, the potential number of stocktypes is several magnitudes higher. A myriad of containers is available, from 8 ml to 3200 ml, with or with copper coatings, with or without air slits in the sides. Within these choices cavity density is another variable, as is the type of material used: Styrofoam® or polyethylene. If both types of nurseries are nearby, then foresters also have the option of outplanting bareroot–container hybrids, commonly referred to as “plug plus” seedlings. These seedlings usually take advantage of the quick and uniform growth possible in the greenhouse, and then the plug seedlings are transplanted into bareroot beds where extensive, fibrous root systems and large stem diameters are possible. Again, a gamut of stocktypes are possible because plugs can range from a month or two in age to a year, and they can be grown in bareroot beds for a month or two to a year or two. A seedling grown one year in the container and one year in a transplant bed would be a “plug + 1" or more commonly, “P+1.”

Once the general morphology of the target seedling is decided, and a stocktype selected that will yield that target, the next step is determining production time.

How Long Will it Take to Produce the Target Seedling?

Crop schedules help foresters understand the time required by nurseries to produce crops. In a contract, these schedules can help both entities plan their work and ensure that planting stock are produced as needed. The best approach for determining crop schedules, or propagation protocols, is to “work backward,” starting at when the seedlings need to be on the outplanting site and then working backward to when the process needs to be initiated (Landis and Dumroese 2000). Although generally only showing the nursery production phase, foresters could include the time needed to harvest cones and scout seed crops from select trees. Schedules will vary by species and stock type (Table 1).

In Production, Who is Responsible For What?

It Starts with Seeds

Both the forester and nursery manager should consult the propagation protocol described above to agree on when seeds need to enter the production timeline. This is necessary so that seeds are supplied, treated (i.e., disinfesting, cold stratification, upgrading), tested (germination, purity, seeds per weight), and sown to meet the outplanting deadline. Although nursery managers are careful with maintaining seedlot integrity, foresters may wish to ask how quality assurance is achieved to ensure they receive the correct seedlings after nursery production.

Planning Along the Way

To ensure that proper resources are committed and scheduled for outplanting the seedlings, foresters need to know the progress of their crop as it grows in the nursery. Usually, it is helpful if the nursery managers provide inventory numbers at logical times throughout the production cycle. Often, the first inventory is “occupancy,” indicating what percentage of containers have a seedling, or “emergence,” an estimate of seedlings per square area of bareroot bed. Usually completed about a month after sowing, this inventory can alert foresters if a large deficit or overage may be occurring in the crop. A second inventory at about the time of bud initiation refines the number of expected plants. A third inventory in the fall can further distill the number of seedlings expected, but the final inventory at harvest provides the definitive number. The forester can use these values as the outplanting time draws nearer to adjust planting contracts and crew logistics. The timing of inventories should be described in the contract. A contract proviso should also address what to do when more seedlings than needed by the forester are produced, and conversely, what penalties should be imposed when inventories fall short.

Assessing Seedling Quality

This is the prickliest portion of the contract for the forester and nursery manager to agree upon—therefore ongoing communication is essential. “Seedling quality” is a euphemism we use to describe how well a seedling is expected to survive and grow after outplanting (Duryea 1985; Mattsson 1997). Another way to describe seedling quality is whether or not the nursery stock meets management objectives—quality then is “fitness for purpose” (Ritchie 1984). Therefore, seedling quality can only really be evaluated after outplanting. So, as you can see, foresters and nursery managers need not only agree on a definition of quality but on how to measure it (Wilson and Jacobs *in press*). [Colombo et al. (2001) segregate seedling characteristics into four categories: physical, physiological, chemical, and pest status, but for brevity in this paper we consider physical and pest status to be morphological and physiological, respectively, and chemical to be physiological.] Fortunately, morphological quality can be easily discerned as seedlings are being harvested from the nursery, but physiological quality is often more difficult, or time consuming, to assess. Therefore, foresters and nursery managers have traditionally focused on morphology (Ritchie 1984),

Table 1. *Hypothetical timeline (shown in reverse order) for production of container pine seedlings in the western USA, beginning with the forester checking trees for cones through outplanting. This scenario requires 36 months (three years).*

Month	Activity	Responsibility
1 - Mar	Outplanting	Forester
2 - Feb	Thaw crop / pick up crop	Manager / Forester
5 - Nov	Harvest crop & put into storage; provide final inventory to forester	Manager
6 - Oct	Test cold hardiness prior to harvest	Specified in contract
7 - Sep	Inspect crop & agree on acceptable seedling specifications — preharvest inventory	Manager & Forester
9 - Jul	Initiate hardening	Manager
11 - May	Inventory and provide to forester	Manager
13 - Mar	Sow crop	Manager
16 - Dec	Stratify seeds based on seed tests	Specified in contract
19 - Sep	Begin testing seeds	Specified in contract
20 - Aug	Harvest & process seeds	Forester
21 - Jul	Sign contract	Manager & Forester
22 - Jun	Meet and discuss target seedling specifications	Manager & Forester
23 - May	Confirm cone collection	Forester
31 - Sep	Confirm cone collection	Forester
35 - May	Look for developing female cones	Forester
36 - Apr	Select “plus” trees for cone harvest	Forester

but, ideally, all parties should be concerned about both because these seedling quality assessments can be intricately related (Grossnickle et al. 1991; Colombo et al. 2001).

Morphological quality

In contracts, and depending on the target seedling, morphological characteristics such as minimum and maximum acceptable heights and stem diameters, sturdiness quotient (height:diameter), incidence of forking, bud set, plug firmness, presence of mycorrhizae, and incidence of pests or disease are commonly used. Other morphological metrics might include first-order lateral roots (especially for bareroot hardwoods), shoot-to-root ratio, and root volume. They can be straight forward and definitive; for example, container seedlings must be 10 to 15 cm tall with a stem diameter > 2.7 mm, no forks, firm rootplug, and disease free. From the forester’s perspective, these quality specifications may sounds good. From a nursery manager’s perspective, they may seem precarious. A manager might be concerned that a forester who didn’t get the outplanting site properly prepared might refuse the seedling crop because *Fusarium*, a potential pathogen, is present on 80% of the crop, even though the seedlings look healthy and the strain of *Fusarium* might have little or no virulence. Or, perhaps the seedlings are all 20 cm tall with stem diameters > 4 mm. They could be rejected by the aforementioned forester for being too tall even though the sturdiness coefficient is 5 (or 50:1), a potentially better value than the 15 cm tall – 2.7 mm diameter seedling (5.6 [56:1]). Or, how exactly do we define a “firm” rootplug, knowing that we need sufficient roots to maintain plug integrity but that too many roots, and root binding, might lead to toppling in plantations? Clearly, the forester and nursery manager must agree on some flexibility in interpretation of the morphological specifications, and resolve how, and when, and by whom the final decision on acceptance or decline of stock is made. Morphological assessments are usually made immediately prior to crop harvest, often synchronized with a pre-harvest inventory. But, this is only half of the story—seedlings of high morphological quality might have low physiological quality (Stone and Jenkinson 1971), or, may even be dead!

Physiological quality

A variety of physiological quality tests are available to evaluate seedlings for reforestation, including root growth potential (or capacity); electrolyte leakage from fine roots, taproots, shoots, needles, and buds; water potential; root moisture content; root carbohydrate levels; mineral nutrition; chlorophyll fluorescence; stress-induced volatile emissions; photosynthesis; and bud dormancy status. Colombo et al. (2001) compare most of the popular tests and provide estimates on ease of assessment, equipment costs, and time required to obtain results. Although most seedling physiological assessments have been developed for conifers, some have applicability to hardwood crops, whereas others do not (Wilson and Jacobs *in press*). For example, chlorophyll fluorescence, a rapid nondestructive test is often done on conifer foliage during the winter dormant period to monitor physiological changes related to harvesting and storage, but is less useful on hardwood seedlings without leaves (Wilson and Jacobs *in press*). So, it is important for foresters and managers to realize that no single test can predict outplanting performance (a "silver bullet" does not exist as per Puttonen 1997), and that physiological tests are mere "snapshots" of seedling viability at the time of the test. Whereas a seedling measured before and after storage will have the same height and stem diameter, cold hardiness values will be different before and after storage, and perhaps vary greatly if the storage conditions were severely affected by a prolonged mechanical disruption.

Therefore, foresters and managers, reviewing their description of the target seedling, should determine which factors are most limiting on the outplanting site and focus physiological tests toward those factors. For example, if the site has low nutrient availability, then perhaps a target calls for loading the seedlings via exponential fertilization (Timmer 1997); an appropriate physiological test would be to measure foliar nitrogen content to ensure the values are optimal. Conversely, if severe browsing is expected on a south-facing clearcut in the mountains of the western US, the same test might be advised to ensure a lower nitrogen concentration to discourage browse (Bergquist and Örlander 1998). Or, if the site is harsh in terms of temperature extremes and low moisture availability, a test of frost hardiness might be appropriate—seedlings with high resistance to cold temperatures may better tolerate other stresses as well. Thus, maximizing cold hardiness may infer advantage over seedlings with low cold hardiness.

Seedling quality assessments are also helpful if it is believed the stock has been damaged during production, storage, or shipping. For example, a freak cold event killed the roots of a container crop just days before harvest. The manager had a root growth potential test and a plant moisture stress test completed before harvesting the crop—the tests confirmed that the seedlings were dead, even though they still "looked" fine, saving the manager the expense of harvesting and storing while also providing the forester sufficient lead time to secure seedlings from other sources.

Because physiological tests are "snapshots," no single test is definitive, conducting tests can be costly, and results are open to interpretation, it is imperative that foresters and managers agree on basic tests to conduct on crops, who pays for the testing, and who interprets results. A minimum testing regime might include a cold hardiness test to ensure the stock is ready to be stored and a post-storage root growth potential test to ensure the seedlings are alive and able to produce new roots.

Storage and Shipping

Seedlings may spend 30 to 50% of the nursery production cycle in storage, or, in the case of container seedlings in the southeastern US or Intermountain areas of the western US, they may be "hot planted" with little or no storage. Traditionally, seedlings destined for spring outplanting are stored overwinter, either in cooler storage for short terms (0^0 to 2^0 C; 1 to 2 months) or cold (freezer) storage for longer terms (-2^0 to -4^0 C; 2 to 6 months). These storage temperatures promote dormancy release (van den Driessche 1977) but at suboptimum rates (Anderson and Seeley 1993) so that stored stock retain higher levels of dormancy and stress resistance than non-stored stock when removed for outplanting. Freezer-stored stock maintains food reserves better than cooler-stored seedlings (Ritchie 2004) and substantially reduces growth of storage molds (Sutherland et al. 1989).

Many nurseries still rely on natural, outdoor storage in the hope being that snowfall will blanket seedlings and insulate them through winter. Using snow-making machines reduces the risk factor. Additionally, many nurseries only have access to cooler storage. Both of these methods can provide satisfactory overwintering of stock. Prudent foresters should ask nursery managers how, and how often, the stock is evaluated during storage to ensure that temperatures are suitable for storage and that storage molds, which can spread rapidly at temperatures just above freezing, are not a problem.

If the stock is frozen, the most critical phase is thawing. Foresters and managers need to agree on the thawing technique and post-thawing handling procedures. Ideally, stock should be thawed very rapidly because several detrimental things can happen during thawing. Uneven thawing between seedlings on the outsides of pallets and boxes and seedlings deep in interiors can result in vast differences in loss of stress resistance, depletion of food reserves, and perhaps even desiccation (Ritchie 2004). And, storage molds can proliferate rapidly. Ideally, pallets should be widely spaced and boxes within pallets rotated to facilitate air movement and promote uniform thawing.

For container stock, it may be possible to outplant seedlings with frozen plugs, avoiding the need for thawing. Recent work by Kooistra and Bakker (2002) demonstrates the applicability of this technique. If foresters wish to use this technique, they must ask managers how the seedlings will be packaged—the seedlings must be wrapped so that root plugs don't touch and freeze together, which would necessitate thawing on site and delays in planting.

One final thought on "hot planting"—if this technique is used, it is essential that the forester ask the manager how the crop will be hardened before outplanting. Even though the seedlings may still be actively growing, the manager can condition the seedlings for the rigors of outplanting by manipulating irrigation frequency and perhaps moving the stock outside if they were growing indoors to acclimate to the ambient exterior environment. Seedlings with succulent growth will perform poorly if hot planted.

It may be a good idea to pack small temperature recorders, such as I-Buttons® or Hobo® recorders, into several boxes during harvesting so that storage and thawing temperatures and durations can be evaluated and critiqued toward improving the entire process. Again, the contract should indicate who is responsible for obtaining, placing, and retrieving monitoring devices and how the data will be interpreted. It may also be prudent to include these during shipment from the nursery to the field, even for hot planted seedlings, to ensure proper temperatures were maintained.

What About Follow-Up?

Often, foresters use "stake lines" or "regen circles" to assess outplanting performance, particularly survival and often growth (Neumann and Landis 1995). These types of survey points should be placed in areas representative of the overall outplanting site. Seedlings should be outplanted by a variety of planters to ensure the incompetence of one planter does not invalidate all of the data. It is also a good idea for the nursery manager to retain a few seedlings—these should be randomly removed from boxes at the moment the seedlings leave the nursery and either transplanted into a nursery bed or into some pots to see how well they perform under optimal conditions. This simple practice will help with diagnosis if an outplanting failure occurs.

For those wanting to make empirical comparisons of stock type performance on outplanting sites for their own purposes, the general physiological condition and morphology of the stock should be measured or, at least, described. A recurring problem is growing seedlings in several different types of containers or as different bareroot stock types but only using one fertility and irrigation regime—this can cause broad discrepancies in seedling quality and invalidate any conclusions on the outplanting site. It is the combination of physiological and morphological characteristics and their interactions with the environment rather than stock type, per se, that will largely determine how the stock performs. Keep in mind that large stock generally grows larger faster than small stock, so measuring growth increments may be more insightful than total growth. Also factor in the additional costs of larger stock, both in production and planting costs, and seedling survival. It may be that planting fewer seedlings from "higher quality" stock on a site is more economical than planting more "acceptable quality" seedlings (South et al. 2005). Another caution about stock type comparisons is to not draw conclusions about survival and growth too soon. Monitoring should be done at the end of the first growing season, but it might take five or more years to be reasonably sure about survival and growth differences. We recommend that test plots be examined at least every second year.

Completing the Cycle

As the forester collects and analyzes data from the field, ideally that information is shared with the nursery manager. Hopefully, this stimulates an eagerness by the manager to periodically manipulate the propagation protocol to further enhance outplanting performance.

References

Anderson, J.L, and Seeley, S.D. 1993. Bloom delay in deciduous fruits. Horticultural Reviews 15:97–144.

Bergquist, J., and Örlander, G. 1998. Browsing damage by roe deer on Norway spruce seedlings planted on clearcuts of different ages: 2. Effect of seedling vigour. Forest Ecology and Management 105:295–302.

Carlson, W.S. 2003. Open-pollinated family management in nurseries. *In* National proceedings: forest and conservation nursery associations—2002. *Coordinated by* Riley, L.E., Dumroese, R.K., and Landis, T.D. USDA Forest Service Proceedings RMRS-P-28, p. 151-158.

Colombo, S.J., Sampson, P.H., Templeton, C.W.G., McDonough, T.C., Menes, P.A., DeYoe, D., and Grossnickle, S.C. 2001. Assessment of nursery stock quality in Ontario. *In* Regenerating the Canadian forest: principles and practices for Ontario. *Edited by* Wagner, R.G., and Colombo, S.J. Fitzhenry & Whiteside Ltd., Markham, Ont. pp.307–323.

Duryea, M.L., editor. 1985. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. Forest Research Laboratory, Oregon State University, Corvallis, Ore. 143 p.

Duryea, M.L., and Brown, G.N., eds. 1984. Seedling physiology and reforestation success. Proceedings of the Physiology Working Group technical session, Society of American Foresters National Convention; 1983 Oct 16–20; Portland, Ore. Martinus Nijhoff/Dr Junk Publishers Dordrecht / Boston / Lancaster. 325 p.

Grossnickle S.C, Arnott J.T., Major J.E. and Le May V.M. 1991. Stock quality assessment through an integrated approach. New Forests 5:77-91.

Kooistra, C.M., and Bakker, J.D. 2002. Planting frozen conifer seedlings: warming trends and effects on seedling performance. New Forests 23:225–237.

Landis, T.D., and Dumroese, R.K. 2000. Propagation protocols on the Native Plant Network. Native Plants Journal 1:112–114.

Mattsson, A. 1997. Predicting field performance using seedling quality assessment. New Forests 13:227–252.

Neumann, R.W., and Landis, T.D. 1995. Benefits and techniques for evaluating outplanting success. *In* National proceedings: forest and conservation nursery associations—1995. Coordinated by Landis, T.D., and Cregg, B. USDA Forest Service General Technical Report PNW-GTR-365. pp. 36–43.

Puttonen P. 1997. Looking for the "silver bullet"—can one test do it all? New Forests 13:9-27.

Ritchie, G.A. 1984. Assessing seedling quality. *In* Forest nursery manual: production of bareroot seedlings. *Edited by* Duryea, M.L., and Landis, T.D. Forest Research Laboratory, Oregon State University, Corvallis, Ore. pp. 243–259.

Ritchie, G.A. 2004. Container seedling storage and handling in the Pacific Northwest: answers to some frequently asked questions. *In* National proceedings: forest and conservation nursery associations—2003. *Compiled by* Riley, L.E., Dumroese, R.K., and Landis, T.D. USDA Forest Service Proceedings RMRS-P-33. pp. 3–7.

Rose, R., Campbell, S.J., and Landis, T.D., eds. 1990. Target seedling symposium: proceedings, combined meeting of the western forest nursery associations; 1990 Aug 13-17; Roseburg, Ore. USDA Forest Service General Technical Report RM-200. 286 p.

South, D.B., VanderSchaaf, C.L., and Britt, J.R. 2005. Reforestation costs can be decreased by lowering initial stocking and outplanting morphologically improved seedlings. Native Plants Journal 6:76–82.

Stone, E.C., and Jenkinson, J.L. 1971. Physiological grading of ponderosa pine nursery stock. Journal of Forestry 69:31–33.

Sutherland, J.R., Shrimpton, G.M., and Sturrock, R.N. 1989. Diseases and insects in British Columbia forest seedling nurseries. B.C. Ministry of Forests FRDA Report 065. 85 p.

Timmer, V.R. 1997. Exponential nutrient loading: a new fertilization technique to improve seedling performance on competitive sites. New Forests 13:279-299.

Tinus, R.W., and McDonald, S.E. 1979. How to grow tree seedlings in containers in greenhouses. USDA Forest Service General Technical Report RM-60. 256 p.

van den Driessche, R. 1977. Survival of coastal and interior Douglas-fir seedlings after storage at different temperatures, and effectiveness of cold storage in satisfying chilling requirements. Canadian Journal of Forest Research 7:125–131.

Wilson, B.C., and Jacobs, D.F. Quality assessment of temperate zone deciduous hardwood seedlings. New Forests (in press).

Making Ends Meet in the Forest Nursery Business

J. Kitchen

Pacific Regeneration Technologies Inc.
#410 – 355 Burrard Street, Vancouver, BC V6C 2G8

For my presentation at the Thin Green Line Symposium, I was asked to address the following three questions:

> *How do forest seedling nurseries remain cost-effective and still meet the needs of a wide range of customers?*
>
> *How do nurseries meet the challenges of rising costs and flat pricing and still make money?*
>
> *How challenging is this for PRT?*

To start with, I have to explain that I was brought up by a teacher and an engineer – a terrific combination I think!

My Dad was a pulp mill engineer and he would come home from work and head straight for the shower, get out of his work clothes because my mom wasn't too fond of the smell. I think I was 5 or 6 yrs old when I started to wonder about that smell, and I asked him what it was. He gave me a very complex answer, and the only thing I can remember is that the human nose can detect 4 parts per billion of sulfur dioxide in the air and that is a very small amount and it won't hurt you, and to get it below that costs more money than I would be able to imagine. I asked him again one day, and if I was anything like my own kids, that was probably about the 30th time I said "Why?" that day.

So I got the short answer when he said "Son, that's the smell of money!" I thought about that answer for a long time - maybe a year or more. Eventually I made a decision. One thing I would never want to have a lot of… was money.

So with that out of the way, let's talk about nurseries. The first step in addressing the challenge of market prices, competition and rising costs is: ***Stop whining about the price.***

In 1962, you could buy a refrigerator for around US$470[1] and if you apply inflation to that number it would cost you US$2,536 by 1998, let alone today. The 1998 average price was about US$750, less than 30% of the 1962 price. Material and energy costs have gone up, shipping has gone up and labor has gone up, but people all over the world got better at making refrigerators. In my opinion, the same applies to seedlings.

The next step is to engage people in solving the problem and there is some magic in this. Inspired people are great people. No matter who they are, if they are inspired by what they are doing, they will invent great solutions. We can talk about a lot of management buzzwords, like "Economy of scale", "production efficiency" and "lean thinking" but inspired people think of these things by nature.

An example of lean thinking is something we call the "Combined Lift Method", but what I personally like to think of as the "Ontario Lift Method", because Ontario is where we learned about it. People will naturally arrange work in assembly lines when they get the chance. Other methods seem counter-intuitive[2] but the reality is that "assembly line" production generally only works for processes that involve very large quantities of identical tasks and products. The reason is that the engineer in all of us can identify and fix bottlenecks one at a time. As each bottleneck is eliminated, a new one pops up. In the business of forest seedlings, we are growing an ever wider variety of seedlings to meet the changing needs identified in my opening questions. Therefore, a more integrated approach, such as the lifting technique used here in Ontario, has proven more cost-effective for us. With this system, one person extracts seedlings, bundles and boxes them. Wasted time is reduced and this method is safer because the employees perform a wider variety of tasks, reducing the risk of repetitive strain injury. The reason for success is that each person is a master engineer of their own best methods. They will naturally find the best time to bend and the worst time to turn. I'm sure you've all watched treeplanters or planted trees yourselves. Imagine what would happen (and used to happen!) if each treeplanter was required to plant trees the exact same way, and in step with a group of other people. The whole operation would slow down to the productivity of the slowest common denominator, and the vast majority of workers would be frustrated by the lack of control over their actions, and disappointed by the low productivity. Let people use their own ingenuity and the best process controller ever known – the one between their ears – will increase productivity more than you could have imagined.

[1] http://qrc.depaul.edu/djabon/cpi.htm, Malkiel, Burton G. A Random Walk Down Wall Street. W. W. Norton and Company, New York 1999.
[2] Womack, James P. Lean Thinking, New York, Free Press, 2003, p. 22

Table 1. *Comparison of three harvest methods.*

Method - 112 cavity styroblock	Capital Cost	Cost per Seedling $12.00 hourly rate	Trees per Shift	Trees lifted per worker - hour - block moving, sorting, packaging and supervision
Conventional harvest line	$5,000 to $15,000	$0.020	Limited by length of conveyor belt	760
Combined lift method	$3,000 to $10,000	$0.019	Limited by number of stations	810
Semi-automated	$160,000	$0.015	One pin extractor feeding two sorting belts – approx 130,000	1,030

The point here is that nursery people, like any other successful business people, must open their eyes to different ways. The answer will be a local one, depending on size of the nursery, labor cost, the variety of seedling products, and the number of seedlings that must be lifted per shift. (Table1).

Economy of scale is undoubtedly important. A competent owner or manager with a ½ time admin person, travel costs, accounting, insurance, office supplies and so on is going to cost $200,000 if not more. If the nursery grows 12 million trees, that's $0.02 per tree. At 6 million trees it's $0.03, and at 3 million trees it's a whopping $0.07.

Nursery size and ability to automate may be even more important as it gets increasingly difficult to find industrious seasonal workers. Two pin extractors or a transplanting line will cost around $200,000 to buy, or about $50,000 a year to achieve a reasonable return. On the same nursery sizes, that's $0.004, $0.008, and $0.016 per seedling respectively, so you can see what I mean.

In times of slim returns, we have to be very careful with capital investments to improve the nursery. I'd like to talk about an example where my own personal views were dead wrong – irrigation booms vs. fixed irrigation. My own nursery in northern BC had booms in every greenhouse and I was a strong believer. If anyone had tried to talk me into fixed irrigation, I would have listened and then dismissed the idea. But let's talk about that. I learned a lot when I sold Summit and joined PRT in 1994 and had the benefit of all those inspired people to set me straight!

With respect to irrigation, issues to think about include, <u>in order of importance:</u>

- seedling recovery and quality;
- capital cost for the equipment;
- efficient water use and fertilizer consumption;
- labor, and;
- maintenance.

PRT proved to me beyond a doubt that by using a well designed fixed system, seedling recovery and quality were the same as what could be achieved with irrigation booms (Table 2).This was a big surprise to me. I looked at over 50 cultural units and the evidence was clear. So with recovery and quality clearly out of the way, let's look at cost.

This results in a savings of about $0.002 per tree – a significant amount in a tight market. This is just one example from a myriad of opportunities that can be explored if nurseries are willing to test their assumptions.

As far as what's ahead, I believe there are two or three significant factors that will change how we all think about seedling prices.

It's important to recognize that the cost of propagules is rising very quickly. Seed cost in BC has increased ten-fold for some species in the last 10 years. This increasing value of propagules, as more seed orchards come on stream – up to $0.05 per seed – will dramatically change the relative value of nursery production. Our future also includes variety based forestry, including somatic embryogenesis and other forms of asexual propagation. There is potential for the value of the propagule to exceed the production cost of the seedling. This could easily lead to requirements for larger seedling size, maximum recovery, single sowing, transplanting and other techniques to ensure that nurseries retain maximum value from expensive propagules. This issue will also test the ability of both nursery people and customers to assess the entire value chain.

Table 2. *Operating cost comparison for boom and fixed irrigation.*

Irrigation Type	Irrigation Boom		Fixed Sprinklers	
Source of Cost	**Description**	**Annual Cost**	**Description**	**Annual Cost**
Invest in equipment	$3,000 amortized over 10 years	$450	$500 amortized over 10 years	$75
Water & Fertilizer	Annual cost	$600	20% more for fixed	$720
Labor	½ hour per boom, twice a week for 20 weeks	$300	15 minutes per greenhouse or bay, twice a week for 20 weeks	$150
Maintenance		$200		$100
Total Annual Cost		$1,550		$1,045

High heating costs are a new reality. Solutions vary by location, but of course careful buying is important. Approaches such as group buying and buying forward will help, but they can not eliminate the new cost for energy. Therefore the best defense is conservation. Can you reduce or eliminate energy consumption? One competitor told me that he can save $1,000 by shutting down his boilers for a week. So he looks ahead at the weather, decides whether or not ambient temperatures will be adequate, and if so, the boilers are shut down. By continuing to watch the weather forecast carefully, he can delay re-firing the boilers until the forecast indicates a need within the next 48 hours. Boiler shock is avoided and he's saved important resources – cash! On the other hand, many growers and heating specialists will tell you this can't be done.

We're just beginning to look at temperature integration for conifers and this may be a significant technique within a few years. Assuming adequate light levels, the growth rate of most plants is determined by the average temperature over a period of time. By looking forward at the weather (and despite all the jokes, weather forecasters have proven to be amazingly accurate) we can wait for sunshine to heat our greenhouses within a few days, and allow the plants to run cooler when artificial heating costs are high. People often ask me "So have you looked at solar as an alternate energy source?" Greenhouse operators have been in the solar heating business forever. By using temperature integration, we can make that even better.

I won't spend much time talking about labor, because that's probably the area we all understand best. I want to make one major point on labor though. Don't get caught in the under-spending game. Industries do not become prosperous by focusing solely on cost-cutting. Remember that we as an industry have improved recovery of cavities sown by at least 20% over the last 20 years, and people are a big part of that. If you single-sow to save thinning costs, you will pay for it in heat and capital for additional greenhouses. You may be forced in this direction due to seed cost, but as long as seed is reasonably priced, be sure to run the cost-benefit analysis comparing empty cavities with saved labor.

So how does PRT cope with the new realities of our business? In my view, there are five fundamentals of successful business: Market, People, Community, Capital and Continuous Improvement. For the next few minutes, I'll talk about each of these from PRT's perspective.

Understanding the Market

We stay focused on our primary job as a business-to-business supplier - helping our customers be more competitive in their industry. That means assisting in their quest to compete with low-cost fiber and labor from around the world. It means understanding why they are certifying their forest operations. It means realizing that they must improve their return on capital. We try to help them with that. If a smaller seedling will do the job, we do some cooperative research and find out. Selling them on the merits of a large seedling to pad the bottom line at the nursery will only hurt the customer and ultimately that will hurt the supplier too. On the other hand, if a larger seedling will negate the need for costly site prep or follow up treatments, then we get out there and prove it. We owe it to our customers and our industry to test the assumptions and help them compete globally.

Inspired People = Great People

No matter what the problem, it is highly unlikely that consultants with silver bullets are going to solve it. It will come from within, from people who understand the problem, care about it, and find local solutions. We spend time to make sure our people know where we stand and what the problems are so they can contribute to the solutions. We keep them informed about what is working well and what is not working well. We engage them in our risk management planning. We help them understand costs and the importance of the capital invested in our business. We invest in leadership at least as much as we invest in technical and administrative training.

Social Acceptance

We encourage everyone at PRT to be active in the industry and in the community. The forest seedling industry has a great story to tell. One entertaining story I heard many years ago was about a crew of employees at a nursery who wanted the afternoon off to attend a logging protest. I can assure you the nursery manager was ready with appropriate options for his people! But more importantly, it opened a dialogue with people to help them understand how we fit within the community, and the obvious importance of the forest industry's well being! I try to devote some time to getting our story out – to help our communities understand that wood is an important and viable renewable resource, and how nurseries fit within the forest industry.

Access to Capital

To ensure ongoing access to capital, we need to make a profit and we need to be careful with capital. This is a focus for us at PRT. You often hear that the reason for a business is to make money. This is not particularly close to the truth. The need to make money is a necessity of business[3], not the end. If we don't make a profit, we will not get the capital to maintain and to improve our business. Improvement and innovation, driven by the industrious nature of people and funded by new capital, is what sustains the business. As a result, businesses support people, help make communities livable and safe, and provide the economic engine for us and for our children. For me, that is what business is all about.

Continuously Improving Process

I don't believe we can rely on others to do our research and development. I think it's important to be realistic and define the real problems. An example for PRT is the high cost of energy. After initiating a plan to reduce consumption 5 years ago, people throughout the company have continued to build on that start. We have managed to keep energy costs relatively stable, despite a doubling of cost per unit of heat energy. Temperature integration will be a big step as well, but for now, we haven't even begun to overcome the obstacles. Growth modeling for conifers would be a big help with this challenge.

In summary, the same five drivers will guide every successful business – market, people, community, capital and continuous improvement. We can understand and use these factors to our advantage, or we can let them dictate what we will be forced to do. My choice is to accept our realities, and be sure that we're wagging our own tail.

[3] Drucker, Peter F. Management: Tasks, Responsibilities and Practices. Harper Business, New York. 1985. p. 71

Growing A Stronger, Greener Ontario

J. Lim

Ontario Forest Industries Association
20 Toronto Street, Suite 820, Toronto, ON, M5C 2B8

The forest industry has been an integral component of Ontario's landscape for over 200 years. However, unprecedented economic challenges are forcing the forest industry to re-examine its business practices in an effort to reduce the cost of doing business while simultaneously maintaining its world class standing as a leader in sustainable forest management.

In her keynote address to the Thin Green Line symposium, Ontario Forest Industries Association (OFIA) President and CEO Jamie Lim will provide an overview of the forest industry and will outline opportunities to reduce renewal costs while ensuring successful regeneration is taking place on the forested landbase. Using the results of an OFIA member case study, Jamie will highlight the need for alternatives to traditional renewal and measurement practices.

Regeneration Practices in Scandinavia: State-of-the-Art and New Trends

A. Mattsson
Dalarna University, Dept. of MNT, S-776 98 Garpenberg, Sweden

Introduction

This overview will focus on the boreal forest of Scandinavia including Sweden, Finland and Norway. The presentation about regeneration practices, including nursery operations and stand establishment, will, regarding nursery operations, focus on containerized stock since it is the type of stock that is totally dominating in these countries.

The forest plays a fundamental role in the ecological, social and cultural well-being of people and this really refers to the Scandinavian countries mentioned. Out of the total land area, under the coniferous forest limit, productive forest and other wooded land represent a large part. (Table 1).

The ownership of this forest is quite different in the respective countries (Table 2). In Sweden, private owners and companies are the dominating landowners. In Finland, private owners and the state owns 90% of the land while the forestland in Norway to a very large extent is privately owned.

Regeneration practices include very few species due to long-term environmental adaptation. In the boreal forest of Scandinavia forest stands are also quite pure dominated by one tree species and also to a large extent even-aged due to management practices. Table 3 shows the species dominating the forestland in the respective countries.

This situation is of course reflected in the regeneration practices regarding the species produced in the nursery (Table 4).

Containerized production is the totally dominating method of producing seedlings as can be seen in Table 5.

Table 1. *Forest land out of the land area under the coniferous forest limit (millions of hectares).*

Country	Land area	Forest land	%
Sweden	41.0	30.3	74
Finland	30.5	26.2	86
Norway	14.8	9.2	62

Table 2*. Ownership (in percent) of forest land.*

Country	Private	Company	State
Sweden	51	39	10
Finland	57	10	33
Norway	80	8	12

Table 3*. Dominant tree species by percent of forest land area.*

Country	Scots pine	Norway spruce	Silver/Downy birch
Sweden	51	39	10
Finland	57	10	33
Norway	80	8	12

Table 4. *Nursery plant production in 2004 for the respective counties by volumes and most important species.*

Country	Volumes (millions)	Scots pine %	Norway spruce %	Birch %	Others %
Sweden	320	37	58	1	4
Finland	163	34	61	4	1
Norway	23	3	93	1	3

Table 5. *Nursery plant production in 2004 by volume and stock type.*

Country	Volumes (millions)	Container %	Bareroot %
Sweden	320	90	10
Finland	163	96	4
Norway	23	98	2

Containerized Nursery Practices

Regarding nursery practices, containerized production is quite similar in the respective country and therefore the following presentation gives a general overview that reflects the major steps in state-of-the-art production.

Containerized systems were first introduced in Finland in the late 60s as the paperpot system originally used for producing rice plants in Japan. It was shortly after then also introduced in Sweden. In this system the seedlings were supposed to be planted together with the paper container.

After experiences in the field with disturbances in the root development due to a slow decomposition of the paperpot container, rigid plastic containers were introduced in the early 70s. The first system had a smooth interior wall and a flat bottom design with a small drainage hole. This design often led to root deformations in the nursery especially in the form of root spiralling. After planting, very few roots grow out from the root system and the fibre structure in the root/stem zone was often seriously disturbed. This situation implied initial stability problems after planting especially for pine seedlings. For stands with these problems there is also a risk that future timber quality can be affected due to, for example, the presence of compression wood.

The introduction of vertical ribs to guide the roots and a new bottom design in the second generation of plastic container systems prevented root spiralling and allowed more intensive root egress during field establishment.

During recent years a third generation of container systems, using different concepts of side slits, have been successfully introduced. All these systems, based on air pruning, produces a lot of active root tips evenly distributed over the whole surface of the growing media and allows a uniform and intense root development after planting.

In Scandinavian boreal forest conditions it can also be of importance for regeneration success to have a lot of active root tips in the upper part of the root system. This due to the fact that root growth in Scots pine and Norway spruce are activated at a temperature of about 5C°. At a planting site in early spring temperature conditions in the soil can differ extensively. In the very upper soil layer temperature during the day can promote root growth while the temperature in the bottom of the root system is to low.

The window for intense root growth activities between the time of planting and the initiation of cell elongation in the shoot is very narrow in Scandinavian boreal forest conditions. Regarding the thin green line concept the presence of a lot of active root tips in the upper part of the root system can therefore be of importance for regeneration success.

The major steps in state-of-the-art production of containerized seedlings start with sowing. Normally one seed per container is sown in highly automated filling and sowing lines. To improve seed quality an extensive tree improvement program, using seed orchards, have been running during many years in Scandinavia.

In Sweden the work is done in close co-operation between public organisations and the major forest companies and is paid for on a 50/50 basis. The seed orchards however is owned and run by the companies. In Sweden the second generation of orchards will now be commercially utilised and the genetic gain in wood production is expected to be about 20%. The first generation has generated a gain of about 10%. The third generation of orchards now under establishment is expected to give about 30% more volume in the future. In Finland and Norway the tree improvement program and the seed orchards are run and paid for by public organisations. In both countries they are now utilising the first generation of orchards and as for the first generation in Sweden the gain in productivity has been about 10%.

When sowing, the growing medium used in the nursery is normally a pure peat mixed with dolomite lime. The container stock is generally grown at densities ranging from 400 to 1000 seedlings per square meter depending on if it is grown for one or two years in the nursery.

During the germination and early growth the seedlings are kept in plastic greenhouses that each can contain up to 2 million seedlings. Depending on geographical location, greenhouse cultivation starts somewhere between the beginning of March and the end of April. The greenhouse has equipment for irrigation and fertilisation and some nurseries control the distribution of water by computers connected to sensors measuring the weight of the container cassette. Also fertilization is conducted through the irrigation system.

Some nurseries also use additional light supply during greenhouse cultivation. This is done to prevent bud set of early sown northerly provenances of Norway spruce. Due to the long nights in early spring, there is a risk for bud set to occur only some weeks after germination. If this happens there will be no more shoot growth during the rest of the vegetation period but by breaking the night with a short light exposure this risk can be prevented.

Also blackout equipment are used in many nurseries during greenhouse cultivation to regulate the growth of Scots pine seedlings. During the first year of growth, only primary needles are normally developed regarding Scots pine seedlings. A long night treatment some weeks after germination will induce bud set. When again exposed to the normal photoperiod, bud break will occur and secondary needles will be developed on the new shoot and you will have a one-year old seedling with the characters of a two-year old one. This technique has been developed to meet the customer demand for a “short and fat” seedling regarding needle biomass and stem diameter.

After the greenhouse phase that covers about 2 to 3 months the seedlings are moved to outdoor areas for completion of growth and hardening off. As for the greenhouse, irrigation and fertilisation at the outdoor area are also managed by using travelling booms. The container cassettes are normally stored on raised pallets all the way from sowing until lifting for field distribution or winter storage. This system facilitates the internal transportation and it also contributes to an effective air pruning of the root system.

To be able to prepare Norway spruce seedlings for planting out in the fall or cold storage during winter, many nurseries are using outdoor blackout equipment for initiation of early bud set. This long night treatment is normally conducted during 2 or 3 weeks in August and is a very effective way to promote the hardening process of Norway spruce during late summer and early fall.

When the seedlings are ready for cold storage they are moved from the outdoor area to the packing line where they normally are put in cardboard boxes. The seedlings are often cold stored during winter in storage facilities at minus 4 ^{o}C, but a lot of seedlings are also stored outdoors on raised pallets. If there is a sufficient snow cover the quality of the seedlings will not be affected. But during cold winters with less snow cover there is a substantial risk for severe root damages due to low temperature exposure.

After the winter storage the distribution to the planting site is often carried out by specially designed trucks. The final strategic distribution of seedling boxes over the site is normally done manually or often also by small four wheelers and in some cases by helicopter.

Stand Establishment Practices

Under this heading the most important methods used for stand establishment in Scandinavia are presented.

Before establishment the regeneration area is normally left for a couple of years to let logging debris decompose to facilitate soil preparation. A very important reason is also to minimise the risks for damages to the seedlings due to attacks from the pine weevil, one of the major problems for regeneration success in Scandinavia. Later in this presentation methods used to improve the situation will be discussed.

Scarification is the dominating method in all countries for preparation of regeneration areas. Different methods for scarification are used depending on local site conditions. In drier sites harrowing is normally used while mounding is used on sites with a higher water table and sites exposed to frost heaving. Due to environmental concerns and the concern for damages to relics of culture in the ground, less radical methods like mounding or scarified patches are more and more used.

In general the public attitude towards forestry has affected the legislation in Scandinavia towards a more restrictive attitude against for example radical site preparation the use of herbicides and clear cutting over large areas. In Sweden for example the new forest legislation now states very clearly that environmental concerns in forest management are of equal importance compared to timber production. This is for example expressed in the question of bio-diversity where forest areas with endangered species often are converted into national parks.

As can be seen from the following figure planting is the dominating method in the respective country but due to adjustments in forest legislation the possibilities for land owners to practice natural regeneration has increased in resent years.

The most common areas for natural regeneration in the boreal forest of Scandinavia is areas with sandy soils and a relative thin humus layer dominated by Scotch pine. Normally about 100 seed trees are left per hectare and soil scarification is done adjusted to the prognosis for a good seed year. The regeneration result is often very good and to lover costs than planting or seeding. Due to the large amount of seedlings that normally establish over the regeneration area there is also favourable conditions for good quality timber production in the future.

Also seeding is conducted on areas with about the same conditions as described for natural regeneration and normally with pine seeds. A very shallow scarification is recommended where only the humus layer is removed in stripes or patches. Often the seeding is done in combination with soil preparation where the soil first is

Table 6. *Different regeneration methods used in Scandinavia during 2004 expressed in percentage of the total regenerated area.*

Country	Natural regeneration	Seeding	Planting	No measures
Sweden	22	2	75	1
Finland	23	20	56	1
Norway	25	2	71	2

prepared to optimise germination conditions after witch the seeding is conducted.

When using strips, 20-25 seeds are distributed per meter and when using seeding in patches 15-20 seeds are distributed in each patch. When using patches about the same amount is prepared per hectare as for the amount of seedlings when using planting, that is about 2000-2500 per hectare depending on site index.

Seeding is a sensitive method where the results can be very variable depending on climate conditions. If successful the costs are lower than for planting and the potential for a good timber quality in the future is equal to natural regeneration.

Planting is the most common regeneration method in boreal Scandinavia both for pine, spruce and birch. It is conducted over a wide range of site conditions and as mentioned the regeneration site is scarified 2-3 years after clear felling by harrowing or mounding. In both cases the distance between the tracks after harrowing or between mounds are about 2 meters. The distance between planted seedlings is also about 2 meters giving a normal plant spacing of 2500 seedlings per hectare.

Planting is normally done by hand with a special planting tool. This planting tool is designed like a tube where the seedling can slide down into the planting hole made by the tool. A skilled worker can plant up to 3 000 seedlings a day using this method. The seedlings can also be planted with machines that have been developed in Scandinavia. For some machines the seedlings are distributed by compressed air through tubes to a scarified spot prepared by the machine. The vehicles can also be equipped with special sensors that avoid planting in rocks or stones.

The regeneration result after planting is often quite good. However, the thin green line between success and failure is often depending on the possibilities to reduce the damages caused by the pine weevil, a major if not the major problem for successful forest regeneration both in Sweden, Finland and Norway.

The pine weevils are attracted by the smell from fresh felling areas and if young seedlings are available at the site the weevil feeds on the bark and normally kills the plant by girdling it. If no protective measures are conducted in areas with a lot of pine weevils you can often expect a survival rate of less than 50%.

Measures taken in regeneration practices in Scandinavia to reduce damages from pine weevils involves different kinds of silvicultural measures such as delayed planting, scarification and the use of resistant plant material.

By letting the clear-cut area rest for 2-3 years before planting the population of weevils will be substantially reduced due to lack of fresh feeding material for the second generation of weevils reproduced in the stumps of the old stand and normally emerging two vegetation periods after clear felling.

A careful scarification before planting will also reduce the damages since it had been shown that seedlings surrounded by mineral soil are less exposed to attacks from the weevil than seedlings planted in humus or close to the humus layer.

Seedling quality and seedling size are also factors of importance to reduce the damages. A vital seedling will respond to the bark damages by an intensive flow of resin which will improve the chances of survival. Also a seedling with a thick stem will have better chances of survival. In trials conducted, the survival rate was dramatically improved for seedlings with a stem calliper of half a cm or more.

Besides silvicultural measures to prevent damages from the pine weevil chemical and technical protection are also used including insecticides, mechanical devises or different kinds of coatings that will prevent the weevil to feed on the stem bark.

Chemical treatments have during many years shown good results. Due to concerns for the environment and human health some of these chemicals have been forbidden and there is, since many years, a general discussion in Scandinavia over the future use of insecticides in planting operations.

This situation has implied a growing interest for alternative methods to chemical treatments. These include different kinds of mechanical devises. A lot of mechanical devises attached around the seedling have been tested with varying results. Besides the protection ability against damages the cost for the device and application is often quite high making large-scale introduction more difficult.

During recent years methods for coating of the stem with glue or wax have therefore been tested. With this technology seedlings can be treated in the nursery in a cost efficient way and planting capacity compared to untreated seedlings will not be reduced. Results for some of these coating methods have also been very promising and raised a lot of interest for expanding the efforts in the development of this technology among forest companies and private land owners.

New Trends in Regeneration Practices

Regarding regeneration practices these are some examples of new trends.

- A growing interest for pre-cultivation followed by transplanting to a larger container mainly for production of large spruce seedlings.
- Storage in freezers at about –4C° is increasing.
- Less radical methods for site preparation like moulding is gradually replacing harrowing.
- Interest in machinery planting is increasing in Sweden and Finland.
- A growing interest for very small containerized seedlings for sites with moderate or low weed competition and also for sites where extensive damages from the pine weevil can be expected.

Regarding the increased storage in freezers, at temperatures below 0°C, the trend is related to the extensive root damages due to low root temperatures during outdoor storage that many nurseries have experienced. Outdoor storage of containerised seedlings on raised pallets in combination with less natural snow cover during the latest years is the background to this situation. Also problems with moulds developing during winter in cold storage with a temperature over 0°C is another factor of importance for the increase in freeze storage.

As mentioned before negative effects of radical methods for site preparation are discussed more and more both from environmental and cultural aspects. Also new forests legislation where environmental concerns have been identified as of equal importance compared to timber production has contributed to the trend against softer methods for site preparation.

The growing interest for machinery planting is connected with a situation where labour for planting operations is harder and harder to find. This is due to rapid urbanisation in many parts of Scandinavia, leaving few people in forested areas at the countryside. Since machinery planting is restricted only to sites suitable for this planting method, a movement towards professional planting crews, as in Canada and the US, can be foreseen.

In recent years many nurseries have noticed a growing demand for large container stock, mainly of spruce. This due to successful regeneration results at fertile sites with extensive weed competition. This demand have also been further more expressed as a result of the major wind throw that hit southern Sweden in the beginning of 2005 which will imply an additional demand of at least 200 million seedlings during the nearest years to come.

When producing large container stock in Scandinavia today, that is containers with a substrate volume over 100 cc and a density under 400 seedlings per m², seedlings are germinated in greenhouses and grown for about 3 months before they are mowed to open land. Seedlings are then grown on open land for the rest of the vegetation period. After winter storage on open land the seedlings are grown for another vegetation period before planting in the fall or next spring.

The low utilisation level of the expensive greenhouse area with a low seedling density in combination with shortage of greenhouses and difficulties for many forest nurseries to have investments approved for additional greenhouses have raised interest for pre-cultivation and transplanting technology.

In initial tests pre-cultivation of conifer seedlings and broad-leaves have been performed under a short period at high seedling densities using both pure peat and stabilized rooting media. Depending on expected difficulties to grow seedlings successfully at very high densities in conventional greenhouses some major companies in Sweden have successfully tested pre-cultivation in a system with a very precise level of climate control and large growing capacity. The system is developed in Sweden by the company QS Growing Systems.

In the system the seedlings are pre-cultivated in a mobile multiple floor production facility not affected by outdoor climate. No pesticides or insecticides are used and the water and fertiliser are recycled. The system also utilises 90% of the waste heat from the production. The cultivation period, under optimal germination and growth environments, extend over a period of 2 to 4 weeks at a density of 2000 to 4000 seedlings per m² depending on species. After cultivation the seedlings are quality graded using a grading and re-plug robot. The production system is certified according to the ISO regulations and has also been environmentally approved based on life cycle analysis.

At a convenient time, decided by the customer, the pre-cultivated seedlings are delivered to the nursery. Transplanting at the nursery is then carried out by a mobile unit used in horticultural transplanting operations. The unit has a capacity of transplanting 25 000 seedlings per hour and the computer system allows that transplanting of pre-cultivated seedlings can be done using any optional container system. By adjusting the time of transplanting to the local climate at the specific nursery the continuous cultivation of the transplanted seedling can be done on the nursery outdoor area without the need of greenhouses.

The companies involved in the tests have identified several advantages with this system.

- The nursery will have a cost-efficient and high quality seedling, grown from there own seed, with no losses due to containers without seedlings or containers with poor quality seedlings.
- No needs for complementary or new capital investments in conventional greenhouse technology with high running costs.
- Nurseries that already have invested in a containerized system can use this system and belonging equipment.
- Environmental stress will be reduced due to less need for greenhouse cultivation.

The interest for planting very small seedlings, so called mini-plants, on specific sites are the result from successful regeneration results in Finland and trials in Sweden conducted by Dalarna University in close co-operation with many of the major forest companies in Sweden.

Mini-plants are defined as containerized seedlings with a root volume of about 20 cc and a density of close to 1500 seedlings per m² and grown for about 10 weeks before planting. The main reason for the interest is the possibilities to reduce regeneration costs both in nursery production, storage, distribution and planting. An additional benefit could also be that these small seedlings are less damaged by pine weevils, compared to seedlings of conventional size, something that has been noticed in the first trials conducted.

Top 10 Principles for Managing Competing Vegetation to Maximize Regeneration Success and Long-Term Yields

R.G. Wagner

University of Maine, 5755 Nutting Hall, Orono, Maine 04469-5755

Introduction

Vegetation (including trees, shrubs, grasses, and forbs) that rapidly establishes on newly disturbed forest sites often determines whether forest regeneration efforts will be successful. Although most plants growing on forest sites are a natural part of the forest, many plant species can invade or re-establish themselves in sufficient abundance and stature to threaten the survival and growth of desired tree species. This competing vegetation exerts its influence on resource availability and conditions in the environment of young trees. Seedling responses to vegetation management are influenced to a large degree by competition for light, water, and nutrients.

If harvested forest stands are to be returned to forests of a desired species composition, structure, and growth rate, strong consideration must be given to the vegetation that grows on all regenerating sites. Unlike protecting young forests from insects, diseases, or wildlife pests, which tend to be localized at certain times, vegetation is generally a problem on every forest site being regenerated. As a result, vegetation management must be an integral part of almost every forest regeneration prescription. In fact, few aspects of silviculture provide more control over the outcome of forest growth and development.

The vegetation associated with young forests is also a vital component of the forest ecosystem and plays an important role in the function, protection, and management of other forest resources. Good forest vegetation management, therefore, seeks to balance the negative effects of competing vegetation with the vital role that it serves in forest ecosystems.

So, what does the latest research indicate about the long-term yield gains associated with managing forest vegetation? Can significant financial returns be realized? Can focused regeneration and vegetation management efforts increase sustainable harvest levels and wood supplies? What principles should forest managers follow to ensure that the highest yield gains can be achieved? The following offers some insight into these questions.

Long-term yield gains from forest vegetation management

Over the past several decades, there has been a substantial amount of research quantifying increases in forest productivity associated with vegetation management in the North American forests. Most of this research, however, has reported growth responses for only several years following vegetation control treatments. Documenting the benefits of effective vegetation management on forest productivity, however, requires measurement over a significant portion of a stand's rotation to document the long-term growth and yield response associated with specific treatments. Toward that end, there is a growing body of longer-term studies for most North American forest types that have documented growth and yield changes over a significant portion of the forest rotation. Rotation-length data are now available for some trees species.

Wagner et al. (2004) recently examined the longest-term studies in North America that have documented gains in wood yield from effective forest vegetation management. Twenty-three replicated studies that included experiment controls (i.e., untreated plots) and a variety of vegetation control treatments from Pacific Northwestern, Southeastern, and Northern forests in the US and Canada were reviewed. Only studies with a minimum of 10 years of post-treatment growth measurements were included. Several studies had between 25 and 30 years of measured growth responses. Nearly all of the studies examined commercially-important conifer species. Percent gains in stand or individual-tree wood volumes from the most effective vegetation treatment relative to that of the corresponding untreated control were reported for each study. Eight studies were reviewed from the Pacific Northwest (primarily for Douglas-fir), ten from the Southeast (primarily loblolly pine), and five from northern forests that examined responses for a variety of northern conifers.

Results from these studies, which included from 10 to 30 years of growth response, revealed substantial increases in wood volume yield gains above untreated controls from effectively managing forest vegetation.

Most of these studies had used herbicides to control the vegetation. Increases from 30–450% were found in Pacific Northwestern forests, 10–150% increases in the Southeastern forests, and 50–450% increases in Northern forests. Most of the 23 studies examined indicated 30–300% increases in wood volume yield for major commercial tree species.

Financial returns from vegetation management

Studies documenting the financial returns associated with these yield gains are far less common. Recent analysis from one of the longer running experiments in northern Maine by Daggett (2003), however, projected 22 year stand-level growth responses through to financial rotation at 50 years for various combinations of aerial herbicide application and precommercial thinning (PCT). The net present value (NPV) using a 4% discount rate at 50 years was $1,549 US per ha for aerial glyphosate and triclopyr herbicide treatments, $1,337/ha for the phenoxy herbicide treatments, and $1,023/ha for the untreated control. The NPV for PCT alone was $890/ha. Combined herbicide + PCT treatments had NPVs around $717/ha. Mean internal rates of return were about 8% for herbicide treatment alone, 6.1% for PCT alone, and 5.8% for herbicide + PCT. Results from this study indicated that the long-term merchantable yields and financial returns from PCT required previous management of competing vegetation.

Influence of successful regeneration and vegetation management on wood supplies

Can effective vegetation management influence the wood supplies and sustainable harvest levels for large forest properties or regions? Wagner at al. (2003) conducted an analysis of the influence of various levels of herbicide and PCT application on the long-term sustainable harvest level and NPV for forestlands in the state of Maine. An optimal future treatment scenario that increased the amount of herbicide application and PCT was projected to increase the level of sustainable harvest for the state by 31% and the NPV of the state's forestlands by 12% than a scenario that included no future silvicultural treatments. Management of competing vegetation was an assumption that made PCT feasible in this study.

Predicted gains in experiments are interesting, but the influence of vegetation management and other effective regeneration practices on the long-term harvest levels of actual forest properties is another. Canada has such a model forest in this regard. The 189,000 ha Black Brook District owned J.D. Irving, Ltd. in northern New Brunswick has been intensively managed since the early 1960s. Projected sustainable harvest levels using a spatially-explicit management plan from 2002 to 2077 reveal the power of focused regeneration and vegetation management activities. Sustainable harvest levels today are roughly 2.5 times higher than if Irving had never initiated intensive silvicultural practices on Black Brook (personal communication, Blake Brunsdon, J.D Irving, Inc.). The most impressive part of the projection is that around 2020, sustainable harvest levels for Black Brook begin to ramp up significantly. By 2040, sustainable harvest levels are projected to be about 4.5 times higher than if intensive silviculture had never been practiced on the District. The landscape-level implications for Irving's intensive management of the Black Brook District have been recently analyzed by Etheridge et al. (in press).

Top 10 principles for managing competing vegetation to maximize regeneration success and long-term yields

Substantial wisdom can be gained from the above studies and operational experience that foresters can apply when managing forest vegetation to maximize regeneration success and yield gains. Based on this research and experience, I offer the top 10 principles that should be strongly considered when developing prescriptions and plans for managing forest vegetation:

1. Plant high-quality seedlings as soon after harvest as possible – any delay can be deadly.

One of the most important principles for achieving successful artificial regeneration is to ensure that tree seedlings are planted as soon after harvest as possible. Competing vegetation on the site will be in its most suppressed state at this point and resource availability (light, water, nutrients) will be at the highest level for new seedlings. This early start gives young trees the greatest chance at achieving a place in the next stand.

Conversely, any delay in establishing desired trees gives unwanted shrubs and trees an opportunity to consume available growing space and competitively exclude desired tree species that might be planted later. Most competitive plants that establish following forest harvest have very rapid early growth rates. The early growth rates for planted tree seedlings are generally much slower, and therefore, put them at a competitive disadvantage in the beginning. Any delay in planting trees accentuates this difference and greatly increases the risk of regeneration failure. Many of the non-sufficiently restocked (NSR) lands I have seen in Canada have occurred due to time delays between harvest and planting.

2. Herbaceous vegetation in small amounts (<20% cover) substantially reduces early stand growth.

One of the most significant discoveries in forest vegetation management research during the 1980s and 90s was how competition from herbaceous vegetation (grasses and broadleaves) can suppress the growth of young trees. Despite substantial documentation of the strong negative effects of herbaceous vegetation in forests around the world, many foresters believe that it is not that competitive and therefore not an important management consideration.

Recent experiments from around North America suggest that the growth potential of young forest stands can be reduced from 50-70% or more by early competition from grass and broadleaved vegetation. Further, results indicate that fairly substantial levels of vegetation control are needed for there to be any freedom from the growth suppression of surrounding vegetation. A minimum-response threshold level of 20% cover has been suggested in a number of studies. That is to say, the abundance of herbaceous vegetation must be reduced below 20% cover before any increases in growth from vegetation control can be realized. These studies indicate that maximum growth occurs under nearly complete vegetation control and that the growth rate of young trees decreases rapidly with increasing cover. Above 20% cover, the full competitive influence of herbaceous vegetation is often achieved. Therefore, increasing the growth rates of young plantations from early vegetation control requires achieving levels of cover far below 20% during the early years of plantation development.

3. Only several years of good vegetation control immediately after planting may be needed.

Although achieving levels of vegetation control below 20% cover may seem daunting or impractical, results from several critical-period competition studies are suggesting that most of the early growth potential for plantations can be achieved with only several years of intensive vegetation control, provided that it occurs immediately after planting. Near maximum growth rates were achieved in an Ontario study if vegetation could be controlled for only two or three years following planting (Wagner et al. 1999). Additional years of control did not provide substantial yield gains. Any delays in achieving this early level of vegetation control after planting substantially reduced early stand growth.

4. Good site preparation is vital.

The most effective way to manage early successional vegetation, achieve levels of cover below 20%, and make available site resources (light, water, nutrients) available to young seedlings is through good site preparation. Site preparation provides a moment in time when foresters can exert the greatest influence over the seed and bud bank of plant propagules that will form the next forest stand. All of the available vegetation management tools (fire, herbicide, machines, manual cutting, grazing) in their varied forms are available and can be applied more economically and effectively during site preparation than at any other point in stand development. Overall regeneration success, achieving high rates of early stand growth, and determining the species composition of the next stand are all determined by how effectively the site was prepared before planting. Recommendations for achieving effective site preparation can be found in Dey and MacDonald (2001), Ryans and Sutherland (2001), McRae et al. (2001), and Campbell et al. (2001).

5. Focus investments on highest productivity sites.

Although several studies indicate that the proportional yield gains from controlling competing vegetation can be similar on high- and low-productivity sites, the actual or absolute yield gains are greatest on sites of high productivity. Some foresters believe that since the proportional gains are similar on sites of high and low productivity that the priority for vegetation management investments should be similar on good and poor sites. Since the cost of vegetation control treatments tend to be the same regardless of site productivity, the returns on investment are not. The highest financial returns come from absolute, not proportional, yield gains. Therefore, treatment priorities for limited vegetation management budgets should be focused on the most productive sites.

6. Target release treatments on tall shrubs and unwanted hardwoods as early as possible.

Although herbaceous vegetation can substantially reduce early stand growth, unwanted hardwoods and tall shrubs (especially those species with high dominance potential) have the greatest potential to reduce long-term yields since they can deny desired trees a place in the overstory. Wagner et al. (2001) identifies the dominance potential of various plant species in Canadian forests. As a result, when woody species of high dominance potential are abundant on newly regenerated sites, release treatments should be applied as early as possible. Early treatments are especially important on sites where shade intolerant tree species (e.g., pines) are being regenerated as most cannot survive more than two years of overtopping. Greatest long-term returns on investment from vegetation management will be achieved on such sites, especially when they are highly productive. There are some herbaceous species (such as *Calamagrostis canadensis*) with high short-term dominance potential that must receive equal treatment priority since they can also competitively exclude planted seedlings in a short time. Experience suggests that targeting vegetation control efforts during site preparation and during the first couple of years after planting will often reduce the longer-term abundance or delay the invasion of many unwanted shrubs and hardwoods.

7. Shade tolerant tree species benefit from vegetation management as much as intolerant species.

There is a myth among some foresters that shade tolerant tree species require some degree of overtopping or competition from surrounding vegetation to be successfully regenerated. The evidence from a number of controlled studies across North America, however, indicates that yield gains from early vegetation control are similar for both tolerant and intolerant tree species. In fact, results from one study suggest that tolerant species may require more intensive vegetation control to achieve the same yield gains as intolerant species (Wagner et al. 1999). The ability of shade tolerant tree species to survive overtopping for extended periods does not mean that they require or grow best under those conditions. As a general rule, vegetation management standards for achieving the highest growth rates in young stands are the same for both tolerant and intolerant tree species.

8. Few studies have demonstrated that tree seedlings benefit from surrounding vegetation.

It is common to find claims, particularly from those opposed to herbicides, that the growth and survival of tree seedlings is enhanced or requires the presence of surrounding vegetation. Hundreds of well-designed experiments have been conducted over the past 25 years that document the growth responses of tree seedlings following the removal of surrounding vegetation. Results from these studies overwhelmingly demonstrate that the growth and survival of tree seedlings are improved by the removal of surrounding vegetation. Rare exceptions can be found when neighbouring vegetation improves certain extreme microclimatic (e.g., topographic frost or direct sunlight) or biological (e.g., susceptibility to pests such as the white pine weevil) conditions. However, when these benefits do occur, they only appear to operate for a short period of time, after which the effects of vegetative competition become detrimental. When beneficial for a longer period, the ameliorating effects of vegetation merely exceed the negative effects of competition, and reflect extreme site conditions rather than general ecological relationships.

9. Stem diameter growth (not height growth) is the best indicator of competitive stress.

Many forest regeneration standards across North America focus on a minimum performance requirement for seedling height growth. While height growth is clearly important for achieving long-term site dominance, many of the studies described above have demonstrated clearly that height growth is far less sensitive to the effects of competing vegetation than stem diameter growth. This difference appears to be the result of a higher allocation priority for height growth in young trees. As a result, the best indicator of competitive stress in young trees is stem diameter growth. Diameter growth is the best predictor of overall root and leaf biomass, and therefore, tends to be the best predictor of future growth performance. Thus, forest managers should also base plantation performance standards for vegetation management on minimum requirements for diameter growth.

10. Natural regeneration benefits from early vegetation control as much as planted seedlings.

Another common belief is that vegetation management is required more for plantations than with natural regeneration. Although most of the vegetation management research has been done with plantations, a number of studies have been conducted in naturally-regenerated stands. The available data suggest that growth and survival increases from managing vegetation in natural regeneration are similar to those for plantations. The longer period of vulnerability for natural regeneration, in fact, suggests that vegetation management should probably be considered for a longer period of time in naturally-regenerated stands than in plantations.

References

Campbell, R.A., Wood, J.E., Thompson, D.G., and Iskra, E. 2001. Site preparation – Chemical. Pp. 221-239 (Chapter 12) *in* Wagner, R.G. and Colombo, S.J. (eds.) Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, ON. 650 p.

Daggett, R.H. 2003. Long-term effects of herbicide and precommercial thinning treatments on species composition, stand structure, and net present value in spruce-fir stands in Maine: the Austin Pond Study. Thesis, University of Maine, Orono, USA.

Dey, D.C., and MacDonald, G.B. 2001. Overstorey manipulation. Pp. 157-175 (Chapter 9) *in* Wagner, R.G. and Colombo, S.J. (eds.) Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, ON. 650 p.

Etheridge, D.A., MacLean, D.A., Wagner, R.G., and Wilson, J.S. IN PRESS. Changes in landscape composition and stand structure from 1945-2002 on an industrial forest in New Brunswick, Canada. Canadian Journal of Forest Research.

Etheridge, D.A., MacLean, D.A., Wagner, R.G., and Wilson, J.S. IN PRESS. Effects of intensive forest management on stand and landscape characteristics in northern New Brunswick, Canada (1945-2027). Landscape Ecology.

McRae, D.J., Weber, M.G., and Ward, P.C. 2001. Site preparation - Prescribed fire. Pp. 201-219 (Chapter 11) *in* Wagner, R.G. and Colombo, S.J. (eds.) Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, ON. 650 p.

Ryans M., and Sutherland, B. 2001. Site preparation – mechanical. Pp. 177-199 (Chapter 10) *in* Wagner, R.G. and Colombo, S.J. (eds.) Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, ON. 650 p.

Wagner, R.G., Bell, F.W., and Campbell, R.A.. 2001. Vegetation management. Pp. 431-457 (Chapter 21) *in* Wagner, R.G. and Colombo, S.J. (eds.) Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, ON. 650 p.

Wagner, R.G., E.H. Bowling, and R.S. Seymour. 2003. Assessing silviculture research priorities for Maine using a wood supply analysis. Maine Forest and Agriculture Experiment Station, Technical Bulletin 186. 115 p.

Wagner, R.G., Mohammed, G.H., and Noland, T.L. 1999. Critical period of interspecific competition for northern conifers associated with herbaceous vegetation. Canadian Journal of Forest Research 29: 890-897.

Wagner, R.G., Newton, M., Cole, E.C., Miller, J.H., and Shiver, B.D. 2004. The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. Wildlife Society Bulletin 32(4): 1028-1041.

Forest Regeneration Trends: Dinosaurs, Political Correctness, and the Future

R.G. Wagner

University of Maine, 5755 Nutting Hall, Orono, Maine 04469-5755

Introduction

In 2004, Wangari Maathai won the Nobel Peace Prize for planting trees in Kenya. Her Green Belt Movement began in 1976 and developed into a broad-based, grassroots organization of women's groups dedicated to planting trees to conserve the environment and improve their quality of life. Over the next thirty years her efforts spread to neighboring African countries and mobilized millions of poor women to plant 30 million trees. Ms. Maathai recognized that regenerating forests was central to achieving sustainable development in Africa.

Since successful regeneration is vital to forest sustainability, how are we doing in North America? What are the trends and where are we going? It is actually very difficult to know how we are doing in successfully regenerating Canadian and US forests since national records of actual reforestation or afforestation success are not kept. Large private landowners and government organizations often collect such data on permanent forest inventory plots, but it is extremely difficult gather these data to identify national trends. It is much easier, however, to find numbers on the amount of regeneration activity (e.g., tree planting, direct seeding, site preparation, tending) that a country is engaged in over a period of time. Although regeneration activity is not a measure of regeneration success, it is an index of commitment to successful reforestation and afforestation.

Trends in US and Canadian Regeneration Activity

Some the longest and best records of forest regeneration activity can be found in records of tree planting. Data describing the area planted each year can be found back to the late 1920s in the US and the mid 1970s for Canada. Since the beginning of record keeping in both countries, there has been a steady increase in the area planted each year. Tree planting in the US increased 7-fold from 197,000 ha/yr in 1950 to 1.37 million ha/yr in 1988. From 1975 to 1990, tree planting in Canada increased almost 4-fold from 128,000 ha/yr to 476,000 ha/yr.

During the late 1980s and early 1990s, however, there was a significant shift in this trend. Tree planting declined in both countries for the first time during the 20th century. Canada also has records of the area of annual site preparation and tending, which are often vital for ensuring successful artificial and natural regeneration. Site preparation and tending trends follow similar patterns as tree planting. From the 1975 to about 1989, there was a steady increase in annual site preparation (from 162,662 ha to 487,140 ha) and tending (from 37,382 ha to 376,132 ha) activities. From 1990 to 2002, Canada shows a consistent decline in the area site prepared (only 292,497 ha in 2002). Tending continues to increase, but the rate of increase declines substantially after 1990.

To interpret whether these trends reflect a change in reforestation commitment, however, it is important to understand what was happening with harvest trends. Regeneration activity can simply increase or decrease with the area harvested. Changing methods of harvest also can influence regeneration activity. For example, even-aged systems (such as clearcutting) are often followed by tree planting or direct seeding to achieve successful regeneration. In contrast, many uneven-aged or partial cutting approaches rely solely on natural regeneration. The viability of even-aged and uneven-aged silvicultural systems varies among forest types and regions, so are not equally applicable everywhere.

Changes in harvest patterns

Canada's National Forestry Database Program provides harvest records by province from 1990 to present. Canadian harvesting increased slightly during the 1990s and dipped back down a bit after 1999, but has remained relatively stable at about 1 million ha per year. Of this harvest, the proportion of clearcutting has been relatively constant on about 85% of the area harvested. Other even-aged methods (shelterwood, seed tree, and commercial thinning) have had relatively minor use. Selection harvesting, an uneven-aged method, has been relatively stable during this period on only about 100,000 ha per year.

Records on forest harvesting in the U.S. are not nearly as complete as those for Canada. Available data from the U.S. Forest Inventory and Analysis Program indicate that harvesting during the 1980s and 1990s was dominated by unspecified partial cutting systems (62%) and by clearcutting (38%). Trends in total harvest area on all

U.S. public and private lands appear to not be available, but harvested wood volumes from the mid 1970s to 2002 indicate a relatively stable annual harvest of 14 to 16 million cubic feet.

Excellent harvest data are available for U.S. Forest Service lands, however. These data indicate a substantial shift in the type of forest harvesting in the late 1980s. After 1988, shelterwood cutting and clearcutting began a continuous decline as a proportion of total harvest area, while the proportion of intermediate cutting (thinning, improvement, sanitation) rose substantially. However, the proportional shift in harvesting method was less impressive than the total reduction in area harvested on U.S. Forest Service lands. From 1990 to 2003, there was 75% reduction in harvest area on U.S. Forest Service lands. The reduction in harvesting resulted from litigation by special-interest groups and a resulting major shift in U.S. federal policy about harvesting on National Forest lands. This event was significant for Canadian public lands because U.S. National Forest lands contain about 48% of the U.S. softwood supply. This shift in harvesting on U.S. federal lands coincides in 1990 with a significant increase in U.S. softwood imports from Canada. The U.S. public essentially transferred softwood demand from U.S. to Canadian public lands.

Based on the above harvest data, there appears to have been little change in the amount or method of harvesting in either the U.S. or Canada that might account for a shift in the amount of regeneration activity seen around 1990. The Canadian data clearly show no mass movement away from clearcutting or the total area harvested during the 1990s. Although the data are not as clear for U.S. private and public forests, there was no apparent large-scale shift in the amount or type of harvest activities from available data. Even though U.S. Forest Service lands make up about 25% of total U.S. forestland and harvesting started to decline dramatically around 1990, there is little evidence of a change in overall wood volume harvested on state and private forestlands, nor a shift in the type of harvesting that was being used.

Regeneration activity as a proportion of clearcut harvesting

One way to examine changes in regeneration activity and reduce uncertainty about the effect of changing harvest area or methods is to express regeneration activity as a proportion of clearcut harvest area in each country. Clearcutting in most North American forests requires some level of tree planting and tending to meet accepted regeneration standards in most jurisdictions.

Without good annual harvest data on U.S. forestlands, several assumptions are required, but it is possible to generate a tree planting area to clearcut area trend line for industry, non-industrial private and federal forestlands combined (Figure 1). From the mid 1970s until about 1988, there was a steady increase in this ratio from 0.49 to 0.91. From 1988 to 1996, however, the ratio declines 29% to 0.64. Using much more complete data from Canada, annual tree planting and seeding area to clearcut area ratios for all Canadian forestlands can be calculated for 1975 to 2002 (Figure 2). The resulting trend for Canada is strikingly similar to that of the U.S., but with a three-year lag in the peak ratio of 0.70 in 1991. From 1991 to 2002, Canadian tree planting and seeding (as a proportion of clearcut area) declined 19% to 0.54. The proportion of clearcut area where site preparation and tending treatments were applied (keys to successful artificial and natural regeneration) also steadily increased from 1975 to 1991 in Canadian forests (Figure 3). After 1991, when site preparation was being applied to 61% of clearcut lands, the ratio declined 42% to only 0.35 in 2002. The trend for tending also makes a substantial shift after 1990. After a steady increase from 0.06 in 1975 to 0.50 in 1990, the rate declines and then comes up again showing a nearly level trend from 1990 to 2002.

What caused the change in regeneration behavior?

It is clear when expressing tree planting, site preparation, and tending activities as a ratio of clearcut area that there was a dramatic shift in regeneration behavior in both Canada and the U.S. around 1990. Why would artificial regeneration and tending have fallen into less favor in Canada and the U.S.? It is difficult to know the exact reasons for such trends. It is likely that the causes vary from jurisdiction to jurisdiction, but it is noteworthy that such similar trends and timing can be seen at the national level for both North American countries. Something significant must have happened.

Potential factors that might drive such a significant trend reversal around 1990 include: 1) artificial regeneration before 1990 was discovered to be not as successful as was hoped, 2) natural regeneration was found to be adequate in many places and at far less cost, 3) changes in harvest area or method that reduced reliance on artificial regeneration, 4) reduced commitment by government and private landowners to pay for regeneration, and 5) reduced advocacy by forest managers for investments in artificial regeneration.

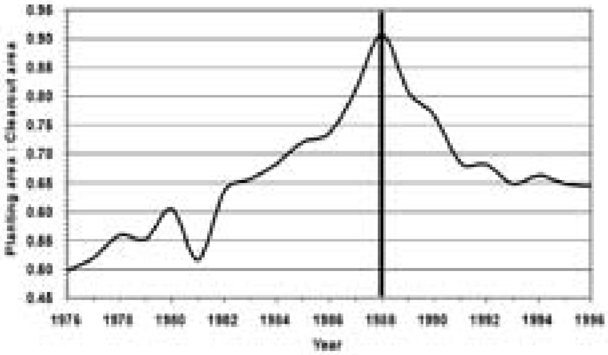

Figure 1. *Ratio of planted area to clearcut harvest area in the U.S. (1976-1996). Vertical line indicates year of a major shift in the trend. Source: Smith et al. 2003. Forest Resources of the United States, 2002. Gen. Tech. Rep. NC-241.; U.S. Forest Planting Report (USDA, FS, Washington, DC); and recent data in Tree Planters' Notes, Volume 49, No. 2. Assumes mean annual harvest area from 1980-92, annual harvest area over period was 9.8 million acres, and 38% of harvest area was by clearcutting.*

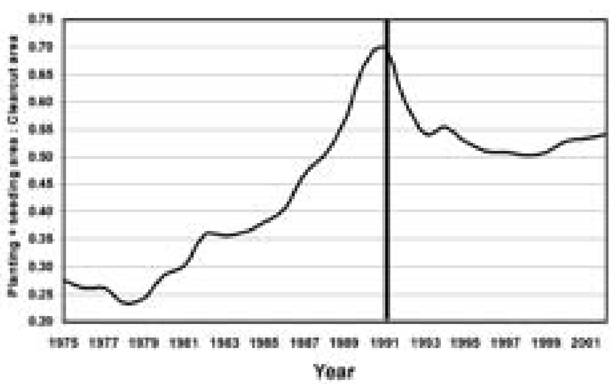

***Figure 2**. Ratio of planted and seeded area to clearcut harvest area in Canada (1975-2002). Vertical line indicates year of a major shift in the trend. Source: National Forestry Database Program, Canadian Council of Forest Ministers and Canadian Forest Service.*

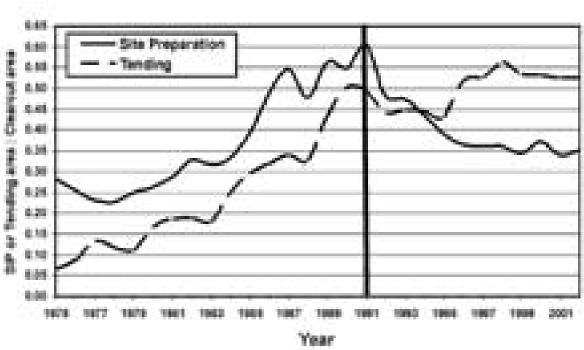

Figure 3. *Ratio of site prepared and tended area to clearcut harvest area in Canada (1975-2002). Source: National Forestry Database Program, Canadian Council of Forest Ministers and Canadian Forest Service.*

Let's evaluate each of these potential causes. I must reject the first potential cause since forestry research and operational experience across North America and the world have clearly demonstrated the value of artificial regeneration. The success and need for artificial regeneration is what prompted the rapid increase in tree planting during most of the 20th century. Natural regeneration certainly costs less, but I have yet to see data from studies in the 1980s demonstrating that natural regeneration was adequate to meet legislative, policy, or wood supply needs in most North American forest types. After all, it was the general inadequacy of natural regeneration across the U.S. and Canada that led to the rapid increase in tree planting during most of the 20th century. So, I must reject the second possible cause as well. As shown above, there were no significant changes in harvest area or method in Canada or the U.S., at least none sufficiently large enough or occurring at the same time to account for the patterns shown in Figures 1 to 3. So, I also must reject the third reason as a possible cause. This leads me to the final two possible causes – reduced commitment by landowners to pay and less advocacy by foresters for artificial regeneration (factors 4 and 5). For those of us whose forestry careers spanned the 1970s to present, however, it would not be surprising if these final two factors were indeed driving these national trends. Something significant clearly happened to forest management about 1990.

New forestry paradigm and stigmatized reforestation technology circa 1990

I can vividly recall this period. In fact, I had just moved from Oregon to Ontario and had a chance to witness what was happening nationally in U.S. and Canadian forestry. There was a "paradigm shift" in North American forestry about this time. Clearcutting was controversial throughout the 1980s. The spotted owl and old growth controversies were raging in the Pacific Northwest. "New forestry" and "ecosystem management" were new terms being introduced and debated. The 1987 Brundtland Report (*Our Common Future*) introduced the term "sustainable development," which struck a chord in Canadian forest policy. E.O. Wilson's 1988 *BioDiversity* book made the term popular with the environmental community and created a new pressure in forest management. Landscape ecology was a new concept in forest management, and we were beginning to discuss emulating natural disturbance through forest management.

Much of this debate suggested that what we had been doing previously in North American forestry was not "sustainable." Since forest research and management effort during the previous decades had focused on improving forest regeneration success (especially artificial forms), the debate seemed to cast doubt on the correctness of forest regeneration itself. Many of us in the forestry profession were afraid of being called "dinosaurs" if we failed to adopt the new paradigm. Doing so, however, meant challenging or deemphasizing that reforestation technology we were all taught and were able to make work so effectively. Many with forestry degrees from universities before 1990 can also probably recall a trend during the early 1990s when forestry faculties, departments, schools, and colleges began to change their names to include more ecological sounding terms.

The forestry paradigm was not all that had changed. During much of the 1980s, many of the technologies that had been developed to solve many reforestation problems during the previous decades became controversial. Pesticides (herbicides and insecticides) became viewed by much of the public as environmentally risky and a threat to public health. Heavy site-preparation and the use of fertilizers were being questioned. Tree improvement (and the dreaded genetic engineering) was being challenged. Forest plantations themselves were being debated as a potential threat to biodiversity. Despite strong scientific evidence to the contrary for many of these issues, it was too late. Much of the time-tested reforestation technologies of the previous decades had become stigmatized. Advocating such treatments was (and continues to be today) politically incorrect in many circles, and are thus to be avoided.

If I am correct with the above suppositions, it would be truly ironic if the 1990s movement to increase the "sustainability" of forests resulted in a reduced commitment to forest regeneration success among forestland owners (public and private) and forestry professionals. Prompt and successful regeneration following harvest is the first principle of forest sustainability. It was this very need that created the forestry profession following European timber famines in the first place.

Factors Likely to Influence Regeneration Trends in Coming Years

It is unclear where forest regeneration trends will go next. We can be confident, however, that we will not likely return to the pre-1990s era. The context and pressures for forest management have evolved in the U.S. and Canada. Just as emergent trends and needs forced forest managers to critically evaluate regeneration practices before and after 1990, the changing global context and complexity for forest management will drive where we go next.

As I look at these emergent trends, I suspect that several global pressures could become dominant forces pushing forest harvesting and regeneration practices in North American forests in particular directions. These emergent pressures include: (1) wood supply demands, (2) global markets, (3) the end of cheap oil, (4) invasive plants and climate change, and (5) high-yield conservation.

Wood supply demands

Human population growth and global wood demand have historically tracked very closely and will likely do so in the future. Based on current estimates, the global wood harvest is likely to increase about 35 million m^3 annually as the world population climbs to around 10 billion or so by 2050. Although the global forest has a tremendous capacity to produce wood, the amount of forestland available for wood production has been shrinking by about 0.22% per year (FAO 2001). The net loss of global forest area between 1990 and 2000 was 94 million ha – an area larger than Venezuela. Assuming that the annual per-capita global consumption of wood (0.6 m^3) remains relatively constant and the human population reaches 10 billion, Sutton (1999) projected an annual 2.2 billion m^3 deficit in the global wood supply by 2050. If the world's population reaches 10 billion by 2050, the 0.22% annual rate of forest area decline continues, and global per-capita consumption remains constant, per ha wood fiber productivity will need to need to increase by 87% (Wagner et al. 2004). If the global per-capita consumption rate for wood increases with living standards in countries such as China and India, or if forest production area declines accelerate above current levels, increases in forest productivity may need to double or more by 2050.

If this scenario comes to pass, the implications for regenerating North American forests (if they are still available and economical for wood production) are clear. Rapid and successful regeneration following harvest will be a requirement on all wood producing lands. Once regenerated, these stands will need to be intensively managed throughout their life to ensure the required forest-level wood flows. There is evidence that meeting increased global wood demands from intensive silviculture is already occurring (Sedjo 2001). Forest plantations currently produce more of the world's commercial timber (34%) than old-growth forests (30%), managed second-growth forests (22%), or minimally managed second-growth forests (14%) (Sedjo and Botkin 1997).

Global markets

There is much discussion today about the long-term influence of global markets on the North American wood products industry. I am not qualified to speculate much on directions here, but it is clear that whatever happens in this regard, the future of forest regeneration will be strongly affected. As described above, productivity of the global forest (at least where wood production is occurring) will likely need to increase. The only question is what regions of the North American forest (if any) will be fulfilling the global demand for wood.

We have all been reading about a mass shift of forestland ownership and wood producing facilities to tropical and sub-tropical regions of the world. In countries like Brazil, Chile, South Africa, and Indonesia, 50 to 70 m^3/ha/yr rates of stand productivity can be achieved, forest laborers will work for only a few dollars a day, and there is substantially less environmental regulation. Depending on the expert that one chooses to believe, it is easy to become either encouraged or discouraged about the future of the North American wood products industry, and thus the future of traditional forest management and regeneration.

Northern forests (North American and European) clearly have some distinct advantages regarding production of certain tree species and especially the close proximity to the largest wood consuming markets. How these advantages will balance favorably or unfavorably against higher operating costs, higher risk from environmental regulation, and lower rates of forest productivity is anyone's guess.

End of cheap oil?

The movement of cheaper wood to global markets will require oil. As the June 2004 issue of National Geographic was aptly titled, it is *The End of Cheap Oil*. I can recall during the last gasoline crisis of the early 1970s planting experiments of hybrid poplar to address the needs of the coming forest biomass markets. As we all know now, the forest biomass markets really never took hold as the price of oil declined over the next three decades. Here we are again. Many experts believe that this time it might actually be true.

There is clearly a renewed interest in the market opportunities for using forest biomass to compete with oil. Forest bioproducts research and business proposals are being discussed across Canada and the U.S. right now. Just as with predicting future directions of the global wood market, it is unclear how the forest bioproducts industry might develop. If it develops in certain regions of North America as some are now speculating, it could have substantial implications for forestry practice in those regions. There will probably be increased demand for large volumes of low quality and small dimension material that would place pressure on silviculture in ways that forest managers have not yet seen. With this new market would likely come an increase in ecological debates about the implications for biodiversity, and a new round of regulatory and policy conflicts for North American forestry.

Invasive plants and climate change

It is hard to find literature about environmental concerns these days where invasive species and climate change are not centerpieces of the discussion. Although it is difficult to predict how these issues will specifically impact forest management in North America during the coming decades, I am struck by how these issues have the potential to influence public perceptions about the reforestation technologies and silviculture in general. Over the past several years interest has been developing by many in the environmental community about regeneration silviculture.

As I have spent much of my career in forest vegetation management, I have been receiving regular inquiries about how to control invasive plants in ecological reserves. Environmental organizations (such as The Nature Conservancy) are now dealing with the practical problems of managing forestlands to achieve specific management objectives. Although the objectives are generally ecological in nature, these organizations are beginning to find valuable information in old reforestation research and operational experience that can help achieve goals of ecological restoration. For example, several invasive exotic shrubs are competitively excluding natural forest regeneration on conservation lands around the eastern U.S.. As the overstories of existing stands begin to decline, there is a high probability that formerly natural forests in some of these areas will be replaced by monocultures of invasive exotic plants. As a result, interest in how to use herbicides to promote successful forest regeneration is growing among some conservation groups.

Similarly, discussions about how to rapidly sequester carbon in forests are bringing greater attention to silvicultural methods and the role that they might play in meeting targets for balancing greenhouse gas emissions. If forests and forestry become increasingly perceived as part of the solution to global climate change by helping achieve targets associated with treaties (such as the Kyoto Protocol), government policies, or carbon credit investments in an emerging marketplace, then much of the research and experience associated with reforestation developed over the past decades may become viewed by the public as important for helping solve a perceived global environmental crisis.

High-yield conservation

Much of the new forestry paradigm and stigmatized reforestation technology that appeared to stimulate (or at least coincide with) the substantial changes in Canadian and U.S. reforestation behavior around 1990 were associated with the rejection of high-yield silvicultural objectives and practices, as much as it was an embrace of new ideas around preserving biodiversity and ecological sustainability. One only needs to read the literature of that time and look at the new standards for North American forestry established by organizations like the Forest Stewardship Council, to see that high-yield silvicultural practices have become viewed by many as inconsistent with the principles of sustainable forestry.

In recent years, however, there is evidence of a shift in thinking about the compatibility of high-yield agriculture and forestry with the conservation of nature. In 2002, a new high-yield conservation movement was initiated by a broad group of food, environmental, farming and forestry experts -- including two Nobel Peace Prize laureates. These experts, including Drs. Norman Borlaug (Nobel Peace Prize winner, Father of the Green Revolution, and forester), Oscar Arias (Nobel Peace Prize winner and Former President of Costa Rica), Patrick Moore (Co-founder of Greenpeace), James Lovelock (author of *The Gaia Hypothesis*), and several other notable leaders invited their colleagues worldwide to co-sign a declaration in favor of high-yield agriculture and forestry. The declaration states that *"…additional high-yield practices, based on advances in biology, ecology, chemistry, and technology, are critically needed in agriculture and forestry not only to achieve the goal of improving the human condition for all peoples but also the simultaneous preservation of the natural environment and its biodiversity through the conservation of wild areas and natural habitat."* Hundreds of supporters of this declaration have now signed up on their web page (http://www.highyieldconservation.org/).

The basic premise of the high-yield conservation movement is that substantial increases in per hectare agricultural yields have not only fed a growing human population, but have conserved millions of hectares of land for biodiversity that would otherwise have fallen to cultivation. As a measure of how much high-yield agriculture has contributed to land conservation, Borlaug (2000) estimated that if the per ha rate of global cereal yields in 1950 had been held constant through the end of the 20th century, three-fold more farmland would have been needed by 1999 (i.e., 1.8 billion ha instead of the 600 million ha that was actually cultivated worldwide). In this regard, the advent of high-yield agriculture over the last century has been by far the world's most successful biodiversity conservation program. Borlaug and his colleagues believe that high-yield forestry will be equally important to conserving forestland for purposes of biodiversity conservation.

If the high-yield conservation idea becomes a dominant natural resource management principle in the coming decades, then much of the work over the past half century by forest researchers and managers to find ways of improving wood fiber yields will be vital to helping conserve land and associated biodiversity.

Conclusion

In discussing the topic of this paper with several of my colleagues, I was impressed with how we can each recall the changes that occurred in forestry education, research, policy, and practice around 1990. The forestry profession in North America experienced a revolution of sorts, especially on public lands. If the trends in regeneration activity described above are accurate, it is clear that the paradigm shift substantially altered the approach and/or commitment to forest regeneration and early stand tending in Canada and the U.S.. While the new concepts introduced during that period (particularly biodiversity and landscape ecology) have contributed substantially to improving the management of North American forests, it would be ironic and disappointing if these ideas also forced forest managers to diminish their resolve in achieving successful regeneration. Prompt and successful regeneration following harvest is the first principle of sustainable forestry.

As the forestry profession moves into the future, it is vital that we examine and debate the trends, implications, and obligations of these reforestation trends. If the "revolution" of 1990 has indeed caused foresters and landowners (public and private) to become lax or lose sight of their obligation for regeneration success, then it is time for a professional "wake-up call". If several of the potential pressures facing forest management and regeneration outlined above are realized in the coming years, then the reforestation expertise and technologies developed over the past decades will be vital to serving human needs and protecting the natural environment. There may yet be a place in the future where politically-incorrect “dinosaurs” can help save the world.

References

Borlaug, N.E. 2000. The green revolution revisited and the road ahead. Special 30th Anniversary Lecture, The Norwegian Nobel Institute, Oslo, Norway. 8 September 2000. (http://www.nobel.se).

FAO (Food and Agriculture Organization of the United Nations). 2001. Global Forest Resources Assessment 2000: main report. FAO Forestry Paper No. 140. Rome, Italy. (http://www.fao.org/forestry/fo/fra/main/index.jsp).

Sedjo, R.A. 2001. The role of forest plantations in the world’s future timber supply. Forestry Chronicle 77:221–225.

Sedjo, R.A., and Botkin, D. 1997. Using forest plantations to spare natural forests. Environment 39:14–20, 30.

Sutton, W.R.J. 1999. Does the world need plantations? Paper presented at intersessional expert meeting on the role of planted forests, 6–9 April 1999, Santiago, Chile.

Wagner, R.G., Newton, M., Cole, E.C., Miller, J.H., and Shiver, B.D. 2004. The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. Wildlife Society Bulletin 32(4): 1028-1041.

Theme 1

Status of Reforestation and Afforestation Around the World

Assessing Plant Quality for Afforestation and Reforestation in Lombardy

E. Calvo[1], L. Ciccarese[2], P. Nastasio[1]

[1] Ente Regionale per i Servizi all'Agricoltura e alle Foreste (ERSAF) della Lombardia, via Ponchielli 38, 20125 Milano, Italy
[2] Agenzia per la protezione dell'ambiente e per i servizi tecnici, via V. Brancati 48, 00144 Roma, Italy

Over the latest decade, an average of 11,000 hectares of new stands, mostly broadleaves, have been established in Italy. In the near future a new momentum for forest tree stand establishment is expected. In fact, as attention on 'conventional' afforestation and reforestation programs is put in place by the regional Administration remains high, several thousand hectares of new plantations are expected to be established in the next decade, as compensation and mitigation means for the impacts of ongoing large strategic infrastructures in northern Italy (including Turin's 2006 Winter Olympics works, new fast trains, railways, and motorways).

In Italy, poor quality planting stock is recognized as one of the main reasons for failure of forest tree plantations intended for timber production, site reclamation and landscape enhancement.

The focus on plant quality assessment has become more intense after the disappointing performance of a significant part of the forest stands established within the European Commission 2080/92 Regulation, which introduced a grant scheme for farmers willing to change the use of their lands from agriculture to forestry.

The Council Directive (EEC) No 105/99, which entered into force in 2003 in all EU countries, lays down the conditions governing the marketing of forest reproductive materials in the Community. The Directive relates to the certification of genetic quality of reproductive material, as well as their physical features.

With the aim of improving planting stock quality of the tree nurseries run by the *Ente Regionale per i Servizi all'Agricoltura e alle Foreste* (ERSAF), an extension agency for Agriculture and Forestry of *Regione Lombardia*, a document containing procedures and standards for producing forest reproductive material was given out.

This document establishes the main methods and instruments for assessing plant quality through morphological and physiological performance tests. The document also provides protocols used by the tree nurseries run by ERSAF to produce planting stock, from seed procurement to handling and dispatching. An Appendix of the document contains the modus operandi for carrying out plant quality control and certification. It represents the first case in Italy of an operationally plant quality assessment program and, if successful, will most likely be extended to the whole tree nursery system in Italy.

Afforestation in the Central Hardwood Forest Region of the USA

A.S. Davis, D.F. Jacobs

[1]Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907, USA

Introduction

The Central Hardwood Forest Region (CHFR) of the USA is dominated by fine hardwood species such as black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), and northern red oak (*Quercus rubra* L.). Tree species in this region are highly valued for veneer and lumber and as sources of wildlife food and habitat. Despite the important economic and ecological contributions of forests to the region, there has historically been a strong focus on agricultural production which has resulted in an overall loss of forest cover. Recently, however, increasing numbers of private landowners are choosing to afforest marginal agricultural land throughout much of the Central Hardwood Forest Region (CHFR) of the USA. In seven Midwestern states there was a total increase in forestland of 5 million ha between 1980 and 2000 (Potts et al. 2004); however, despite this increase, many states are well below historical forest cover levels. Indiana, for example, was approximately 85% forested 200 years ago, but only about 8% at the beginning of the 20th century and is now approximately 21% (Tormoehlen et al. 2000).

Despite recent efforts to increase forest cover, the success of plantation establishment on private lands is variable and can be improved. In Indiana, approximately 65% of seedlings planted on non-industrial private forest (NIPF) lands survive at the end of five growing seasons (Jacobs et al. 2004). It would appear that most mortality occurs in the first growing season as there was little change in survival following the first year. Correspondingly, about 22% of seedlings had three or more leaders one and five years following outplanting, while over 32% of seedlings had 3 or more leaders three years after outplanting.

In the same study, the percentage of seedlings that were free-to-grow ranged from less than 3% in year one to almost 50% in year five. Further examination of the 6 most commonly-planted species at year 5 revealed that approximately 80% of black cherry, 70% of white ash (*Fraxinus americana* L.), 65% of yellow poplar (*Liriodendron tulipifera* L.), 50% of white oak (*Quercus alba* L.), 40% of black walnut, and 30% of northern red oak seedlings were free-to-grow. The relatively low percentage of black walnut seedlings that were free-to-grow at year 5 was attributed to a number of evident species-by-site mismatches.

Mortality and poor form of planted seedlings are often attributed to competing vegetation and damage due to animal browse. While specific silvicultural practices are able to mitigate these pressures, there has been little synthesis of the effects of silvicultural practices on plantation establishment success in this region. The plantation establishment figures presented by Jacobs et al. (2004) identify that the pressures placed within the first three years following outplanting are critical to avoid as a means of improving plantation establishment success.

The objective of this paper is to present a review of current, relevant research relating to hardwood seedling quality issues, some potential benefits associated with use of alternative seedling production methods, and the effects of various forms of early stand silviculture used in afforestation in the CHFR. Collation of this information should aid nursery managers and foresters in assuring the availability of high quality hardwood seedlings to enhance outplanting success.

Mitigating Outplanting Stresses Through Improved Seedling Quality

While hardwood seedling production in the USA is not well tracked, hardwood species represent only a fraction of the more than 1.6 billion seedlings produced annually in the USA (Moulton and Hernandez 1999, Jacobs and Davis 2005). Given the importance of successful plantation establishment, the seedlings used must be of high quality. However, the question of what constitutes a quality seedling is difficult to answer. Quality may be defined as “superiority in kind” (Merriam-Webster 2004), and therefore one may say that a quality seedling is one which meets its desired level of performance upon outplanting (Duryea 1985; Mattsson 1996). However, seedling quality must be defined within a myriad of parameters. These include the cost of the seedling, planting operation, and subsequent tending, the actual cost of establishment (i.e. at maturity, how much did it cost to plant that tree), site conditions, seedling availability, and growth rate to name but a few. As well, seedling quality is directly influenced by the genetic composition, size, vigor, environmental conditions, handling, planting, and storage practices.

Seed zones

Well-documented genotype × environment interactions in forest tree species illustrate the importance of tracking seed source. Use of seed geographically adapted to a specific region can increase resistance to pest and pathogen damage (Macdonald 1986) and yield higher seedling survival and better performance (Williams et al. 1974; Bresnan et al. 1994). As mentioned earlier, extensive guidelines for transfer of conifer seed and seedlings exist in the USA. The development of seed transfer zones for southern pine species [i.e., loblolly (*Pinus taeda* L.), slash, (*P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand (*P. clausa* (Chapm. ex Engelm))] was based on yearly average minimum temperatures (Schmidtling 2001). In Washington, USA seed zones have been developed based on genetic information in addition to climatic, vegetative, and topographic data (Randall and Berrang 2002).

The importance of provenance tracking extends to hardwood species as well. In British Columbia, transfer of red alder (*Alnus rubra* Bong.) beyond 100 km towards or from the coast led to a decrease in survival and height growth (Hamann et al. 2000). In the case of fine hardwoods, provenance testing resulted in the recommendation that black walnut may be moved northward as much as 322 km without risk of cold damage (Bey 1980; Bresnan et al. 1994). The findings of Bey (1980) were extrapolated by Deneke et al. (1980) to develop “Preliminary seed collection zones for black walnut.” The recommendations yielded 22 seed collection and planting zones; however, these recommendations are not enforced and generally not followed.

Despite research identifying the importance of seed origin to hardwood seedling performance (Williams et al. 1974; Rink 1984; Rink and Van Sambeek 1985; Williams et al. 1985), there are few examples of seed source regulation with regards to hardwood species in the eastern USA beyond the aforementioned recommendations for black walnut. While many factors (e.g., animal browse, competing vegetation, and weather) determine the success of plantations, it is possible that the use of seed of unknown origin accounts for some of this mortality. Failed efforts to establish plantations of hardwood seedlings in Tennessee, USA have been partially attributed to a lack of seed zones, prompting the development of seed zones based on ecoregions, elevation, and weather data (Post et al. 2003). Combining spatially explicit seed transfer zones with provenance testing could help to improve plantation establishment success.

In a survey of hardwood nurseries in the eastern USA (A.S. Davis, unpublished data), approximately 71% of respondents stated that they identify seed zones for hardwood seedling production. However, those zones range quite liberally in definition, some being as vague as ‘within a couple of states’ to others which are as clearly defined as a specific county. Of those nurseries that identify seed zones, 30% do not attempt to ensure that the zone of seed collection corresponds to the intended outplanting zone. Approximately 75% of nurseries that responded stated that they thought seed zones were beneficial to forestry in their region, indicating that perhaps greater development of and adherence to seed zones will occur in the future.

Genetic improvement

In the eastern USA, approximately 6.8% of hardwood seedlings produced are of genetically superior origin, compared to 36% of conifers produced in the same region (Jacobs and Davis 2005). According to that same survey, most respondents (64%) indicated that they intend to increase their use of genetically improved material in the next 10 years. With improved micro-propagation techniques developing for many hardwood species (Navarette et al. 1989), one would expect to see an increase in improved material in the future.

Seedling quality

Recent investigation of the relative contribution of above and below-ground morphological parameters to prediction of outplanting success will enable nursery managers to better quantify hardwood seedling quality. Jacobs et al. (in press a) found that for predicting first-year height and diameter growth of three hardwood species, initial root-collar diameter, height, and root volume were the most important morphological characteristics. Further identification of how seedling morphological and physiological characteristics can be applied to predict field performance is necessary to improve seedling quality.

Similarly, research examining the relationship between seedling size and drought stress will enable foresters to target for stock with a greater likelihood to thrive under specific environmental conditions. For example, a greenhouse experiment conducted to investigate the recovery of bareroot northern red oak seedling after simulated drought stress found that seedlings with larger root volumes were less able to mitigate drought stress than those with smaller root volumes (Jacobs et al. in press b).

Alternatives to Bareroot Seedlings

The majority of seedlings planted in the CHFR are bareroot nursery stock. Given limited plantation establishment success using bareroot seedlings, other stocktypes, such as container seedlings, may be more effective at establishing forest cover on harsher sites characteristic of the region (e.g., former surface coal mines or floodplains). Reclamation of surface coal mines can demand large portions of nursery stock (approximately 20% of seedlings grown at Indiana Department of Natural Resources Division of Forestry nurseries are purchased for mine reclamation).

Container-grown seedlings

Presently, containers used for operational hardwood seedling production in the CHFR are large (> 4 L) and costly. However, use of this stock has been shown to help promote free-to-grow status at time of outplanting (Jacobs et al. in press), an important consideration in the effort to mitigate heavy animal browse pressures on seedling growth and survival.

Loss of roots during lifting is a major cause of transplant shock (Struve and Joly 1992). Given that containerized seedlings maintain their entire root system when transplanted, transplant shock can be considerably reduced through use of containerized seedlings (Miller 1999; BCMOF 2001). Container seedlings also maintain higher water potential during the first year following out-planting compared to bareroot seedlings (Dixon et al. 1983; Crunkilton et al. 1992; Davis 2003), which can further reduce shock to the seedling caused by site acclimatization. Reduction of transplant shock can lead to increased survival and growth rate, as Vyse (1981) estimated that transplant shock could equate to the loss of 1 or 2 years of growth. Container seedlings often yield more uniform growth than do bareroot seedlings upon out-planting (van Eerden 1999; Wilson and Vitols 1999), along with a more fibrous root system (WRP 1993). Given the multitude of container shapes and sizes available, it is possible to produce a specific size and shape of seedling roots for a specific purpose such as mined land reclamation (e.g., shallow containers for shallow soils) (Bainbridge 1994).

New methods for production of broadleaf container forest tree seedlings are in need of development, as present methods are in many cases poorly refined and unable to provide optimal growing conditions. Application of horticultural methods to forest tree seedling production will likely accelerate this process. For example, overhead irrigation, which is typically used in hardwood seedling container production, results in salt buildup on foliage and low irrigation uniformity. Irrigating from below using flood irrigation may provide a viable alternative and ameliorate this problem.

Direct seeding

Direct seeding is an option that, while currently not extensively practiced, has potential. Direct seeding as a means of plantation establishment could reduce stresses related to outplanting. In addition to potential benefits realized in seedling establishment, the cost of transporting seed is lower than that of seedlings (Van Sambeek 2004). Bullard et al. (1992) found that on old-field sites in the southern United States the cost of direct-seeding oak was approximately 1/3 of those of planting seedlings and that given proper stand management there would be no benefit of planting seedlings over direct seeding.

Direct-seeding operations typically involve broadcasting large volumes of seed across the area designated for reforestation (Johnson 1981, 1983). Disadvantages associated with the direct seeding of black walnut include unpredictable germination and seed predation (Van Sambeek 2004). Germination of seed prior to sowing resulted in successful plantation establishment with uniform spacing and survival rates > 90% (Jacobs and Severeid 2004). Further, Mullins et al. (1998) found no significant difference in height or diameter of bareroot, containerized or direct-seeded cherrybark oak (*Quercus falcata* Michx. var. *falcata*) seedlings five years after planting. However, not all attempts have been successful, with mixed results reported for direct-sown black walnut having somewhat poorer performance, which has been attributed to poor germination and growing conditions in the field (Robison et al. 1997).

Early Stand Silviculture

Plantation establishment

Typically, plantations in the CHFR are established late-winter through early spring (Selig et al. in review). The majority of seedlings are planted using a tractor-hauled coulter with trencher and packing wheels (Figure 1). This method is well suited to seedlings with large root systems and relatively uniform and pliable soil and site conditions. Faster planting rates, in some cases in excess of 1,000 trees per hour, have been reported for mechanical-planting (Thompson 1984; Wray 1997; Slusher 1999), compared to up to 500 trees per day for hand-planted sites (Wray 1997). Mechanical planting of this nature resulted in significantly higher survival and higher percentage of seedlings being free-to-grow than hand-planting in Indiana (Jacobs et al. 2004). This may have occurred due to less J-rooting and less exposure to drying conditions for mechanically planted seedlings.

Incorporating relatively new concepts, such as use of controlled release fertilizer at time of outplanting, into silvicultural operations may also help to improve plantation establishment success. In a study of three hardwood species, Jacobs et al. (2005) found that first-year height growth could be increased by as much as 52% with use of CRF.

Control of competing vegetation

Although commonly employed, mowing has not been identified as a substitute for subsequent chemical weed control of hardwood plantations (von Althen 1984). Herbicide application represents the most effective form of control of competing vegetation. In a study of 16 herbicide treatments on 9 commonly planted hardwood species, Seifert and Woeste (2002) found that there was a notable herbicide treatment × species interaction, but that in general herbicide application benefited seedling growth.

Figure 1. *Tractor-hauled coulter with trencher and packing wheels, also equipped for herbicide application.*

In an assessment of initial control of competing vegetation on abandoned agricultural fields in hardwood bottomlands Groninger et al. (2004) found that herbicide treatment benefited green ash (*Fraxinus pennsylvanica* Marsh.). However, soil tillage without herbicide application did not benefit seedling establishment. Correspondingly, Jacobs et al. (2004) found that herbaceous vegetation was taller and had greater percent cover when mechanical site preparation was practiced without a corresponding herbicide application. As well, Jobidon (1990) found that mechanical site preparation increased the diversity of herbaceous vegetation that subsequently re-colonized. Given the contribution of buried seed-banks to stand development, incorporation of old-field succession patterns into management planning may be beneficial (Groninger et al. 2004).

A minimum of a single application of herbicide during plantation establishment can vastly improve the likelihood of seedling survival (Baer and Groninger 2004). However, in many cases, such as for *Quercus* spp., it is important that minimum stocking levels are reached as a means of promoting seedling growth (Kruse and Groninger 2004). In some situations, this may involve allowing for volunteer tree species to contribute to stocking levels, and thus herbicide application may need to be altered accordingly.

Conclusions and Future Directions

There is a multitude of uses, in addition to timber production, for which landowners manage non-industrial private forest plantations in the Central Hardwood Forest region of the USA (Ross-Davis et al. in press). Developing quality seedlings and appropriate silvicultural treatments will help present landowners with effective management options for their land. As many plantations are established for wildlife or aesthetic purposes, it is important that foresters use all the tools available to maximize plantation establishment success and help meet landowner objectives.

Further research is needed to identify those site conditions and tending requirements that will ensure successful establishment, as well as determining the economic and ecological costs and benefits of this method for reforestation and afforestation. Tracking the long-term contribution of silvicultural treatments to plantation development will help to develop standards for future planting operations. Additionally, research into herbicides that are suitable for use with direct seeding (Willoughby et al. 2003) will lead to improved flexibility in field experimentation and ultimately in actual operational practice.

Improved seedling quality through more accurate grading standards, better understanding of the stresses associated with plantation establishment, and effective implementation of silvicultural treatments will improve plantation establishment success. Development of new technologies to produce higher quality seedlings and exploitation of genetically superior material will also benefit forestry in the region. Afforestation is an important component of forestry in the CHFR and must continue to help increase forest cover.

References

Baer, S.G., and Groninger, J.W. 2004. Herbicide and tillage effects on volunteer vegetation composition and diversity during reforestation. Rest. Ecol. 12: 258-267.

Bainbridge, D.A. 1994. Container optimization – field data supports container innovation. In Landis, T.D.; Dumrose, R.K., tech. coord. Proceedings, Forest and Conservation Nursery Associations, 1994, July 11-14; Williamsburg, VA. USDA For. Serv. Rocky Mtn. Res. Stn. Gen. Tech. Rep. RM-GTR-257.

BCMOF. 2001. Effects of stock type on seedling performance in the northern interior of British Columbia: Twenty year results. Silviculture Note 29. British Columbia Ministry of Forests.

Bey, C.F. 1980 Growth gains from moving black walnut provenances northward. J. For. 78, 640-645.

Bresnan, D.F., Rink, G., Diebel, K.E., and Geyer, W.A. 1994. Black walnut provenance performance in seven 22-year-old plantations. Silvae Genet. 43, 246-252.

Bullard, S., Hodges, J.D., Johnson, R.L., Straka, T.J. 1992. Economics of direct seeding and planting for establishing oak stands on old-fields in the south. South. J. App. For. 16: 34-40.

Crunkilton, D.D., S.G. Pallardy, and Garrett, H.E. 1992. Water relations and gas exchange of northern red oak seedlings planted in a central Missouri clearcut and shelterwood. For. Ecol. Manage. 53: 117-129.

Davis A.S. 2003. Performance of northern red oak under adverse conditions. MS Thesis. Purdue University. 111 pp.

Dixon, R.K., S.G. Pallardy, H.E. Garrett, and Cox, G.S. 1983. Comparative water relations of container-grown and bareroot ectomycorrhizal and nonmycorrhizal *Quercus velutina* seedlings. Can. J. Bot. 61: 1559-1565.

Deneke, F.J., Funk, D.T., and Bey, C. 1980 Preliminary seed collection zones for black walnut. US Department of Agriculture Forest Service, NA-FB/M-4. 5 p.

Duryea, M.L. 1985. Evaluating seedling quality: importance to reforestation, pp.1-6. In Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. Edited by M.L. Duryea. Forest Research Laboratory, Oregon State University, Corvallis, OR.

Hamann, A., Koshy, M.P., Namkoong, G., and Ying, C.C. 2000. Genotype × environment interactions in *Alnus rubra*: developing seed zones and seed-transfer guidelines with spatial statistics and GIS. For. Ecol. Manage. 136: 107-119.

Groninger, J.W., Baer, S.G., Babassana, D.-A., and Allen, D.H. 2004. Planted green ash (Fraxinus pennsylvanica Marsh.) and herbaceous vegetation response to initial competition control during the first 3 years of afforestation. For. Ecol. Manage. 189: 161-170.

Jacobs D.F., Salifu K.F. and Seifert J.R. In press a. Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. New For.

Jacobs D.F., Salifu K.F. and Davis A.S. In press b. Drought susceptibility and recovery of transplanted *Quercus rubra* seedlings in relation to root system morphology. In Weigel, Dale R., Van Sambeek, Jerry W., Michler, Charles H., editors. 9th workshop on seedling physiology and growth problems in oak plantings (abstracts); 18-20 October 2004; West Lafayette, IN. USDA For. Ser. North Cent. Res. Stn. Gen. Tech. Rep. NC-.

Jacobs, D.F. and Davis, A.S. 2005. Genetic considerations in the operational production of hardwood nursery stock in the eastern United States. Native Plants. 6: 4-13.

Jacobs, D.F. and Severeid, L.R. 2004. Relative competitiveness of interplanted American chestnut [*Castanea dentata* (Marsh.) Borkh.]. For. Ecol. Manage. 191: 111-120.

Jacobs, D.F., Salifu, K.F., and Seifert, J.R. 2005. Growth and nutritional response of hardwood seedlings to controlled-release fertilization at outplanting. For. Ecol. Manage. 214: 28-39.

Jacobs, D.F., Ross-Davis, A.L., and Davis, A.S. 2004. Establishment success of conservation tree plantations in relation to silvicultural practices in Indiana, USA. New For. 28: 23-36.

Jobidon, R. 1990. Short-term effect of three mechanical site preparation methods on species diversity. Tree Plant. Note. 41: 39-42.

Johnson, R.L. 1981. Oak seeding - it can work. South. J. Appl. For. 5: 28-33.

Johnson, R.L. 1983. Nuttall oak direct seedings still successful after 11 years. USDA Forest Service Southern Forest Experiment Station. Research Note No. SO-301. 3 p.

Kruse, B.S. and Groninger, J.W. 2003. Vegetative characteristics of recently reforested bottomlands in the Lower Cache River Watershed, Illinois, U.S.A. Rest. Ecol. 11: 273-280.

Macdonald, B. 1986 Practical woody plant propagation for nursery growers. Timber Press, Portland, OR. 669 p.

Mattsson, A. 1996. Predicting field performance using seedling quality assessment. New For.13:227-252.

Merriam-Webster. 2004. Merriam-Webster online dictionary. Available online at: http:/www.m-w.com

Miller, S. 1999. Successful tree planting techniques for drastically disturbed lands: a case study of the propagation and planting of container-grown oak and nut trees in Missouri. In Vories, K.C. and D. Throgmorton (eds.). Proceedings of Enhancement of Reforestation at Surface Coal Mines: Tech. Inter. For. Pp. 57-172.

Moulton, R.J. and Hernandez, G. 1999. Tree planting in the United States - 1998. Tree Plant. Note. 49, 23-36.

Mullins, J.A., Buckner, E.R., Hopper, G., and Percell, G.G. 1998. Early growth of sheltered and unsheltered cherrybark oak established by planting 1-0 bareroot and 1-0 containerized seedlings and by direct-seeding. In: Waldrop, T.A. (Ed.) proceedings of the 9th biennial southern silvicultural research conference; 25-27 February 1997. USDA For. Ser. South. Res. Stn. Gen. Tech. Rep. SRS-20. Pp 234-237.

Navarrete, N.E., Van Sambeek, J.W., Preece, J.E., and Gaffney, G.R. 1989. Improved micropropagation of white ash (*Fraxinus americana* L.). In Proceedings of the 7th Central Hardwood Forest Conference 5-8 March 1989. G. Rink and C.A. Budelsky (eds.). USDA For. Ser. North Cent. For. Exp. Stn. Gen. Tech. Rep. NC-132. Pp. 146-149.

Post, L.S., Schlarbaum, S.E., van Manen, F., Cecich, R.A., Saxton, A.M., and Schneider, J.F. 2003 Development of hardwood seed zones for Tennessee using a geographic information system. South. J. Appl. For. 27, 172-175.

Potts, R., Gustafson, E., Stewart, S.I., Thompson, F.R., Bergen, K., Brown, D.G., Hammer, R., Radeloff, V., Bengston, D., Sauer, J., and Sturtevant, B. 2004. The Changing Midwest Assessment: land cover, natural resources, and people. USDA For. Ser. North Cent. Res. Stn. Gen. Tech. Rep. NC-250. 87 p.

Randall, W.K., and Berrang, P. 2002 Washington tree seed transfer zones. Washington State Department of Natural Resources. 63 p.

Rink, G. 1984 Trends in genetic control of juvenile black walnut height growth. For. Sci. 30, 821-827.

Rink, G., and Van Sambeek, J.W. 1985 Variation among black walnut seedling families in resistance to competition and allelopathy. Plant Soil. 88: 3-10.

Robison, T.L., Yoder, W.G., and Hoss, G. 1997. Direct seeding and seedling production in nursery beds. In: Proceedings of the 5th black walnut symposium, Van Sambeek, J.W. (ed.) 28-31 July 1996. USDA For. Ser. North Cent. For. Exp. Stn. Gen. Tech. Rep. No. NC 191. Pp 96-103.

Ross-Davis, A.L., Broussard, S.R., Jacobs, D.F., and Davis, A.S. In press. Afforestation behavior of private landowners: an examination of hardwood tree plantings in Indiana. North. J. Appl. For.

Schmidtling, R.C. 2001. Southern Pine Seed Sources. USDA For. Ser. Gen. Tech. Rep. SRS-44. 25 p.

Seifert, J.R., and Woeste, K. 2002. Evaluation of four herbicides and tillage for weed control on 1-0 planted tree seedlings. North. J. Appl. For. 19: 101-105.

Selig, M.F., Seifert, J.R., and Jacobs, D.F. In review. Influence of annual variation in time of planting on afforestation field performance of six temperate deciduous forest tree species. New For.

Slusher, J.P. 1999. Mechanical tree planters. Co-operative Extension, University of Missouri-Columbia, Agricultural Publication G-05009.

Struve, D.K., and Joly, R.J.. 1992. Transplanted red oak seedlings mediate transplant shock by reducing leaf area and altering carbon allocation. Can. J. For. Res. 22: 1441-1448.

Thompson, M.A. 1984. Evaluation of a mechanized tree-planting operation. USDA For. Ser., North Cent. Res. Stn., Res. Pap. NC-258.

Tormoehlen, B., J. Gallion, and T.L. Schmidt. 2000. Forests of Indiana: A 1998 Overview. USDA For. Serv. NA-TP-03-00. 18p.

van Eerden, E. 2001. The history and a glance into the future of forest seedling production in British Columbia. Presented at NSC/NIVMA 2001 winter workshop. Available from www.prtgroup.com (Cited 20 June 2005).

Van Sambeek, J.W. 2004. Direct seeding. Walnut notes. (online). Available from http://www.ncrs.fs.fed.us/pubs/wn/walnutnotestoc.html. (Cited 20 June 2005).

von Althen FW. 1984. Mowing versus mechanical or chemical weed control in sugar maple afforestation. Tree Plant. Note. 35: 28-31.

Vyse, A. 1981. Growth of young spruce plantations in interior British Columbia. For. Chron. 57: 174-180.

Williams, R.D., Funk, D.T., Phares, R.E., Lemmien, W., and Russell, T.E. 1974 Apparent freeze damage to black walnut seedlings related to seed source and fertilizer treatment. Tree Plant. Note. 24, 6-8.

Williams R.D., Rink, G., and Funk, D.T. 1985 Planting site and genotype affect black walnut seedling development more than nursery environment. Can. J. For. Res. 15, 14-17.

Willoughby, I., Clay, D., Dixon, F. 2003. The effect of pre-emergent herbicides on germination and early growth of broadleaved species used for direct seeding. Forestry. 76: 83-94.

Wilson, E.R., and Vitols, K.C. 1999. Growth potential and field performance of fall-planted container and bareroot seedlings of red oak (*Quercus rubra* L.). Research Project for Nipissing Forest Resource Management, Inc. Silviculture Research international (SRi).

Wray, P.H. 1997. Tree planting: Establishment and care. Iowa State University Extension, PM–1677.

WRP. 1993. Container oak seedlings for bottomland hardwood (BLH) restoration. WRP Tech. Note VN-EM-1.1.

Intensive Management of Stump-Sprout Reproduction In Coppice-Regenerated Coast Redwoods

C.R. Keyes, P.J. Matzka

Department of Forestry and Watershed Management, Humboldt State University
Arcata, California 95521, USA

Introduction

The habit of coast redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.) to regenerate naturally from epicormic basal sprouts (stump sprouts) after severe damage or removal of the main stem has contributed greatly to the species' renewal and has been responsible for the regeneration of many of the region's second-growth redwood stands. However, unmanaged stump sprouts generated by the harvest of second-growth redwood stands contribute to an aggregated, patchy spatial distribution of tree stems within regenerating third-growth stands. This concentration was not problematic with sprouts from old-growth stumps due to large size of the stumps and the resulting distance between sprouts, but it will be increasingly problematic for sprouts from the smaller second-growth stumps that are much closer in proximity. This concentrated, unmanaged condition might be most effectively and efficiently ameliorated by the control of stump sprout densities at an earlier age than has previously been considered. A reconsideration of traditional concepts of stand thinning and a new consideration of the intensive silvicultural control of redwood sprout reproduction is warranted. With this paper we present an argument for an innovative silvicultural approach to the management of third-growth redwood coppice-generated forests.

Redwood Renewal in Context

Redwoods occur in a limited range defined as a very narrow Pacific coastal strip that is 450 miles long and 5-35 miles wide (Roy 1966). Despite the small range, the species constitutes a vital share of the California timber economy. The redwood region's fertile soils, combined with a moderate climate of plentiful precipitation, results in forests of high productivity and tremendous growth rates. For example, one celebrated plot in a second-growth stand first measured in 1923 achieved a periodic annual increment of 5,000 bf/acre, and had by 1995 (age 137) accrued a basal area of 935 ft^2/acre and a volume of 343,000 bf/acre (Fritz 1945, Allen 1996). Moreover, redwood's natural decay resistance makes the species desirable for wet and outdoor environments and returns high per-volume prices (Wilcox 1996). With sawlog prices commonly approaching or exceeding $1,000/mbf (nearly double the value of Douglas-fir), the species is favored by foresters far above its associates. And unlike Douglas-fir, there is nearly no market competition from other states and countries in North America.

On most commercial redwood timberlands, the main regeneration method for redwood is by clearcutting in blocks that are constrained in size by the California Forest Practices Act to 20 acres (ground-skidded) or 40 acres (cable-yarded) (California Department of Forestry and Fire Protection 2002). Logging of virgin redwood forests on a grand scale began with the 1849 California gold rush and rapidly became one of coastal California's main industries. Selective logging of old-growth redwood forests was predominant by the 1940s, and reached its peak in the 1950s-1960s (O'Dell 1996). Yet an economy based on the utilization of smaller, primarily even-aged second-growth forests emerged and grew as the region's old-growth forests declined. By 1986, approximately 63 percent of the original redwood range was in second-growth status (Fox 1996). As these second-growth forests have reached maturity in recent decades, an increasing proportion of the redwoods are now in third-growth status.

Natural regeneration of redwood from seedfall has always been of concern to the region's foresters due to low seed viability rates. Seed crop years are not infrequent (Boe 1968), but even during those years of high seed production years, seed crops are up to 85 percent infertile (Olson et al. 1990); the germination rate of sound seed is high (Boe 1961), but the occurrence of defective seeds is very high. Concern over redwood's regeneration potential, together with a concern over the size and quality of second-growth logs, resulted in dim expectations for the redwood timber economy following logging of virgin forests. Reflecting upon the state of redwood regeneration at the end of the 19th century in *National Geographic Magazine*, one observer lamented,

When the timber has been cut there is no sign of reproduction from seed. In many localities sprouts are growing from stumps in the cut areas, but even this form of reproduction is limited. Indeed everything appears to indicate that for some reason…with the clearing away of the present forests the end of the species as a source of lumber will be at hand (Gannett 1899).

In the same issue, a second author fatalistically reported,

The reproduction of the species is said to be very low. Cut-over areas show no evidence of reforestation with the same species. Thus hemmed in by inimical climatic conditions and unable to maintain its stand, its extinction seems assured at no very remote period (Leiberg 1899).

But those fears were never realized. Stands of redwood developed from the brushy thickets of sprouts emerging from virgin stumps, mills retooled to accommodate smaller log sizes, and fears about the quality of second-growth redwood sawnwood were allayed. Still, as a hedge against risks, cutover redwood forests even as late as the 1950s-1960s were aerially seeded with mixtures that included alternate species such as Douglas-fir and Sitka spruce. Today, however, redwood is the unambiguous reforestation species of preference wherever site quality is permitting, and commercial nurseries are developing redwood seedlings of greater drought tolerance that, it is hoped, will expand redwood plantings beyond the species' current geographic range.

Due partly to redwood's limited potential for natural regeneration from seedfall, and largely to California's stringent reforestation requirement of full restocking within two years following harvest, most redwood forest managers today rely on artificial regeneration with nursery seedlings to ensure successful reforestation. However, stump sprouts are also heavily depended upon to contribute substantially to full stocking. One survey revealed that stump sprouts comprised the majority of stems in fully-stocked stands following harvest and reforestation (Lindquist and Palley 1967). When they are grown together, sprouts outpace planted seedlings, so planted seedlings are generally used to interplant between distant stumps.

Coppice-Regenerated Redwood Forests

Redwood is the only North American conifer species of any commercial value that is regenerated largely under variations of the traditional coppice system. Redwood sprouting occurs rapidly and prolifically following burning or cutting of the main stem. Regardless of season, sprouts commonly materialize 2-3 weeks after stem removal from stumps and root crowns, often exceeding 100 per stump (Olson et al. 1990). So persistent was the sprouting by old-growth stumps that many prospective ranching attempts in the redwood empire during the 19th century were abandoned. Sprouts outgrow planted seedlings during the initial years, reaching heights of 2-6 feet within a year of emergence.

Second-growth forests that emerged from the sprouts of virgin stumps yielded useful log sizes because they were distantly spaced; the sprouts were distantly spaced because the stumps were very large, and because the stumps themselves were distantly spaced. Structures of virgin redwood forests varied, but overstory densities were often less than 100 stems per acre (Fujimori 1977, Sugihara 1992, Van Pelt and Franklin 2000). Sprouts in many cases therefore had sufficient space on at least two sides to reduce intra-stump sprout competition, to enable expressions of dominance among them, and to facilitate their differentiation into crown classes.

In contrast, stumps of the second-growth redwood forest are located with many nearby neighbors, especially where they were successfully interplanted with redwood seedlings. At diameters that are typically 24 inches or less, second-growth stumps are also substantially smaller and younger than were the virgin redwood stumps. Sprouting frequency has been shown to be greater among smaller stumps than larger stumps (Neal 1967). Moreover, among those stumps that do sprout, sprout density (sprouts per area of stump circumference) is greater for stumps of younger, smaller trees rather than older, larger trees (Powers and Wiant 1970).

Taken together, these factors are resulting in the following condition: the third-growth coppice-generated redwood forest is initiating in aggregated conditions at spacings that are substantially lower than was previously common. It is therefore not realistic to assume that unmanaged third-growth sprouts will develop in the same way and produce products of comparable size and quality as the previous generation of redwood forests. It is more reasonable to expect that some form of density management will be necessary to remediate the high initiating densities of third-growth coppice-regenerated redwood forests.

Complications of Dense Redwood Stands

The dense concentration of third-growth stems in an aggregated spatial pattern potentially diminishes wood qualities, log sizes, and stand yields. Crowded stems grow together as single logs, embedding bark, branches, and other debris within the wood of the butt-log. The close proximity of redwood stump sprouts establishes a need for thinning at an early age to promote growth and minimize losses to mortality; such thinnings rarely yield logs of value and are conducted as pre-commercial thinnings. If thinning is delayed until stems reach a merchantable dimension, growth and yields suffer.

The primary issue of concern, however, is in the area of forest protection. Coppice-regenerated stems growing in dense conditions fail to develop the stem and root capacity necessary to weather the strong seasonal winds that frequent the redwood range; furthermore, the stems develop asymmetrical crowns that exacerbate this instability. As such stands develop, they become increasingly unstable with height:density ratios that increase their susceptibility. Foresters have also noted that commercial thinning sprout clumps often results in wind damage to residuals on the leeward side of stumps when windward-side stems are removed. This threat of blowdown is greatest for those sprouts emerging from the tops and sides of stumps (rather than from the root crown). Fundamentally, such sprouts are mechanically weak and susceptible to wind. Even in the absence of strong winds, it is not uncommon for mature sprouts located high upon the stump to simply peel off eventually under their own weight.

Pre-commercial thinning that retains windward stems and stems emerging from the root collar can ameliorate this condition. However, pre-commercial thinning appears to attract cambium-feeding black bears, whose effects have been increasingly observed with dismay within the past decade. Black bears tear long vertical strips of the fibrous redwood bark to consume the cambium beneath, most often from the bases of young trees (10-30 years; 6-10 inches dbh)(Olson et al. 1990). In mixed stands, redwood is preferentially targeted over other species, including Douglas-fir (Glover 1955, Russell et al. 2001). Cambium-feeding bears typically target the largest trees in a stand, may girdle trees completely, and often return to the same stand repeatedly. A recent study of the activity revealed positive associations of bear damage with recently harvested stands and with stands of pole-sized trees (Russell et al. 2001). This is a relationship that managers corroborate; bears appear to be drawn to young redwood stands immediately following pre-commercial thinning.

Bear damage has been recognized since the 1950s (Glover 1955), but has increased in either intensity or observation in recent years, and has become a management priority for some ownerships. Their devastating effects led industrial forest ownerships to rate bears and other mammals as the forest health concern of primary importance in the redwood region, above fire, insects, diseases, and alien plants (Stuart 1996). However, options for addressing bear damage that are both effective and socially acceptable are scarce. Direct control of bear populations in the form of animal disposal is a highly restricted activity, and in California is highly controversial. Therefore, silvicultural approaches that minimize the susceptibility of stands to bear utilization may hold the greatest potential for reducing the scale of bear damage

New Silvicultural Treatments for Coppice-Regenerated Redwoods

Taken together, these concerns suggest the high potential value of stand density management at a very early age. Sprout thinning enables coppice-regenerated stands to be shaped to desired spacings and in a manner that favors low, windward sprouts over high, leeward sprouts; importantly, it performs this function before stands become susceptible to black bears. But most prior research in redwood stand density management addresses the commercial thinning or precommercial thinning of coppice-generated stands at age 10 and older (e.g. Boe 1974, Lindquist 2004), or sprout emergence from virgin stumps (Cole 1983, Neal 1967, Powers and Wiant 1970). The potential for managing stump sprouts at a very early age until recently had not been addressed in any comprehensive way. To address this deficiency, we recently initiated a study of redwood sprout ecology and management that is the first to test the operational feasibility of methods for managing the density of sprout reproduction from second-growth stumps (Keyes and Matzka 2005).

Previous research on the sprouting behavior of coast redwood suggests that opportunities exist for intensive sprout reproduction management as an operational practice. Sprout densities are directly influenced by stump size, age, and height (Neal 1967). Past studies in redwood and other species have shown an effect on sprout density and vigor by partial sprout removal, thermal wounding, shading, exposure to hormones, and bark integrity (Powers and Wiant 1970, Finney 1993, Tappeiner 1996).

Our study has been established for the purpose of identifying practical and efficient techniques for the operational control of immediate post-harvest stump sprouting capacity (basal bud management) and early sprout density management. It is being conducted in operationally-harvested stands that are dominated by mature coast redwood trees and are representative of the region's second-growth forests. In this study, differences in the sprouting response of redwood stumps to various treatments designed to debilitate the capacity of stumps to produce sprouts – including varying stump heights, mechanical stump scarification, bud incineration, and mechanical sprout removal – are being quantified. Three separate analyses constitute the project.

In the first study, the effect of overstory density retention levels from thinning on later post-harvest sprout proliferation is assessed. This study tests the hypothesis that thinning prior to harvest can reduce the quantity of stump sprouts when harvest occurs 5-10 years later. It assesses commercial thinning as a form of pre-emergent regeneration density management in the post-harvest, sprout-regenerated stand. The hypothesis is tested by measuring sprout density and sprout height from stumps in stands previously thinned to reduced levels of overstory density (33/66/100 percent density retention).

In the second study, the effectiveness of sprout removal on the height growth response of residual sprouts is assessed. This study tests the hypothesis that sprout growth rates are affected by different levels of sprout removal and post-removal sprout densities. It assesses a new practice of sprout thinning as a form of pre-precommercial thinning. This study is conducted among stumps within 2 years following clearcut harvest with numerous sprouts (tens or hundreds) per stump. The hypothesis is tested by utilizing chainsaws and motorized brush-cutting tools to thin sprout clumps to pre-determined density levels, and then monitoring sprout height and caliper growth.

In the third study, the effects of stump morphology and different methods of stump treatment on sprout densities and spatial distributions are assessed. This study tests the hypothesis that different forms of stump and bud treatment (stump height, bud incineration, mechanical bark removal) exhibit varying levels of effectiveness in achieving sprout density and distribution targets. It assesses a new practice of stump morphology treatment as a form of pre-emergent regeneration density management in the post-harvest, sprout-regenerated stand. The treatments are conducted on stumps immediately following clearcut harvest. The hypothesis is tested by implementing stump treatments based on the previously-described tools, and then monitoring the density and spatial arrangement of sprouts.

The Future of Redwood Coppice Silviculture

Intensive sprout density management as an operational practice has not been codified, but there is ample evidence that it will work, and that it (or something very similar) is necessary. Intensive sprout management offers multiple potential benefits, including:

- Captured volume that is otherwise lost to mortality
- Decreased rotation length to desired product size
- Or, increased product size at desired rotation length
- Improved quality of the lowermost log; reduction in embedded bark and debris
- Selection of most stable and enduring sprouts on a stump
- Reduction of losses associated with high winds
- Reduction of losses associated with cambium-feeding bears

The history of forestry in the redwood empire is one that has been written by engineering technology, biological limits, and societal influences. That history is still being written today. Nearly 80 years ago, The Humboldt Redwood Reforestation Association (1926) refuted popular misconceptions of the futility of redwood renewal, concluding that,

...there is no chance whatsoever that redwoods will become extinct….California can look forward to being perpetually in the redwood lumber business, and at the same time tourists will always have, in addition to parks of virgin trees, great timbered areas in which the grandeur of Nature has been enhanced by the hand of man.

Its since-demonstrated capacity for aggressive regeneration from stump sprouts casts doubt on the notion that redwood's extinction was ever at stake. Yet steps may be taken to develop innovative silvicultural techniques for the management of today's redwood forests to ensure that they continue to yield the quality and quantity of logs upon which the health of the redwood forest products economy depends.

Acknowledgements

This project has been made possible by a USDA-CSREES research grant, and by in-kind contributions from the Green Diamond Resource Company and the L.W. Schatz Demonstration Tree Farm.

References

Allen, G., J. Lindquist, J. Melo, and J. Stuart. 1996. Seventy-two years' growth on a redwood sample plot: The wonder plot revisited. Pp. 61-62 *in* Proceedings of the Conference on Coast Redwood Forest Ecology and Management. University of California, Berkeley, California.

Boe, K.N. 1961. Redwood seed dispersion in old-growth cutovers. USDA Forest Service Research Note PSW-RN-177. 7p.

Boe, K.N. 1968. Cone production, seed dispersal, germination in old-growth redwood cut and uncut stands. USDA Forest Service Research Note PSW-RN-184. 7p.

Boe, K.N. 1974. Thinning promotes growth on sprouts on old-growth redwood stumps. USDA Forest Service Research Note PSW-RN-290. 5 p.

California Department of Forestry and Fire Protection. 2002. California Forest Practice Rules, 2002. California Department of Forestry and Fire Protection, Sacramento, California. 272 p.

Cole, D.W. 1983. Redwood sprout growth three decades after thinning. Journal of Forestry 81(3):148-150,157.

Finney, M.A. 1993. Effects of thermal wounding, shading, and exogenous auxin on some sprouting responses of coast redwood seedlings. Tree Physiology 12(3):301-309.

Fritz, E. 1945. Twenty years' growth on a redwood sample plot. Journal of Forestry 43(1):30-36,

Fujimori, T. 1977. Stem biomass and structure of a mature *Sequoia sempervirens* stand on the Pacific Coast of northern California. Journal of the Japanese Forestry Society 59(12):431-441.

Fox, L. III. 1996. Current status and distribution of coast redwood. Pp. 18-20 *in* Proceedings of the Conference on Coast Redwood Forest Ecology and Management. University of California, Berkeley, California.

Gannett, H. 1899. The redwood forest of the Pacific Coast. National Geographic Magazine 10(5):145-159.

Glover, F.A. 1955. Black bear damage to redwood reproduction. Journal of Wildlife Management 19(4):437-443.

Humboldt Redwood Reforestation Association. 1926. The Redwood Reforester, Volume II – Number One. Humboldt Redwood Reforestation Association, Samoa, California. 28 p.

Keyes, C.R., and P.J. Matzka. 2005. Silvicultural treatments to control stump sprout density in coast redwoods. Pp. ?? in Proceedings of the Redwood Region Forest Science Symposium. USDA Forest Service General Technical Report PSW-GTR-194.

Leiberg, J.B. 1899. Is climatic aridity impending on the Pacific Slope? The testimony of the forest. National Geographic Magazine 10(5):160-181.

Lindquist, J.L. 2004. Precommercial stocking control of coast redwood: A seventeen-year status report (1981-1998). California Forestry Report No. 2. Department of Forestry & Fire Protection, Sacramento, California. 24 p.

Lindquist, J.L., and M.N. Palley. 1967. Prediction of stand growth of young redwood. California Agricultural Experiment Station Bulletin 796. University of California, Berkeley, California. 47 p.

Neal, R.L., Jr. 1967. Sprouting of old-growth redwood stumps: first year after logging. USDA Forest Service Research Note PSW-RN-137. 8 p.

O'Dell, T.E. 1996. Silviculture in the redwood region: An historical perspective. Pp. 15-17 *in* Proceedings of the Conference on Coast Redwood Forest Ecology and Management. University of California, Berkeley, California.

Olson, D.F, Jr., D.F. Roy, and G.A. Walters. 1990. Redwood (*Sequoia sempervirens* [D. Don] Endl.). *In* Silvics of North America: Conifers. USDA Forest Service Agriculture Handbook 654, Vol. 1. 675 p.

Powers, R.F., and H.V. Wiant, Jr. 1970. Sprouting of old-growth coastal redwood stumps on slopes. Forest Science 16:339-341.

Roy, D.F. 1966. Silvical characteristics of redwood (*Sequoia sempervirens* [D. Don] Endl.). USDA Forest Service Research Paper PSW-RP-28. 20 p.

Russell, W.H., K. Carnell, and J.R. McBride. 2001. Black bear (*Ursus americanus* Pallas) feeding damage across timber harvest edges in northern California coast redwood (*Sequoia sempervirens* [D. Don] Endl.) forests, USA. Natural Areas Journal 21(4):324-329.

Sugihara, N.G. 1992. The role of treefall gaps and fallen trees in the dynamics of old growth coast redwood (*Sequoia sempervirens* [D. Don] Endl.) forests. Ph.D. dissertation, University of California, Berkeley. 189 p.

Tappeiner, J.C. II, J. Zasada, D. Huffman, and B.D. Maxwell. 1996. Effects of cutting time, stump height, parent tree characteristics, and harvest variables on development of bigleaf maple sprout clumps. Western Journal of Applied Forestry 11(4):120-124.

Van Pelt, R., and J.F. Franklin. 2000. Influence of canopy structure on the understory environment in tall, old-growth, conifer forests. Canadian Journal of Forest Research 30:1231-1245.

Wilcox, W.W. 1996. Coast redwood as a future supplier of wood products. Pp. 48-49 *in* Proceedings of the Conference on Coast Redwood Forest Ecology and Management. University of California, Berkeley, California.

Mini Seedlings – A New Forest Regeneration System

A. Lindström, C. Hellqvist, E. Stattin
Dalarna University, Dept. of MNT, S-781 88 Borlänge, Sweden

Introduction

Swedish forest tree nurseries produce approximately 300–350 million seedlings annually for outplanting. Most seedlings (80%) are containerised i.e. they are produced in small containers or pots that are filled with a growing media. The most common growing media is peat. The volume of the containers vary between 45 and 150 ml and seedlings are grown at densities of about 300 – 900 seedlings m^{-2}. The seedlings when outplanted are usually 1–3 years old.

Large seedlings cause high costs when they are raised in the nursery due to the long growing time at low densities. Also, costs for handling, transportation and planting normally increase with the size of the seedling. Large seedlings also put strain on the environment as the need for energy, fertilization and pesticides are high.

One of the largest problems in Swedish forestry is the damage caused by the large pine weevil (*Hylobius abietis* L.) in conifer reforestation areas. The adult weevil gnaws the stem bark of conifer seedlings and may often cause severe plant mortality (Eidmann 1969). The first years after planting are critical (Långström 1982) and to make a normal seedling survive the pine weevil, the seedlings must either be protected by mechanical or chemical means (insecticides) (Pettersson 2004). In the future synthetic pyrethroides and other insecticides will probably be prohibited. Therefore alternatives to chemical protection of seedlings need to be found. By postponing planting until 2–3 years after clear cutting the risk for pine weevil attacks are normally reduced (Örlander et al. 1997), but the delayed planting may cause other problems such as production losses and problems with competition from vegetation.

Studies have shown that the pine weevil prefers planted seedlings before small naturally generated or seeded seedlings (Trädgårdh 1939, Selander et al.1990, Selander and Immonen 1992). This knowledge was the main reason for the start of a project with the aim of testing very young seedlings (mini seedlings) in field trials (Gyldberg and Lindström 1999). Other arguments for testing mini seedlings was the known fact that short growth in the nursery could reduce risks for root deformation and instability of the tree when outplanted (Rune 2003) as well as the potential of reducing forest regeneration costs.

Mini Seedlings – A New Cultivation System

The mini seedling is grown for only 8–12 weeks in small containers, 10–20 ml, at a density of 1500–2000 m^{-2}. The seedling is quite small when outplanted, only 4–6 cm high. Using this short cultivation time, roots have small possibilities of armouring the substrate. Therefore, suitable cultivation systems for mini seedlings include a reinforcement of the substrate either by encasing the growing media in a net or by the use of binding agents.

There are numerous advantages and possible potentials with mini seedlings. As a result of the short cultivation period the need of fertilizers and pesticides in the nursery will be reduced which makes the system environmentally friendly. The nurseries will also be able to deliver seedlings continuously for planting and fulfil orders at short notice. The need for greenhouse and storage space will be reduced which will lower production costs. Also the need of over wintering seedlings will be reduced. This considerably lowers the risk for seedling losses. The small size of the seedling enables transportation, handling and planting to become more efficient.

Field Experiences

Numerous field trials in central Sweden show that mini seedlings are attacked by pine weevil to a lesser extent than normal sized 1-year-old containerized seedlings (Lindström et al. 2000, 2002, 2004). The difference in pine weevil attacks between the plant types is very large after 1 year but is reduced in the second year, when mini seedlings have grown into a size that is more preferred by the pine weevils (Figure 1). However, the attacks on the mini seedlings in the second year are still lower than for the normal sized reference seedlings. Due to less injury from the pine weevil, survival rates are the same and in some cases even better for the mini seedlings than for normal sized reference seedlings (Lindström et al. 2004).

Results also indicate that the mini system can be used both for Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.). So far experiences from five years of field testing indicate that insecticide treatment is not needed for mini seedlings before planting and that planting can be done one or two years earlier after the final felling than with conventional sized seedlings.

Shoot growth during the first year is usually small for the mini seedling. The mini seedling seems to give priority to root growth during the first year of establishment. This may partly explain the limited shoot growth. During the second year however the growth is comparable to a conventional seedling. Results from 2–3 years old field trials indicate that the initial difference in height will remain for at least a few years (Lindström et al. 2004).

There are also results indicating that less radical soil scarification is needed for the mini seedling (Gyldberg and Lindström 1999). However, the mini seedling should be planted in mineral soil or in a mixture of mineral soil and humus in order to obtain high survival and growth. Planting in mounds or in humus will cause high risks for water stress.

Field storage experiments have shown that mini seedlings dry out faster than conventional seedlings. Therefore precautions have to be taken to protect the seedlings at field storage. The use of protective blankets increases the time of safe field storage (Lindström et al. 2004).

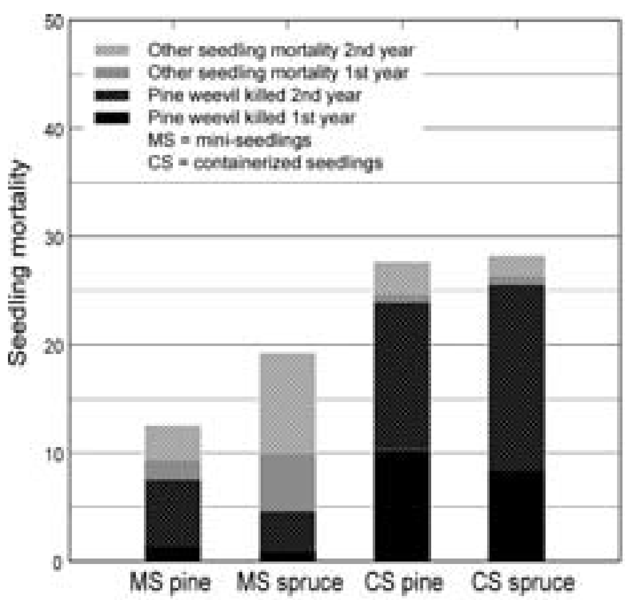

Figure 1. *Mean seedling mortality during the first and second year after outplanting for three field experiments in central Sweden. The experiments were planted in early summer in 2001, 2002, and 2003. Mini seedlings were approximately 10 weeks old and had a height of approximately 5 cm at the time of planting and the containerized seedlings were 1-year-old seedlings, with a height of 10-15 cm. N = 300*

Nursery Experiences

The cultivation period as well as the treatments in the nursery is important for the mini seedling vitality and potential of good field establishment. Both pine and spruce are positively affected by a 2–3 week outdoor hardening phase after the greenhouse period. Long night treatment of pine in late spring/early summer has also improved field establishment.

The time when late sown mini seedlings are safely stored occurs a few weeks later than for conventional older seedlings. Root freezing tolerance develops slowly in young pine and spruce. For spruce this is the case also for the shoot freezing tolerance. Since the hardening processes are a bit slower for mini seedlings it is extra important to test storability before seedlings are put into storage (Lindström et al. 2004).

Future Development and Research

The mini seedling system is presently being implemented in Swedish forest companies and small scale enterprises. The system is still under development and further work is needed to find optimal solutions on practical aspects of nursery and planting techniques.

Further research is needed to better understand the reasons for the limited pine weevil attacks on mini seedlings and at what developmental stage a seedling becomes attractive to pine weevils. There is also a need to identify at what site indexes the mini seedling can be used with success. Suitable fallow period, planting time and selection of scarification method are other urgent research areas to deal with before the mini seedling concept can be launched in a large scale.

References

Eidmann, H. 1969. Rüsselkäferschäden an verschiedenen Nahrungsflanzen. Anz. Schädlingsk. 42: 22-26.

Gyldberg, B. and Lindström, A. 1999. Kan små skogsplantor ge billigare och bättre föryngringar? [In Swedish.] Plantaktuellt 4: 1-2.

Lindström, A., Hellqvist, C., Gyldberg, B. and Håkansson, L. 2000. Odlingssystem för små skogsplantor. [In Swedish.] Högskolan Dalarna, Avdelningen för Skog och Träteknik. Stencil nr 17. 13 pp.

Lindström, A., Hellqvist, C. and Håkansson, L. 2002. Resultat från fältförsök med miniplantor 2002 samt återinventering av äldre försök. [In Swedish.] Högskolan Dalarna, Institutionen för matematik, naturvetenskap och teknik. Stencil nr 29. 17 pp.

Lindström, A., Hellqvist, C., Håkansson, L. and Stattin, E. 2004. Resultat från fältförsök med miniplantor 2003 samt återinventering av äldre försök. [In Swedish.] Högskolan Dalarna, Institutionen för matematik, naturvetenskap och teknik. Stencil nr 36. 22 pp.

Långström, B. 1982. Abundance and seasonal activity of adult *Hylobius* – weevils in reforestation areas during first years after final felling. Commun. Inst. For. Fenn. 106: 1 – 23.

Örlander, G., Nilsson, U. and Nordlander, G. 1997**.** Pine weevil abundance on clear-cuttings of different ages: A 6-year study using pitfall traps. Scand. J. For. Res. 12: 225-240.

Petersson, M. 2004. Regeneration methods to reduce pine weevil damage to conifer seedlings. Doctoral diss. Southern Swedish Forest Research Centre, SLU. Acta Universitatis Agriculturae Sueciae. Silvestria 330.

Rune, G. 2003. Instability in plantations of container grown Scots pine and consequences on stem form and wood properties. Doctoral thesis. Acta Universitatis Agriculturae Sueciae, Silvestria 281.

Selander, J. and Immonen, A. 1992. Effect of fertilization and watering of Scots pine seedlings on the feeding preference of the pine weevil (*Hylobius abietis* L.). Silva Fenn. 26(2): 75-84.

Selander, J., Immonen, A. and Raukko, P. 1990. Resistance of naturally regenerated and nursery-raised Scots pine seedlings to the large pine weevil [In Finnish with English summary]. Folia For. 766. 19 pp.

Trägårdh, I. 1939**.** Sveriges skogsinsekter. [In Swedish.] Gebers förlag. 508 pp.

Improving Regeneration Performance Standards: Comments Based on Early Experience With Three New Approaches In British Columbia

P.J. Martin[a], S. Browne-Clayton[b], K. Day[c], G. Taylor[d]

[a] Forest Practices Branch, BC Ministry of Forests, Victoria, BC
[b] Riverside Forest Products Ltd., Kelowna, BC
[c] University of British Columbia Research Forest, Williams Lake, BC
[d] Canadian Forest Products Ltd., Fort St John, BC

Introduction

Regeneration performance standards are widely used across Canada. These standards specify the acceptable state of regeneration (or more broadly, of tree cover) on areas that have been harvested. Typically, the standards both specify the range of acceptable condition and define a number of years after harvest within which this condition must be achieved. Regeneration performance may be assessed at various times and for several different purposes. In this paper, we focus on the final assessment of the adequacy of regeneration that typically occurs 10 to 20 years post-harvest. In most provinces, the regeneration performance standards applicable at this time are termed free-growing or free-to-grow standards (e.g., BC Ministry of Forests 2000, Manitoba Conservation 2001, Saskatchewan Environment 2004) though they are termed performance standards in Alberta (Alberta Sustainable Resource Development 2004).

Across the country, interest in improving regeneration performance standards is high. In Alberta, regeneration standards were recently examined by an expert review panel (Alberta Reforestation Standards Science Council 2001) and subsequently revised (Alberta Sustainable Resource Development 2003). New regeneration standards have recently been released in Saskatchewan (Saskatchewan Environment 2004) and a major initiative to revise standards is underway in Ontario. Many provinces no longer prescribe the system with which regeneration standards must be set. In many provinces, forest licence holders are free to propose new formulations for regeneration performance standards.

Changing the system used to set standards and assess performance potentially has many significant impacts. System changes may result in changes in post-harvest condition that lead to changes in stand composition and structure through time, impacting future yields of timber and other values. Changes can have economic consequences, altering regeneration cost structure, the total cost to achieve a given outcome, and the cost-effectiveness of treatments. Changes may impact the work routine of those who prescribe regeneration treatments, survey regenerating areas, manage regeneration performance data, and verify that standards have been met.

Our objective in this paper is to contribute to improving regeneration performance standards and the associated methods of assessing regeneration performance. In this paper we first present a concept model of regeneration performance standards. Next, we review two methods traditionally used to set standards and assess regeneration performance in British Columbia (BC). Then, we briefly review three new approaches to setting regeneration standards that we have participated in developing. Last, based on our experience with both old and new approaches in BC, we offer comments on the design and implementation of new systems for specifying standards for regeneration performance.

Concept Model of Regeneration Performance Standards

A concept model and the definition of key terms will facilitate our discussion of regeneration performance standards. By regeneration performance, we mean the degree to which the achieved treed state approximates the goal state at the assessment date. The goal state is the post-harvest forest cover condition that will achieve the management objective. To measure performance, critical characteristics of the goal state are identified and then measures are selected that portray them. Regeneration performance standards specify threshold levels for those measures. Harvested areas are surveyed to estimate the achieved levels of the performance measures. When the performance measures are within the prescribed limits, regeneration performance is satisfactory – and it is assumed that the actual state approximates the goal state and thus the objective will be achieved. When the performance measures are outside of the prescribed limits, regeneration performance is unsatisfactory, and, typically, treatments are required to create the desired condition. A stand-level standard describes a condition that must be met on a portion of a cutblock or over an entire cutblock. If the standard describes a condition that must be met in a population comprising many cutblocks, we term it a multi-block standard. As illustrated below, measures may be input to a function to transform them into a new variable that we term a synthetic measure.

Within a single jurisdiction, one or at most a few different systems are used to specify regeneration performance standards. The concept of a widely applicable system for setting regeneration performance standards implies certain commonalties of goals, factors critical to goal achievement, and relevant measures for those factors, across a variety of sites, stands, and administrative settings.

Two Traditional Approaches in British Columbia

In BC, two systems are widely used to set regeneration performance standards and measure outcomes. As discussed above, in describing these systems it is useful to identify the performance measures, compliance thresholds, critical factors, goal, and scale of application.

The standards most widely used in BC measure regeneration performance in the units of free-growing trees per hectare. These standards are applied to young, even-aged stands. On mesic sites in the BC interior, the compliance threshold is 700 free-growing trees per hectare. At the final assessment, a cutblock must not contain a patch one hectare or larger with less than 700 free-growing trees per hectare. Thus, this is a stand-level standard. In this system, the critical factor is crop tree stocking, where a crop tree is a desirable species, exceeding some minimum height, healthy with good form and condition, unimpeded by brush, more than a certain distance (e.g., 2 m) from other tallied crop trees.

Defining the goal that the system is designed to further is much more challenging. A careful reading of the system description (Wyeth 1984, BC Ministry of Forests 2000) suggests that BC's even-aged system was designed to control the level of conifer sawlog production. Recent studies have confirmed that when harvested areas are re-stocked to levels above the compliance threshold, most of the timber production potential of the site is captured (Bergreud 2002, Martin et al. 2005).

The second most commonly used system in BC sets regeneration performance standards for partial-cut stands that require some regeneration. In this multi-layer system, there are four performance measures: (1) the density of crop trees ≥ 30 cm height, (2) the density of crop trees ≥ 1.3 m height, (3) the density of crop trees ≥ 7.5 cm diameter (dbh), and (4) the density of crop trees ≥ 12.5 cm dbh. Multi-layer standards specify a set of four compliance threshold densities. At assessment, the density of crop trees exceeding the size limit is estimated for each of the four tree size groups. The performance standard is met when any one of the four observed densities exceed the associated compliance threshold.

Like BC's even-aged system, the critical factor in the multi-layer system is crop tree stocking, where a crop tree is a desirable species, exceeding some minimum size, healthy with good form and condition, and unimpeded by brush. Common compliance thresholds are 300 per hectare large trees (dbh ≥ 12.5 cm), 400 per hectare trees with dbh ≥ 7.5 cm, 500 per hectare trees with height ≥ 1.3 m, and 700 per hectare trees with height ≥ 30 cm. Note that the inclusion of trees retained at harvest (both advance regeneration and mature trees) is an expansion of the term and concept of regeneration performance. The goal driving the design of the system is to control the level of conifer timber production in stands managed under the selection silvicultural system (BC Ministry of Forests 1992). However, like the even-aged system previously described, BC's multi-layer system is used to set performance standards on sites where non-timber goals dominate. And, like BC's even-aged system, the multi-layer system specifies stand-level standards.

Three New Approaches in British Columbia

Over the last several years, we have been involved in the development of three new systems for setting standards for regeneration performance: (1) the multi-block volume system, (2) the DFP system, and (3) the boreal mixedwood system.

In the multi-block volume approach, a simple equation is developed to predict volume at harvest from silviculture survey estimates of the condition of regeneration. Model parameters correspond to the critical factors and measures: (1) site productivity as measured by site index, (2) stocking as measured by mean stocked quadrants, (3) degree of stand development as measured by height at assessment relative to expected height, and (4) species composition as indicated by species group. Values for the four measures are input to the volume equation to obtain predicted volume, the synthetic measure of regeneration performance. The explicit system goal is to control the level of conifer volume production. The standard must be met in a population comprising multiple cutblocks.

At the final assessment date, the cutblocks in the population are surveyed. The current values of the inputs to the yield prediction model are estimated. These values are input to the model to translate observed conditions into predicted future volume. Values are chosen for two model parameters, stocking and height, that define "potential performance." The compliance threshold is computed with the volume equation using the predefined values for potential stocking and height and the sample-based estimates of site index and species group. Minimum required regeneration performance is expressed as a percent of potential performance (e.g., 90% of potential). Achieved performance is required to exceed minimum acceptable performance. The method is fully described in several documents (Martin et al. 2002, 2004; Fort St John Pilot Project Participants 2004, J.S. Thrower and Associates Ltd. 2003, 2004). Additional information is available at http://www.for.gov.bc.ca/hfp/forsite/multi_block.htm.

The multi-block volume method is in operational use in the 4.7 million hectare Fort St John Timber Supply Area in northeastern BC. It has been proposed for use, with a variety of additional components, in a second management unit (TFL 49) near Kelowna, BC. The recently completed revision of BC's forest practice regulations allows other forest licence holders to adopt "multi-block" approaches, with Chief Forester approval (Province of BC 2004).

In the DFP approach, regeneration performance is measured in terms of the deviation from potential volume production that an observed condition represents. Deviation From Potential (DFP) ranges from 0 (full stocking) to 1 (unstocked). The compliance threshold is often established at a mean DFP of 0.20 (e.g., Przeczek 2004). The critical factors and associated performance measures are: (1) seedling and sapling stocking as measured by the number of free-growing trees in a 0.005 hectare plot, and (2) overstory tree amount as measured by basal area per hectare around the sample point (trees with dbh ≥ 12.5 cm). The tangible, physical measures (free-growing trees density and overstory basal area) are combined and transformed into the synthetic measure DFP. The system goal is seedling and sapling stocking adequate to achieve a desired proportion of potential volume production. DFP-based standards apply to individual stands.

The DFP method was created to provide a reliable method of assessing seedling and sapling stocking in partially cut stands with heterogeneous structure. Development began in 2002 in response to general dissatisfaction with existing methods of assessing stocking in this stand type. The method has very recently been adopted for use in the southeastern portion of BC (BC Ministry of Forests 2004) and is being considered in other locations. The DFP method is fully described elsewhere (BC Ministry of Forests 2004, Martin et al. 2005a, b). See the DFP web site for more information: http://clients.tmnewmedia.com/mpbi/index.htm

To explore issues that should be addressed in the design of regeneration standards for the sustainable management of boreal mixedwoods, Martin (2005) proposed a new system for setting regeneration standards for boreal mixedwoods in western Canada. This method is not in use in BC. The system goal is to regulate the conditions necessary to produce the desired character of, and yield from, the mixedwood. The standards apply at the multi-block scale. The factors critical to achieving the goal and the associated measures are: (1) overall crop tree stocking as measured by stocking percent, (2) proportion of harvested area dominated by free-growing conifers as measured by percent of plots dominated by a free-growing conifer, and (3) proportion of harvested area in mixed (deciduous-coniferous) patches as measured by the percent of plots in mixed patches. The compliance thresholds depend on the nature of the harvested area and the objectives in the forest management plan. Thresholds could, for example, be set at 90% overall crop tree stocking, 20-40% area dominated by free-growing conifers, and 20-40% area in mixed patches.

Comments on Designing and Implementing New Systems

The three new approaches described above give us some experience designing and implementing new systems for specifying regeneration performance standards. When discussing improvements to standards, it is useful to distinguish among four alternative improvement paths: (1) changing the definition of key parameters of the existing system (e.g., updating the criteria used to assess a free-growing tree), (2) changing the level of the compliance minimum within the existing system, (3) changing the way in which the existing system is administered and enforced, and (4) a wholesale change to a completely new system. Our comments relate to the fourth path. Distilling experience to-date, and mindful of the hazards associated with drawing conclusions from short-term results of localised pilot projects, we offer the following comments.

Costs and benefits

The benefits expected from a new approach must justify the cost of the change. We have found that the cost to develop, test, obtain approval, and implement new systems can be substantial and is easily underestimated. New approaches create a workload and costs for many groups. Agency costs increase as new approaches must be reviewed and approved. Both surveyors and silviculturists must be trained in the new system. Existing hand-held data collectors, field forms, and central databases may need to be changed. Various business processes may need to be revised and new capacities may be required to obtain all of the potential benefits that a new system offers. Even when a new regeneration performance assessment system is designed to deliver cost-savings, our experience indicates that an increase in costs should be expected over the short-term. The savings, if they materialise, will come over the medium and longer terms.

In BC, the interest in alternative approaches is partly driven by dissatisfaction with the cost-effectiveness of existing standards. We have concluded that inefficiencies derive from both the structure and the implementation of the current regeneration performance standards. Current approaches restrict a forester's ability to find the least cost method to deliver a given outcome (Martin et al. 2004). We recommend that developers of new approaches identify the inefficiencies in their current systems and use this insight to design flexible new systems that allow efficient action (and do not force inefficient action).

In addition to direct costs (and benefits), developers should consider indirect costs (and benefits) of a change. For example, there is value in maintaining consistency over time, and throughout a jurisdiction, in the measure of performance – even if that measure is imperfect. In BC, new approaches have identified certain deficiencies in free-growing trees per hectare as the ultimate measure of success. The new approaches reject the traditional measure, thus breaking the time trend in performance reporting. In the rush to embrace new approaches, we caution against sacrificing the valuable information in performance trends over time. In some cases, it may be desirable to maintain the traditional measure (or possible to predict its value from a new measured variable) to maintain continuity of the long-term record.

Critical factors and measures of performance

The new approaches confirm crop tree stocking as a critical performance driver. However, each new approach challenges the prevailing view that crop tree stocking is the only critical factor. With the goal to sustain the boreal mixedwood, for example, the new mixedwood approach recognises three critical factors: (1) overall stocking, (2) proportion of free-growing, conifer-dominated area, and (3) proportion of area in mixed (conifer-deciduous) patches. We suggest that efforts to improve regeneration performance standards should not assume that crop tree stocking (whether represented by stocking percent or well-distributed trees per hectare) is the sole determinant of the adequacy of regeneration.

Performance standards can directly control one or more physical characteristics of the regeneration (e.g., mean height, stocking percent, etc) or the physical measures can be combined to form a synthetic measure, and the standard can control this variable. For example, in the multi-block volume approach four observable characteristics (site index, stocking, height, and species composition) are combined into a synthetic measure – predicted volume per hectare at harvest. A single synthetic measure can account for the combined effect of multiple physical measures on the goal. Synthetic measures link short-term observables to the long-term goal and handle curvilinear relationships between measures and the goal. Two of our new approaches utilise the synthetic measure predicted volume per hectare at harvest age. This synthetic measure improves the alignment of regeneration assessment with the timber production goal – but further improvements seem possible. Synthetic measures of board-foot volume (or net value) at harvest, for example, should be considered by developers of new regeneration performance standards.

We fully endorse the concept of setting regeneration standards in terms of predicted yield and coupling survey simulation with distance-dependent individual-tree growth model simulation to relate silviculture survey parameters, such as stocking percent, to future yield (e.g., Bergerud 2002, J.S. Thrower and Associates Ltd. 2003, 2004). For the timber production goal, this approach helps address the common criticism of the short-term focus, and apparent arbitrariness, of current regeneration standards.

Scale of application

Two of our new approaches raise the issue of scale of application. BC's existing standards must be met on individual cutblocks or portions thereof. The multi-block volume and mixedwood approaches are constructed to apply to a population of cutblocks. At which scale (or scales) is regeneration performance best assessed? Our experience with new approaches suggests that some aspects of desired performance may only be relevant - and are best controlled - at a level of resolution above the individual cutblock. For example, it has been argued that species composition should be loosely controlled at the individual cutblock level with more stringent controls operating at the landscape level (Kneeshaw et al. 2000, Greene et al. 2002). Initiatives to improve regeneration performance standards should consider the optimal scale of application. We increasingly believe that it is often at a level above that of the individual cutblock.

Design

Our new approaches tend to make greater use of new tools (e.g., stand growth models, site index estimation methods, and juvenile height growth curves), more advanced sample designs (e.g., sub-sampling and combinations of fixed and variable radius plots), and improved methods (e.g., the use of GPS units to navigate to sample points located on 100 m UTM grid). In BC, the existing standards are implemented with province-wide, standardised survey protocols (BC Ministry of Forests 2002) developed many years ago that are less advanced. Our experience suggests that in the process of developing new formulations for standards it is possible to incorporate new knowledge and tools and employ more accurate - and efficient - measurement methods and sample designs. While it is theoretically possible to upgrade the existing approaches, it appears easier to reach all affected parties and institutionalise changes through the introduction of new systems.

Early in the design phase, it is necessary to decide what the new system must do. A common objective is that the system must ensure that the post-harvest condition matches the condition assumed in the management plan – or more particularly, the condition assumed in the forest-level simulation, fully or partially represented by the yield curves assigned to regenerated areas. We have not made this a mandatory design specification for our new approaches. We have taken the view that when significant opportunities to improve current standards are identified, improvements should be made - even if these improvements do not assure that management plan assumptions are being met. This choice must be made by all development teams: will only those new systems be considered that provide assurance that management plan assumptions are met?

To some degree, our experiments with new approaches can be viewed as a search for formulations that better reflect the biology of tree and stand growth. Our experience suggests that the biological basis for current regeneration standards can be improved. New assessment systems, designed to more closely reflect stand growth principles, can provide a better basis for setting performance standards.

Implementation

New ways to measure the adequacy of regeneration sometimes challenge conventional concepts and elicit strong negative reactions as concepts to which some individuals have a long-standing and deep attachment are openly challenged. The prohibition against NSR (not satisfactorily reforested areas) is one such “sacred cow” that has been challenged by two of our new approaches. Our experience indicates that developers of new approaches should not under-estimate the negative reaction that can be triggered if new approaches threaten conventional views. Engagement in the development of new systems provides both a challenge and an opportunity to critically re-examine beliefs and assumptions. The soft, people management skills of leadership, negotiation, and communication can help gain acceptance for new ideas. Nevertheless, when resistance to change remains, we believe that implementation of new systems should proceed if it is clear that they use the best available science, lead to better management decisions, and provide better outcomes per dollar expended.

When a new system is implemented the appropriate level for the compliance minimum must be established. Typically, agency staff fear that the level will be set too low and industry staff fear that the level will be set too high. To address these concerns, proponents of new systems should consider an annual review and revision of minimums for the first few years of system operation.

Verification is a key component of forest certification (e.g., Sustainable Forestry Initiative 2004) and a core function within public agencies. We advise developers of new systems to work with those responsible for verifying that standards have been met. Work areas may include creating new inspection procedures, completing agreements on the content, format and schedule for information transfer between industry and government, developing new procedures for assessing conformance with the new requirements, and creating processes for compelling compliance, or assessing penalties, when standards are not met.

Goals

Our new systems result from either (1) a re-statement of the current goal in terms more conducive to quantifying the relationship between the measures and the goal, or (2) promulgating a new goal. In the multi-block volume approach, the traditional goal of conifer sawlog production is simply re-stated as the new goal to achieve a specified percent of potential volume production. In contrast, the mixedwood approach demonstrates that a change in the dominant goal can require a change in regeneration performance standards.

In building and describing new systems, we have found it useful to specify a single goal around which a new system is organised. In two of our systems, we adopted some form of a timber production goal. However, a system developed to serve a timber production goal can also be used to set standards and assess performance in harvested areas where goals other than timber production are important. It is useful to distinguish between a system allowing a non-timber goal to be achieved and a system providing assurance that a non-timber goal will be achieved. Several situations arise. First, some non-timber goals are achieved by the same conditions that are necessary to achieve the timber production goal. In these cases, the same system is usually sufficient to protect the non-timber values. Second, some non-timber goals can be achieved by setting system parameters at levels that allow - but do not specifically assure - that the conditions necessary to achieve these other goals are realised. For example, BC's even-aged system has been used to set regeneration standards on sites where a key objective is to "maintain or enhance grizzly bear forage supply" (BC Ministry of Forests 2001). The desired condition can be created when the minimum stocking threshold is reduced and the definition of the area to be reforested is changed. Third, in some cases, the factors critical for achieving a non-timber goal are so different that additional standards and/or alternative systems are required. For example, post-harvest forest cover characteristics such as structural complexity and spatial heterogeneity are not specifically controlled by most systems designed around a timber production goal. However, these characteristics have been identified as important for some goals, such as sustaining mule deer winter range (Dawson and Armleder 2000) and restoring biodiversity (Carey 2003).

New systems can be designed to make it easier for foresters to accommodate non-timber goals and to provide them with better information for making treatment decisions. New multi-block systems (such as our multi-block volume and boreal mixedwood systems) provide increased flexibility to implementing foresters, allowing them greater freedom to accommodate non-timber goals. Frequently, some timber production must be sacrificed to achieve a non-timber goal. By providing estimates of volume production foregone, the multi-block volume system provides an estimate of the opportunity cost of a given accommodation, improving the information base supporting the balancing of competing goals.

Conclusion

When a problem with existing regeneration performance standards has been identified, changes to the administration, compliance threshold, or definition of key system parameters sometimes will be sufficient to rectify the problem. However, in other cases, it will be necessary to design and implement an entirely new system for specifying regeneration performance standards. We suggest that individuals contemplating new systems should consider the following questions. Have the goals changed? Of the many goals, which ones must the system specifically address? For this set of goals, what are the critical characteristics of forest cover at assessment that determine the degree to which the goals are achieved? What variables should be used to measure these critical factors? Within what range must the measures be maintained to produce the desired levels of these goals? Can a synthetic measure be created to expose the relation of short-term condition to long-term outcome? What opportunities exist to incorporate improved tools, sample designs, and measurement methods? Will the benefits of a new system exceed the development and implementation costs? Is there an implementation plan to help all affected parties and to resolve linkages to inventory, forest-level planning, and various databases? What is the appropriate scale of application for the new standard?

Acknowledgements

We thank Dave Weaver and Ralph Winter for constructive comments on an earlier version of this paper. Many foresters and technical specialists contributed to the development of the new systems and thus the ideas that we discussed in this paper. In particular, we thank Bryce Bancroft, Lorne Bedford, Phil Burton, Eleanor McWilliams, John Przeczek, and Ken Zielke. Last, we thank Ken Greenway for helping us draw conclusions from our projects.

References

Alberta Reforestation Standards Science Council. 2001. Linking regeneration standards to growth and yield and forest management objectives. Alberta Sustainable Resource Development, Edmonton, AB. 57 p. Available March 15, 2005 at http://www3.gov.ab.ca/srd/forests/fmd/arssc/

Alberta Sustainable Resource Development. 2003. Alberta regeneration survey manual. Forest Management Branch, Alberta Sustainable Resource Development, Edmonton, AB. 96 p. Available March 15, 2005 at http://www3.gov.ab.ca/srd/forests/fmd/manuals/

Bergerud, W.A. 2002. The effect of the silviculture survey parameters on the free-growing decision probabilities and projected volume at rotation. Research Branch, B.C. Ministry of Forests, Victoria, B.C. Land Manage. Handb. No. 50. 23 p. Available March 15, 2005 at http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh50.htm

B.C. Ministry of Forests. 1992. Correlated guidelines for management of uneven-aged drybelt Douglas-fir stands in British Columbia. Silviculture Branch, B.C. Ministry of Forests, Victoria, B.C. 59 p.

B.C. Ministry of Forests. 2000. Establishment to free growing guidebook: Prince George Forest Region. Forest Practices Branch, B.C. Ministry of Forests, Victoria, B.C. 162 p. Available March 15, 2005 at http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/guidetoc.htm

B.C. Ministry of Forests. 2001. Grizzly bear habitat in managed forests: silviculture treatments to meet habitat and timber objectives. Research Branch, B.C. Ministry of Forests, Victoria, B.C. Extension Note #54. 7 p. Available March 15, 2005 at http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En54.htm

B.C. Ministry of Forests. 2002. Stocking and free growing survey procedures manual. Forest Practices Branch, B.C. Ministry of Forests, Victoria, B.C. 119 p. Available March 15, 2005 at http://www.for.gov.bc.ca/hfp/pubs/silvman/index.htm

B.C. Ministry of Forests. 2004a. Rocky Mountain Forest District partial cutting stocking standards. Rocky Mountain Forest District, B.C. Ministry of Forests, Cranbrook, B.C. 8 p. Available March 15, 2005 at http://clients.tmnewmedia.com/mpbi/index.htm

B.C. Ministry of Forests. 2004b. A new approach to stocking assessment in stands resulting from MPB salvage partial cutting: Training session workbook. Forest Practices Branch, B.C. Ministry of Forests, Victoria, B.C. 46 p. Available March 15, 2005 at http://clients.tmnewmedia.com/MPBI/index.htm

Carey, A.B. 2003. Biocomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry 76(2): 127-136.

Dawson, R., and Armleder, H. 2000. Structural definitions for management of mule deer winter range habitat in the interior Douglas-fir zone. Cariboo Forest Region, B.C. Ministry of Forests, Williams Lake, B.C. Extension Note #25A. 8 p. Available March 15, 2005 at: http://www.for.gov.bc.ca/rsi/research/cextnotes/extnot25.htm

Fort St. John Pilot Project Participants. 2004. Sustainable forest management plan. Canadian Forest Products Ltd., Fort St. John, B.C. 238 p. Available March 15, 2005 at http://fsjpilotpro-ject.com/sfmp.html.

Greene, D.F., Kneeshaw, D.D., Messier, C., Lieffers, V., Cormier, D., Doucet, R., Coates, K.D., Groot, A., Grover, G., and Calogeropoulos, C. 2002. Modelling silvicultural alternatives for conifer regeneration in boreal mixedwood stands (aspen/white spruce/balsam fir). For. Chron. 78(2): 281–295.

J.S. Thrower and Associates Ltd. 2003. Stand survey and growth modelling for the Fort St. John TSA. Contract report for Canadian Forest Products Ltd., Fort St. John, B.C. 38 p. Available March 15, 2005 at http://www.jsthrower.com/qsilv_surveys

J.S. Thrower and Associates Ltd. 2004. Stand survey and growth modelling for the TFL 49 results-based pilot project: Year 3 final report. Contract report for Riverside Forest Products Ltd., Kelowna, B.C. 82 p. Available March 15, 2005 at http://www.jsthrower.com/qsilv_surveys

Kneeshaw, D.D., Leduc, A., Drapeau, P., Gauthier, S., Paré, D., Carignan, R., Doucet, R., Bouthillier, L., and Messier, C. 2000. Development of integrated ecological standards of sustainable forest management at an operational scale. For. Chron. 76(3): 481–493.

Manitoba Conservation. 2001. Forest Renewal Standards. Forestry Branch, Manitoba Conservation, MB. 8 p. Available March 15, 2005 at http://www.gov.mb.ca/conservation/forestry/forest-renewal/fr-contents.html

Martin, P.J. 2005. Design of regeneration standards to sustain boreal mixedwoods in western Canada. Int. For. Rev. In press.

Martin, P.J., Browne-Clayton, S., and McWilliams, E. 2002. A results-based system for regulating reforestation obligations. For. Chron. 78(4): 492–498.

Martin, P.J., Browne-Clayton, S., and Taylor, G. 2004. A results-based system for regulating reforestation obligations: Some developments in 2003. For. Chron. 80(2): 201–208.

Martin, P.J., Bancroft, B., Day, K., and Peel, K. 2005a. A new basis for understory stocking standards for partially harvested stands in the British Columbia interior. West. J. Appl. For. 20(1): 5-12.

Martin, P., Peterson, E., Bancroft, B., Day, K., Peel, K., and Zielke, K. 2005b. A procedure to assess stocking in British Columbia stands partially cut to salvage beetle-infested pine. Contract report prepared by Western Ecological Services Ltd. for Forest Practices Branch, BC Ministry of Forests, Victoria, BC. 93 p. Available March 15, 2005 at http://clients.tmnewmedia.com/MPBI/index.htm

Province of BC. 2004. Forest planning and practices regulation. B.C. Reg. 14/2004, Forest and Range Practices Act. Queen's Printer, Victoria, BC.

Przeczek, J.P. 2004. Partial cutting stocking standards: Summary of the current status and suggested options for additional consideration. Interior Reforestation Co. Ltd., Cranbrook, B.C. 11 p. Available March 15, 2005 at http://clients.tmnewmedia.com/MPBI/index.htm

Saskatchewan Environment. 2004. Regeneration assessment. Forest Service, Saskatchewan Environment, Prince Albert, SK. 42 p. Available March 15, 2005 at: http://www.se.gov.sk.ca/forests/

Sustainable Forestry Initiative. 2004. 2005-2009 Standard. Sustainable Forestry Board, Arlington, VA. 26 p. Available March 15, 2005 at http://www.aboutsfb.org/index.htm

Wyeth, M. 1984. British Columbia Ministry of Forests regeneration survey system. In Proceedings of the 1983 SAF Convention: New forests for a changing world, Portland, OR. Society of American Foresters, Bethesda, MD. pp. 40-43.

Hardwood Genetics and Tree Improvement – A Midwest USA Perspective

C.H. Michler[1], R. Meilan[2], K.E. Woeste[1], P.M. Pijut[1], D. Jacobs[2], P. Aldrich[3], J. Glaubitz[4]

[1]USDA Forest Service, Hardwood Tree Improvement and Regeneration Center (HTIRC),715 W. State Street, West Lafayette, IN, 47907-2061, U.S.
[2] Purdue University, Department of Forestry and Natural Resources
[3]Benedictine University, Department of Biology, 5700 College Rd., Lisle, IL, 60532, U.S.
[4]University of Wisconsin, Department of Genetics, Henry Mall, Madison, WI, 53706, U.S.

Introduction

Fine hardwood trees in the Central Hardwoods region of the United States are an important resource for the furniture, cabinetry, flooring, modular home, and paneling manufacturing industries. Consumers find wood from these trees to be very desirable because of quality factors such as grain, strength and color. To enhance wood production, tree improvement programs can address quantity and quality issues through alterations in genetic traits for growth and vigor, straightness, defects such as pin knots and irregular grain, amount of heartwood and in some cases, wood color.

Tree improvement in fine hardwoods through improved seed production is lagging well behind programs that improve pulp and paper species such as poplar, loblolly pine and Douglas fir. In addition, the majority of hardwood seedlings that are produced by public nurseries are unimproved. Seed is purchased from vendors and collectors and only rarely separated by source. Seed is normally harvested where ease of harvest is the most important factor, thus yard, park, and fencerow trees are often used. Improvement of fine hardwoods has also lagged due to the lack of capital within the industry to fund research and development on the resource. Limited funds tend to be directed towards research in product manufacturing. In the absence of traditional funding sources for tree improvement similar to those that fund conifer programs for pulp production, HTIRC (Hardwood Tree Improvement and Regeneration Center) relies on industry associations, federal agencies, universities and private endowments to generate annual funding for its program.

The HTIRC program intends to address improvement of genetic traits in improved planting stock of black walnut (*Juglans nigra*), black cherry (*Prunus serotina*), butternut (*Juglans cinerea*), and northern red oak (*Quercus rubra*), through (1) tree breeding and genetic modification, (2) developing propagation and seed production systems, (3) improving nursery production methods, (4) developing standards for improvement of seedling quality and (5) developing guides for management of the genetics in small, fragmented stands.

Early Selection of Improved Black Walnut Genotypes

Several geneticists have researched black walnut improvement in the USA for over forty years. In this time there have been a large number of families identified as phenotypically superior for growth and form, but there has been minimal advanced generation selection. The walnut breeding program at HTIRC is actively evaluating about 350 phenotypically superior black walnuts. A little more than half of these trees were selected from wild populations, the rest were identified in even-age plantations or progeny tests. From this germ plasm, about 40 parents will be progeny tested yearly, including a core set of about 15 elite clones. Some of the progeny tests will be converted to seed orchards as they mature. The best 15 clones will be intermated using controlled crosses, with the goal of identifying superior trees for clonal plantations. How and when the progeny of these trees will be selected is the subject of the remainder of this section.

Studies have suggested that selection for vigor (height and/or diameter growth) could take place as early as age four to six (Rink, 1984b) or at any time after age eight (Rink and Kung, 1995). To provide an empirical validation of the value of early selection in black walnut, we performed a post-hoc analysis of a provenance/progeny test. In 1981, about 1,300 bareroot, 1–0 seedlings derived from open-pollinations of 80 phenotypically superior black walnuts growing in 12 states and Canada were planted at the Southeast Purdue Agricultural Center (SEPAC) in Jennings County, Indiana, USA. We performed a *post-hoc* analysis of the data from these trees to determine the age at which selection for diameter growth would be most effective. We evaluated the effect of setting selection intensity at ten and 20 percent. In each year for which there was data, the selected families were identified and their family mean in the year 2000 (20 years from seed, 19 years after planting, and the last year for which there was data) was compared to the mean of the entire population in 2000. The relative efficiency of early selection as compared to selection of the top ten percent of the families at 20 years of age was calculated as standard deviations of improvement per year.

A two-stage breeding strategy where phenotypic selection is followed by clonal testing or progeny testing is often more efficient than single-stage selection (Danusevicius and Lindgren, 2002). We therefore envision a breeding strategy where selection for diameter growth on family means would be followed by the clonal propagation of families as rooted cuttings or as scions on mature rootstocks. After four years on mature rootstocks the selected families would bear enough flowers to complete one cycle of breeding. Selection before age four would not be advantageous since selected trees need to have enough wood for second-stage propagation. Given the current feasible strategy of early selection, clonal propagation to mature rootstocks, and a delay of four years for production of flowers, the efficiency of early selection as compared to selection at age nineteen was calculated using an age adjustment factor of (19 + 4) / [(selection age) + 4] where the minimum selection age was four years. The age adjustment factor corresponds to the number of breeding cycles possible if selection is in a given year relative to the number of cycles if selection is at age nineteen. The results indicate that selection at or near age eight would have resulted in the greatest gain in diameter per year. We calculated the expected gain from selection of the top 20 percent of the families at age eight as follows: selection differential x age adjustment = 0.65 x 23/12 = 1.25; gain = 1.25 $h^2\sigma_P$ (the heritability and phenotypic standard deviation of diameter growth in the population) or (1.25)(0.35)(3.4 cm) = 1.5 cm. This is a conservative estimate based on an assumption of heritability for diameter growth in the range of 0.34 to 0.5 (Beineke, 1989; Rink, 1984a). A gain of 1.5 cm is about 0.3 cm more than would be expected from selecting the top ten percent of the families at age nineteen. The advantage of early selection is maintained even under a two-stage breeding strategy where phenotypically selected families are rooted or grafted and evaluated for straightness after 15 years. An important additional benefit of early selection is that families could be selected before stand thinning is necessary, resulting in considerable savings. Early selection permits either savings in land costs or higher selection intensity because young trees need less space.

Vegetative and Tissue Culture Propagation

Clonal reproduction of commercially important hardwood tree species is necessary, in a tree improvement program, in order to provide improved planting stock for use in progeny testing and for production forestry. Vegetative propagation methods (via rooted cuttings) will be required to produce clones of elite genotypes. Many ecologically and economically important hardwood tree species have a low genetic or physiological capacity for adventitious root formation, and are considered recalcitrant to routine, commercial-scale vegetative propagation. However, successful propagation of difficult-to-root species can be achieved if the type of cutting, date of collection, stock plant or cutting manipulation, rooting treatment, and greenhouse parameters are carefully considered.

Preliminary results with 9-year-old black cherry trees appear promising. We achieved 63 percent rooting when cuttings were collected in mid-June and treated with either K-IBA (12, 29, or 62 mM) or IBA (15, 34, or 74 mM). Fifty-six rooted cuttings are presently being overwintered in a controlled cold-storage environment. After overwintering the rooted cuttings will be returned to the greenhouse, allowed to flush and initiate new growth, and then outplanted to the field.

An example of our improvement effort utilizing tissue culture and genetic modification is with black cherry. In vitro shoot cultures have been established for three genotypes of black cherry from nodal explants obtained from juvenile seedlings growing in the greenhouse. Shoot cultures can be routinely micropropagated for regeneration and rooting studies. Adventitious shoots have been successfully regenerated from in vitro leaf explants and rooting experiments are underway. Once the complete protocol has been established, elite black cherry genotypes will be introduced into in vitro culture. The development of transgenic elite black cherry trees with resistance to pests or engineered for reproductive sterility will potentially have great economic benefits to landowners, lumber mills, and the forest products industry. Genetic gain in black cherry genotypes through this research will complement traditional tree improvement efforts at the HTIRC.

Trees grown for wood production

Once in vitro regeneration systems have been developed, economic traits such as form, wood quality, and stress tolerance can be modified by genetic transformation.

Form. Plant domestication is the conversion of a wild plant, which has become adapted, through the process of natural selection to a plant whose morphology and physiology have been altered by selection to yield useful products when cultivated. Ideally, a fully domesticated tree would be relatively short and have a disproportionately large diameter stem. This could result in less reaction wood, higher harvest indices, improved handling efficiency, and greater unit-area yields. A domesticated tree should also have reduced numbers and sizes of branches, which should also be favorable for conducting water. Crowns of dwarfed trees will likely be narrower, which, when coupled with reduced sensitivity to competition, will allow a greater number of stems to be planted in a given area. Crown geometry could also be optimized to capture sunlight in tight spacing by altering expression of or introducing genes that affect leaf size and shape, branch allocation, and branch angle (Bradshaw and Strauss 2001).

Clonability. Being able to vegetatively propagate forest trees will allow growers to practice clonal forestry, which will permit them to fully capture genetic gains that have been achieved through conventional breeding. The ease with which trees can be vegetatively regenerated shows great diversity within and among species, suggesting that genes and control mechanisms can be isolated that will strongly modify competence for regeneration. One factor that can strongly influence propagation success is the ontogenetic age (maturation state) of the donor plant. The progressive change in a number of traits, including a pronounced decline in rooting ability due to maturation, has been well documented (Greenwood and Hutchison 1993). The existence of differential rooting ability across tree taxa presents an opportunity to conduct comparative studies, contrasting the molecular and developmental events that occur in those that successful produce adventitious roots with those that do not.

Engineering reproductive sterility

Before genetically engineered trees are deployed commercially, it would be advisable to develop a system to minimize the risk of transgene spread in the environment. One way of accomplishing this objective is to engineer reproductive sterility.

The three most common ways to engineer reproductive sterility involve using: (1) floral tissue-specific promoters to drive the expression of a cytotoxin gene; (2) dominant negative mutations (DNMs), to suppress floral gene function by over-expressing a mutant version of the encoded protein; and (3) double-stranded RNA, a potent inducer of post-transcriptional gene silencing, an approach known as RNA interference (RNAi) (Meilan 2004).

Hardwood Seedling Nursery Culture and Plantation Establishment

For a tree improvement program to be most effective, scientific advances in genetic quality should be complemented by research involving nursery culture and plantation silviculture. Tree improvement serves as an additional silvicultural tool available to foresters, and its effectiveness is only realized when used in conjunction with other silvicultural practices. In the early stages of a tree improvement program, it is likely that far greater gains in operational plantation productivity will be realized by improving methods to produce high quality nursery stock and nurture seedlings through the plantation establishment phase.

Most hardwood plantations established in the Midwestern USA involve afforestation of private lands, in which seedlings are planted on open fields that were formerly in agricultural production. Quality hardwoods are an important component of these plantations and a recent survey in Indiana identified northern red oak, black walnut and white oak (*Quercus alba* L.) as the three most commonly planted species (Jacobs *et al.* 2004). Although timber production is a motivation for private landowners to establish plantations in Indiana, leaving a legacy for future generations, providing wildlife habitat, and conserving the natural environment rank higher in priority (Ross-Davis *et al.* 2004).

Establishment success of hardwood plantations is highly variable, and plantation failure is not uncommon. A survey of 87 randomly selected operational plantings in Indiana (one to five years of age) found that seedling survival across all sites averaged approximately 65%, with the majority of mortality occurring the first year after planting (Jacobs *et al.*, 2004). After five years, only 49% of surviving seedlings were deemed “free-to-grow”. Planting performance is generally associated with the condition of nursery stock, planter experience, control of competing vegetation, and animal browse. These results indicate that substantial improvement in hardwood plantation establishment could likely be made by improving the quality of nursery stock available for afforestation and the silvicultural techniques employed at outplanting.

Seedling quality is a major focus of hardwood seedling nursery production, and may be defined in both morphological and physiological terms. Morphological quality is relatively easy to assess, and hardwood seedlings may be operationally graded for variables such as height, stem diameter, and number of permanent first-order lateral roots (FOLR). Though there is debate as to the relative importance of specific morphological variables for predicting field performance of hardwoods (Dey and Parker 1997, Jacobs and Seifert 2004a), collectively these variables tend to be positively correlated with outplanting performance. Nursery seedling morphology is largely dependent on cultural factors such as bed density, fertilization, irrigation, and undercutting to manipulate root growth. These practices may be modified to produce a seedling meeting specific morphological standards.

The benefits of using high quality hardwood nursery stock are best realized when integrated with effective silviculture during plantation establishment. Matching species to the appropriate site conditions, consulting with a professional forester, aggressive control of competing vegetation, and minimizing damage from animal browse help to promote vigorous hardwood plantation establishment (Jacobs *et al.* 2004). Hardwood afforestation plantings are susceptible to failures associated with heavy pressures from deer browsing and competing vegetation, and it is critical to promote rapid growth immediately following planting to encourage seedlings to quickly reach free-to-grow status. Competing vegetation in hardwood plantations is most effectively controlled using chemical means, and different herbicides have been tested with a variety of hardwood species to help identify optimal protocols for weed control specific to hardwood plantations (Seifert and Woeste 2002).

Fertilization at the time of planting is another practice that may promote early plantation development. Technical advances in fertilizer technology have resulted in a product more compatible with the nutritional needs of forest trees than traditional agronomic fertilizers (Jacobs *et al.* 2003). In a recent afforestation trial involving three hardwood species, application of 60 g per seedling of a polymer-coated controlled-release fertilizer to the planting hole resulted in significantly greater height (52%) and diameter (37%) growth during the first growing season as compared to non-fertilized seedlings (Jacobs and Seifert 2004b).

Genetics of Native Stands

In addition to afforestation activities described above that are accomplished through genetically improved plantations, the sustainable management of natural stands is equally important and partly dependent upon knowledge of population genetics and their conservation.

To this end, we are developing molecular genetic markers for black walnut and northern red oak. Microsatellite markers, or short sequence repeats (SSRs), are highly variable and provide sufficient genetic resolution to characterize germplasm, track pollen and seed movement, and evaluate the genetic organization of native and managed populations. We have developed thirty microsatellite markers for black walnut (Woeste et al. 2002) and thirty for northern red oak (Aldrich et al. 2002a, 2003a). The latter amplify well in several red oak species, and some perform well in chestnut (*Castanea*) and beech (*Fagus*).

Since species are a common unit for management, oaks represent a unique challenge at this level due to unclear species boundaries. As with European white oaks (Muir et al. 2000), North American red oak species are thought to hybridize readily (Jensen 1995), and red oak species may have a more recent origin compared to species in the white oak group (Guttman and Weigt 1989). Consequently, it is not always possible to treat their respective gene pools as independent when species co-occur, though genetic differences typically are evident. For example, we examined genetic (SSR) differences between northern red oak (*Q. rubra*), Shumard oak (*Q. shumardii*), and pin oak (*Q. palustris*) in an old-growth stand and found small though significant genetic differentiation, with pin oak the most distinct (Aldrich et al. 2003b).

At the regional level, black walnut and northern red oak exhibit high levels of genetic diversity within their populations and relatively low genetic differentiation among populations. This is as expected for long-lived, predominantly outcrossed, woody species (Hamrick and Godt 1989). Currently we are using microsatellite markers to explore the diversity of black walnut in native stands across several states (unpublished data). In northern red oak, a survey of variation in the chloroplast genome (Romero-Severson et al. 2002) revealed inter-stand variation across Indiana. Preliminary evidence from a nuclear study using microsatellites (unpublished data) supports this pattern, showing that germplasm collected from sites near one another are more genetically similar in their nuclear genomes compared to those collected far apart. These data may prove useful in directing germplasm sampling for tree improvement and nurseries.

Unfortunately, oaks and other shade tolerant species are experiencing recruitment failure in many forests of the Central Hardwood Region (Abrams 2002). Fire, timber harvest, and grazing have been important factors in the development of these forests, and 20th century suppression of these disturbance regimes has altered successional trajectories, favoring shade-tolerant later seral species such as maple and beech. Though the ecological consequences for the less tolerant species like the oaks are well-described, including changes in density and spatial structure (Aldrich et al. 2002b), it remains unclear what genetic consequences will hold for the gene pools in the region.

Developing Guides for Sustaining Genetic Variation

Forest management can be considered sustainable only if attention is paid to the conservation of the genetic resources of the managed species (Ledig 1992). Such genetic resources are essential since they encapsulate the ability of tree species to adapt to future environmental challenges such as global warming and new insect and disease pests. However, scant attention has been paid to date to conservation of the genetic resources of even the most valuable Central Hardwood species. As a consequence, the gene pools of our most valuable fine hardwoods may be in peril. What was once a vast continuum of forest cover has been reduced to a patchwork of isolated fragments. Furthermore, repeated targeted harvesting of only the very best phenotypes in the remaining fragments, or 'high-grading' (McGuire *et al*. 1999), may have resulted in the loss of some of the most valuable alleles. Moreover, since selective harvest is generally the silvicultural method of choice in the remaining relict woodlots, widespread recruitment failure has been documented for shade intolerant species (Lorimer 1993); our most valuable species – such as black walnut , northern red oak , or black cherry – are shade-intolerant. An additional threat to the genetic resources of our fine hardwoods is a consequence of the extensive establishment of plantations on formerly cleared land. The seedlings that make up these plantations are supplied by a small number of nurseries; in general, these source nurseries pay little attention to the genetic origin of their seedling crops, the bulk of which are derived from locally-collected seed. As a result, seedlings of limited genetic origin are being deployed over vast areas, possibly causing genetic pollution (via pollen flow and seed dispersal) of the remnant native gene pools.

Hence the time is more than ripe for systematic gene conservation efforts to be undertaken for the fine hardwoods of our region. Gene conservation in trees is typically carried out via two complementary approaches, *in situ* and *ex situ* (Yang and Yeh 1992). *In situ* programs attempt to conserve genetic resources in their natural surroundings through management of native stands (Ledig 1988). *Ex situ* programs utilize seed stores, seed orchards, clone banks, and/or progeny or provenance tests (Lipow *et al*. 2002).

Genetic Resource Management Units (GRMUs) have been proposed as an economically realistic means of effectively conserving the genetic resources of valuable tree species *in situ* (Ledig 1988). The concept of GMRUs is to allow some level of timber extraction via partial logging, provided that this does not interfere with the overarching goal of conserving the local genetic resources. The question then arises as to just how much harvesting should be allowed in GMRUs, or, given that harvest of a certain intensity has taken, what regeneration targets are appropriate to minimize the risk of losing genetic resources? We are developing a computer simulation model to help answer such questions (Glaubitz *et al.* 2004). Our simulation identifies, for a given harvest intensity of a focal tree species, how much regeneration is needed so that there is no more than a ten percent risk of retaining less than ninety percent of the original allelic richness present in the stand. Results to date, based upon a 'virtual' tree population, indicate that such genetic diversity retention targets could be readily achieved via appropriate management (Glaubitz *et al.* 2004). This would be the case even for shade intolerant species – where high harvest intensities would be required to allow regeneration – provided that adequate care is taken to ensure that the regeneration is derived from local germplasm sources. Our simulation was based upon the assumption that the regeneration is produced via pre-harvest random mating among the local adult population. We are currently incorporating the empirical results from our above ongoing studies of population genetic processes in native stands of black walnut and red oaks, in order to make our model more realistic.

For many tree species, *ex situ* gene conservation can be effectively carried out using seed stores (Lipow *et al*. 2002). However, this is not possible for the fine hardwood species of the Midwest, since the seeds of most of these species rapidly lose viability after only one or two years in storage (Schopmeyer 1974). To supplement the genetic resources captured in tree improvement programs, we have proposed the establishment of Gene Conservation Plantations (GCPs). These could be established with the dual purpose of producing veneer or saw-logs while conserving the genetic resources of targeted local regions. The GCPs associated with a particular region (or seed transfer zone) would be established from seed collected from a variety of remnant natural stands within that region. Prior to harvest of GCPs for timber, seed could be collected from the GCPs themselves and then cycled into the establishment of second generation GCPs.

In sum, the genetic research that we are conducting at the HTIRC should facilitate the effective conservation of the genetic resources of fine hardwood species in the Midwest. Perhaps the greatest challenge lies not in developing the scientific knowledge and expertise to carry out efficient *in situ* and *ex situ* conservation programs, but rather in fostering the political will to implement the fruits of our labor in reality.

References

Aldrich, P.R., Jagtap, M., Michler, C.H., and Romero-Severson, J. 2003. Amplification of North American red oak microsatellite markers in European white oaks and Chinese chestnut. Silvae Gen. 52: 176-179.

Aldrich, P.R., Michler, C.H., Sun, W., and Romero-Severson, J. 2002. Microsatellite markers for northern red oak (Fagaceae: *Quercus rubra*). Mol. Ecol. Notes 2: 472-474.

Aldrich, P.R., Parker, G.R., Michler, C.H., and Romero-Severson, J. 2003. Whole-tree silvic identifications and the microsatellite genetic structure of a red oak species complex in Indiana old-growth forest. Can. J. For. Res. 33: 2228-2237.

Aldrich, P.R., Parker, G.R., Ward, J.S., and Michler, C.H. 2002b. Spatial dispersion of trees in an old-growth temperate hardwood forest over 60 years of succession. For. Ecol. Man. 180: 475-491.

Beineke, W.F. 1989. Twenty years of black walnut genetic improvement at Purdue University. N. J. Appl. For. 6: 68-71.

Bradshaw, H.D., Jr. and Strauss, S.H. 2001. Breeding strategies for the 21st century: Domestication in poplar. In: Poplar culture in North America. Part B, Chapter 14, D.I. Dickmann, J.G.T. Isebrands, J.E. Eckenwalder, and J. Richardson (eds.). NRC Research Press, National Research Council of Canada, Ottawa, ON K1A OR6, Canada, pp. 383-394.

Danusevicius, D., and Lindgren, D. 2002. Two-stage selection strategies in tree breeding considering gain, diversity, time and cost. For. Genet. 9: 147-159.

Dey, D.C. and Parker, W.C. 1997 Morphological indicators of stock quality and field performance of red oak (Quercus rubra L.) seedlings underplanted in a central Ontario shelterwood. New For. 14: 145-156.

Falconer, D.S. 1981. Introduction to Quantitative Genetics. 2nd edn. Longman Scientific and Technical. Essex. 340 pp.

Glaubitz J.C., Robichaud R.L., Woeste K. and Rhodes O.E. Jr. 2004. Towards guidelines for harvest intensities with minimal impact upon retained genetic diversity in central hardwood tree species. In Proceedings of the 14th Central Hardwood Forest Conference, March 16-19, 2004, Wooster, Ohio. D.M. Hix, P.C. Goebel, D.A. Yaussy and R.P. Long (eds). U.S. Department of Agriculture, Forest Service, Northeastern Research Station, NE-GTR 316.

Greenwood, M. and Hutchison, K.W. 1993. Maturation as a developmental process. In: Clonal Forestry I: Genetics and Biotechnology, M.R. Ahuja and W.J. Libby (eds.). Springer-Verlag, Berlin, pp. 14-33.

Guttman, S.I., and Weigt, L.A. 1989. Electrophoretic evidence of relationships among Quercus (oaks) of eastern North America. Can. J. Bot. 67: 339-351.

Hamrick, J.L., and Godt, M.J. 1989. Allozyme diversity in plant species. In Plant population genetics, breeding and germplasm resources. A.H.D. Brown, M.T. Clegg, A.L. Kahler, and B.S. Weir, B.S. (eds). Sinauer, Sunderland, Mass., pp. 43-63.

Jacobs, D.F., Rose, R., and Haase, D.L. 2003. Incorporating controlled-release fertilizer technology into outplanting. In National Proceedings: Forest and Conservation Nursery Associations-2002. L.E. Riley, R.K. Dumroese, and T.D. Landis (eds). US Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-28, pp. 37-42.

Jacobs, D.F. and Seifert, J.R. 2004a. Re-evaluating the significance of the first-order lateral root grading criterion for hardwood seedlings. In Proceedings of the Fourteenth Central Hardwood Forest Conference. Wooster, OH, 17-19 March 2004. US Department of Agriculture Forest Service Northeastern Research Station, NE-GTR-316.

Jacobs, D.F. and Seifert, J.R. 2004b. Facilitating nutrient acquisition of black walnut and other hardwoods at plantation establishment. In Proceedings of the Sixth Black Walnut Symposium. West Lafayette, IN, 25-28 July 2004. US Department of Agriculture Forest Service North Central Experiment Station, NC-GTR-243, pp. 66-70.

Jacobs, D.F., Ross-Davis, A., and Davis, A.S. 2004. Establishment success of conservation tree plantations in relation to silvicultural practices in Indiana, USA. New For. 28: 23-36.

Jensen, R.J. 1995. Identifying oaks: the hybrid problem. J. Intern. Oak Soc. 6: 47-54.

Ledig, F.T. 1992. Human impacts on genetic diversity in forest ecosystems. Oikos 63(1): 87-108.

Lipow, S.R., St. Clair, J.B. and Johnson, G.R. 2002. Ex situ gene conservation for conifers in the Pacific Northwest.. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, PNW-GTR-528. 53 pp.

McGuire, M., Stevens, J. and Potter-Witter, K. 1999. Assessing scarcity of the north central veneer log resource. N. J. Appl. For. 16: 160-166.

Meilan, R. 2004. Molecular Biology of Forest Trees. Encyclopedia of Forest Sciences. Acad. Press, Oxford, U.K. (in press).

Muir, G., Fleming, C.C., and Schlotterer, C. 2000. Species status of hybridizing oaks. Nature 405: 1016.

Rink, G. 1984a. Black walnut progeny tests/seed orchards for National Forests in the eastern region. Unpublished progress report of FS-NC-1151, CG-425. St. Paul, MN: North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture.

Rink, G. 1984b. Trends in genetic control of juvenile black walnut height growth. For. Sci. 30: 821-827.

Rink, G. and Kung, F.J. 1995. Age trends in the genetic control of Juglans nigra L. height growth. 10th Central Hardwood Forest Conference: proceedings of a meeting held at West Virginia University, Morgantown, WV, March 5-8. St. Paul, MN: North Central Forest Experiment Station, Forest Service, U.S. Dept. of Agriculture, p. 247-255.

Romero-Severson, J., Aldrich, P., Feng, Y., Sun, W., and Michler, C. 2003 Chloroplast DNA variation of northern red oak (Quercus rubra L.) in Indiana. New For. 26: 43-49.

Ross-Davis, A.L., Broussard, S.R., Jacobs, D.F., and A.S. Davis. 2004 Afforestation behavior of private landowners: An Examination of Hardwood Tree Plantings in Indiana. N. J. Appl. For. In press.

Schopmeyer, C. S. 1974. Seeds of Woody Plants in the United States. Agricultural Handbook No. 450. Forest Service, U. S. Department of Agriculture, Washington, D.C., 883 pp.

Seifert, J.R, and Woeste, K. 2002. Evaluation of four herbicides and tillage for weed control on 1-0 planted tree seedlings. N. J. Appl. For. 19: 101-105.

Woeste, K., Burns, R., Rhodes, O., and Michler, C. 2002. Thirty polymorphic nuclear microsatellite loci from black walnut. J. Heredity 93: 58-60.

Theme 2

Nursery Methodologies to Produce Target Seedlings

Turning Off the Tap: Controlling Nutrient Leaching, Growth and Hardening of Containerized White Spruce Seedlings Through Irrigation Management

S.A. Carles[1], D.C. Stowe[1], M.S. Lamhamedi[2], B. Fecteau[1, 3], H.A. Margolis[1], P.Y. Bernier[4], L. Veilleux[2] and M. Renaud[2]

[1]CRBF, Université Laval, Sainte-Foy, QC G1K 7P4
[2]Direction de la recherche forestière, Ministère des Ressources naturelles et de la Faune, 2700 rue Einstein, Sainte-Foy, QC G1P 3W8
[3]Pampev Inc., 662 rang St.-François, Saint-Louis-de-Blandford, QC, G0Z 1B0
[4]Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, 1055 rue du PEPS, Sainte-Foy, QC G1V 4C7

Introduction

Water is a very precious resource. In arid and semi-arid regions of the world, where water resources are scarce, water conservation is a primary concern. On a global scale, 500 000 ha are lost annually due to poor irrigation practices (Burger 2003). In regions where supplies of fresh water are more abundant, over-irrigation and groundwater contamination from agricultural and nursery runoff are more pressing concerns.

Prudent irrigation and fertilization management can diminish costs of containerized forest seedling production and minimize groundwater contamination. Through diligent monitoring of substrate water contents during the growing season, substantial irrigation water savings can be achieved without adversely affecting seedling quality (Lamhamedi et al. 2000, 2001a, 2002, 2003; Stowe et al. 2001; Bergeron et al. 2004). Although the quantity of chemical fertilizers used in forest nurseries is small, when compared to agricultural and horticultural applications, leaching of nitrogen and other minerals is a constant concern (Juntunen et al. 2002; Juntunen 2003). Nitrate is the most common contaminant. North American standards limit nitrate levels in drinking water to 45 mg/l (10 mg/L as NO_3-N) (USEPA 2004; Health Canada 2003), whereas the European Community and the World Health Organization have established maximum nitrate concentrations at 50 mg/l (11.3 mg/L as NO_3-N) (European Community 1998; World Health Organization 1993). To our knowledge, the amount and content of mineral leachate has not been monitored on a continuous basis over an entire growing season in a container forest nursery.

There are six public and 19 private forest nurseries in the province of Quebec. Of the 162 million plants that were seeded in the spring of 2005, 94% (152 million plants) will be cultivated in containers. Over 26 million white spruce (*Picea glauca* (Moench.) Voss) seedlings (16.5% of total production) will be produced in the 2005-2007 production cycle. This is second only to black spruce (*Picea mariana* (Mill) BSP) (85 million seedlings: 52.4% of production). White spruce is an important commercial species which is used for both lumber and pulpwood. Although the species is adapted to a variety of edaphic and climatic conditions, it grows best if it has an adequate supply of well-aerated water. It demands higher soil fertility than other conifers growing on the same sites (Nienstaedt and Zasada 1990) and is sensitive to periods of water stress. Crops of white spruce seedlings exhibit heterogeneous growth. This is thought to be due to both genetic and environmental factors (Labbé 2004, Lamhamedi et al. 2005a).

Containerized seedlings are produced on a two-year cycle in Quebec. The plants are habitually seeded in May. Two to four seeds are placed in each container cavity, depending on the seedlot. The seeded containers are placed directly into an unheated polyethylene-covered tunnel (opacity: 45%). After a five week establishment period, the germinants are thinned to one plant/cavity. The seedling containers, which are elevated 12 cm above the surface to facilitate rhizosphere aeration, remain under the tunnel for the remainder of the first growing season, an average of about 150 days. During this period the plants are irrigated and fertilized by boom sprinklers with a coefficient of uniformity ≥ 95%. In mid-October the tunnel cover is removed to promote hardening and the seedlings are moved outside for the winter. The plants are grown outdoors, under unsheltered conditions, during their second growing season. Pivoting or pop-up sprinklers and tractor-mounted booms are used for irrigation and fertilization, respectively (Labbé 2004, Lamhamedi et al. 2005a). The coefficient of uniformity for sprinkler irrigation systems varies between 39% and 92%. The question that naturally comes to mind is whether or not there is a relationship between the heterogeneous growth of white spruce seedlings observed during their second growing season and heterogeneous substrate water contents caused by less than adequate water distribution by sprinklers.

Labbé (2004) found that substrate water content in an outdoor bed of containerized seedlings exhibits both spatial and temporal variability. The growing medium is exposed to wind and rain. Because the seedling crop is not homogeneous, both the interception of water droplets and evaporation from the substrate surface are not uniform. Nursery managers have a tendency to over-irrigate to prevent dry spots developing in the seedling bed. This induces leaching of mineral nutrients from the substrate and the subsequent addition of more fertilizers to compensate for these losses. The white spruce seedlings in this study showed a large variability in height growth at the end of the second growing season. It was hypothesized that maintaining uniform substrate water contents throughout the production cycle would limit leaching, and aid in the production of homogeneous seedling lots.

Water also plays an important role in the fall and spring, as the plants harden and deharden, respectively. During these periods seedlings are kept outdoors, unsheltered from temperature extremes. In recent years, freezing temperatures have been experienced as early as September 2 and as late as June 4 at Pampev Inc., the private forest nursery where the present study was conducted. Because the seedlings are not insulated by snow cover and are not fully dormant, they are at risk of being damaged by frost. Millions of seedlings are lost due to frost damage each year. In Quebec, these losses may account for 5% to 30% of a seedling crop. The best protection against frost damage is to irrigate the seedlings. As water freezes around the stems and branches, it releases energy. This phenomenon maintains the temperature of the shoot tissue ≥ 0°C. To maintain a consistent layer of protective ice, irrigation must be continued throughout the period of frost risk. This type of protection requires large quantities of water, much of which is leached into the water table. If nursery managers had a simple tool to help them predict whether or not their plants were at risk, they would only irrigate when absolutely necessary.

The desire to reduce the amount of water used in forest seedling production prompted the installation of an experiment in a crop of (2+0) white spruce seedlings grown under semi-controlled conditions in a tunnel. The objectives of the present study were to:

(i) quantify the amount of mineral leaching from containerized white spruce seedlings grown under three different irrigation regimes (30%, 40% and 55% v/v) and to determine the effect of substrate water content on their growth, nutritional status and acquisition of frost tolerance, and

(ii) develop a hardening schedule specific to (2+0) white spruce seedling production in southern Quebec (ecological zone 2bT, Saucier et al. 1988).

Materials and Methods

A completely randomised-block experiment consisting of six repetitions of three irrigation regimes (IR) was installed on April 30, 2002 in a crop of air slit containerized (IPL 25-350A; IPL®, Saint-Damien-de-Bellechase, QC; 25 cavities/container, 350 cm3/cavity) white spruce seedlings growing in an unheated polyethylene-covered tunnel at Pampev Inc., a private forest nursery located in Saint-Louis-de-Blandford, Quebec (46º25'N 72º00'W), about 100 km south west of Quebec City. The sheltered conditions eliminated the effects of wind and rain and allowed us to control irrigation inputs and to monitor leaching and seedling morphophysiological variables over the seedlings' second growing season.

Three different irrigation regimes (30%, 40% and 55% v/v; cm^3 water/cm^3 substrate) were maintained between May and October 2002. Substrate water content was monitored six times a week for the duration of the experiment with a MP-917 soil moisture system (ESI Environmental Sensors Inc., Victoria, B.C.) (Fig. 1), which is based on the principles of time domain reflectometry (TDR) (Topp and Davis 1985). The seedlings were irrigated and fertilized using a motorized boom system (Aquaboom, Harnois Industries, Saint-Thomas-de-Joliette, Quebec) equipped with 32 nozzles (models 8006 and 8008, Harnois Industries, Saint-Thomas-de-Joliette, Quebec) (Fig. 2). Each pass of the boom increased the substrate water content by ±1% v/v. To verify the irrigation treatment, the substrate water content measurements were repeated thirty minutes after irrigation as suggested by Lambany et al. (1996). Substrate fertility was monitored and adjusted bi-weekly using PLANTEC software (Girard et al. 2001). This insured consistent substrate nutrient levels among the three IR throughout the growing season. Eleven destructive samplings of five seedlings/IR/block (90 seedlings) were made on a bi-weekly basis between May and October 2002. Seedling height, root collar diameter, shoot and root biomass, and tissue N contents were monitored. Seedling growth was later modeled using allometric models. These models describe the relative growth rate of each variable of interest.

The soil solution leaching through one seedling container per experimental unit was captured in a 4-litre plastic bottle on a continuous basis between the months of July and October 2002. The bottles were emptied once a week and the quantity of leachate was noted. The solution was analyzed to determine the amounts of N-NO_3, N-NH_4, P, K, Ca and Mg present in the leachate.

The kinetics of bud formation of one seedling/IR/block was monitored beginning on July 29. Beginning in mid-September, the ratio of drymass/fresh mass of the shoot apex was calculated for five seedlings/IR/block. The latter measurement has been shown to be an excellent indicator of a seedling's degree of hardening and frost tolerance (Lamhamedi et al. 2005b).

On September 16 and 30 and October 14 and 28, seedlings were subjected to artificial frost tests to monitor the evolution of hardening and the acquisition of frost tolerance. On each sampling date 240 seedlings were harvested and four seedlings/IR/block were frozen at each of the target temperatures (+4°C, -4°C, -8°C, -12°C and -20°C). Root plugs were left intact during the freezing procedure to simulate the seedlings' state under natural conditions of frost risk in a nursery.

Immediately following the artificial frosts treatments electrolyte leakage measurements were made on two shoot apices/IR/block, and water loss tests were conducted on two root systems/IR/block. These two procedures measure the extent of damage to the cell membranes. Once cells have been damaged by frost, they are unable to retain fluid and electrolytes. A morphological assessment of frost damage was also conducted. Seedlings were repotted and grown under ideal conditions for 21 days. The acquisition of frost tolerance was measured by assessing the amount of needle mortality as well as the capacity of the seedlings to produce new white roots over the bioessay period.

Results and Discussion

All seedling containers were saturated to a uniform water substrate content (± 60% v/v) before the experiment was installed. Frequent monitoring permitted us to maintain three distinct irrigation regimes (IR30%, IR40% and IR55% v/v) throughout the sampling period (Fig. 3). During the growing season, the standard deviation of the water content measurements varied between 1.1 and 9.2%.

The total amount of irrigation (L/m^2) applied to maintain the three treatments was 223.69, 235.03 and 282.85 L/m^2 for IR30%, IR40% and IR55%, respectively. Twenty percent more water was used for IR55% than for IR40% (Fig. 4).

Neither seedling height (Fig. 6) nor root biomass (Fig. 7) growth was affected by substrate water content. On the last sampling date (October 24, 2002) there was no significant difference among the absolute seedling heights of the plants grown under the three IR. The mean heights of the seedlings grown under IR30%, IR40% and IR55% were 34.95 cm, 35.94 cm and 35.65 cm, respectively at the end of their second growing season. There was a marked increase in the dry biomass of the root tissue at the beginning of August (Fig. 7). This coincided with the end of the period of rapid shoot elongation and the onset of bud formation, which was similar for all three irrigation regimes.

Figure 1. *Determination of substrate water content in an IPL-25-350A seedling container using the MP-917 soil moisture system.*

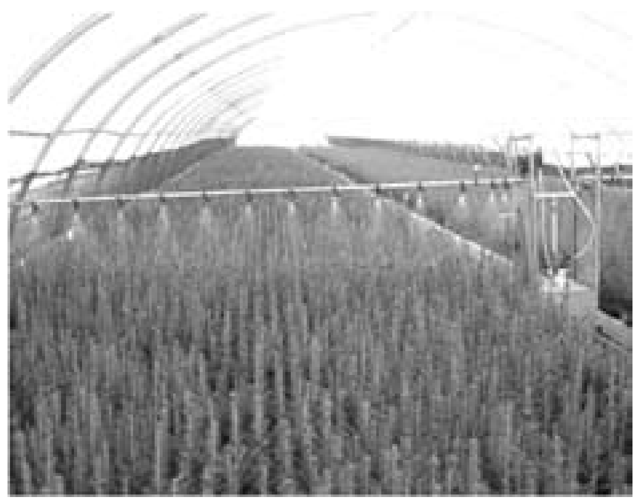

Figure 2. *Irrigation of (2+0) white spruce seedlings under tunnel conditions by a Aquaboom motorized boom system.*

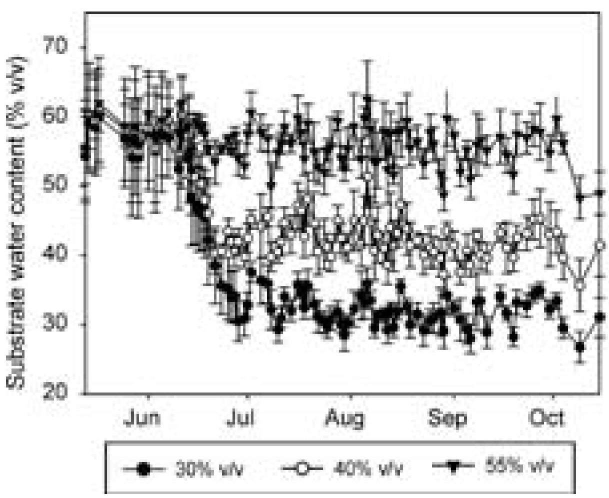

Figure 3. *Evolution of substrate water content under three irrigation regimes.*

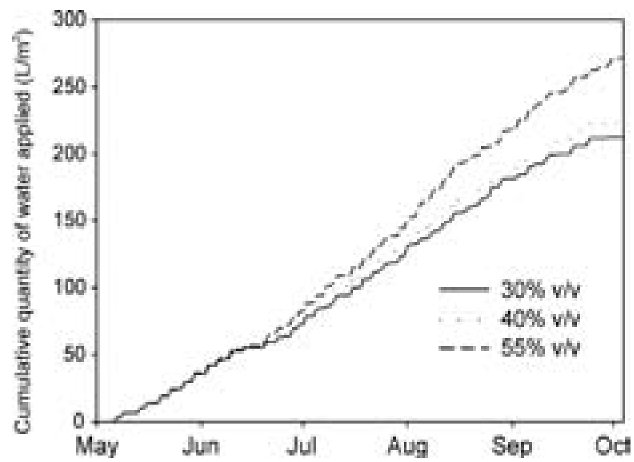

Figure 4. *Cumulative quantity of water applied to (2+0) white spruce seedlings in the form of irrigation.*

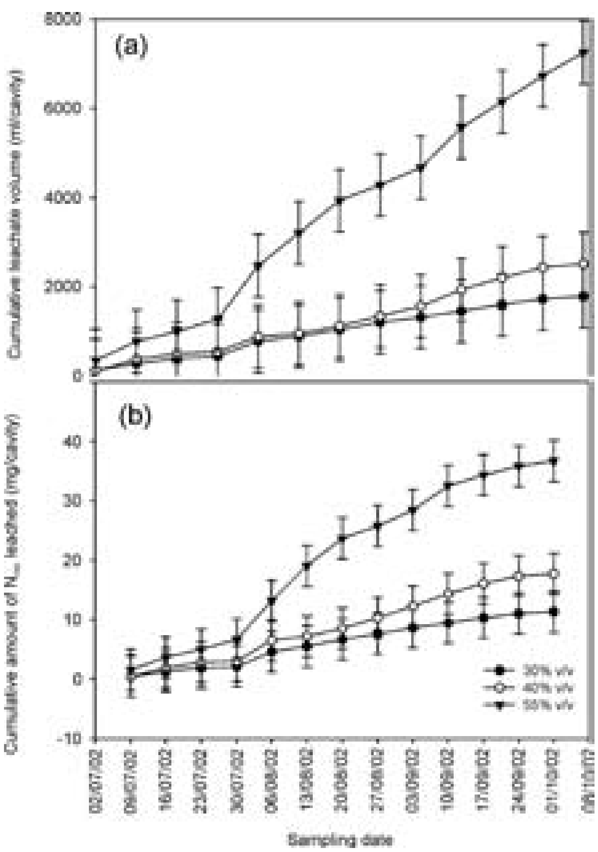

Figure 5. *(a) Cumulative total leachate volume and (b) amount of N (N-NO3 + N-NH4) leached from the seedling containers.*

Carbon allocation between root and shoot tissue was unaffected by a decrease in substrate water content. The same regression equation was used to model the relationship between the above- and below-ground components of the seedlings grown under the three irrigation regimes (Fig. 8).

The evolution of bud formation and the results of the electrolyte leakage and root water loss tests were similar for all three irrigation regimes, indicating that the acquisition of frost tolerance is unaffected by substrate water content. From these results, as well as the assessments of tissue damage and new root growth during the 21 day bioessay, threshold temperatures that root and shoot tissues can tolerate without sustaining frost damage can be determined for each sampling date. These temperatures can then be associated with the corresponding dry mass ratio of the shoot apices on the individual sampling dates to produce a hardening schedule (Fig. 9). Given the dry mass ratio of the shoot apex, the level of frost tolerance of root and shoot tissues can be easily read from the hardening schedule, making it a useful tool under operational forest nursery conditions. The rate of acquisition of frost tolerance can also be calculated directly from the schedule. For example, between September 16 and 30, shoot tissue increased its frost tolerance by 0.3ºC/day, whereas between October 14 and 28, the frost tolerance increased by 0.9ºC/day (Fig. 9). It is important to note that the hardening schedules are designed to underestimate seedling frost tolerance for a given date and, therefore, guarantee that tissue will not be damaged at temperatures warmer or equal to those stated on the schedule. Nursery managers

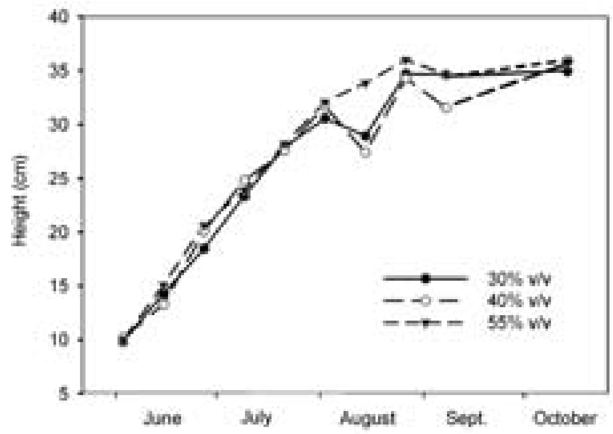

Figure 6. Evolution of seedling height growth over the growing season.

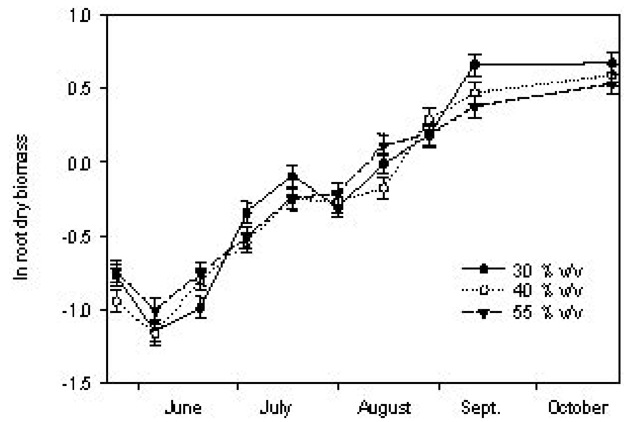

Figure 7. Evolution of relative root biomass growth over the growing season.

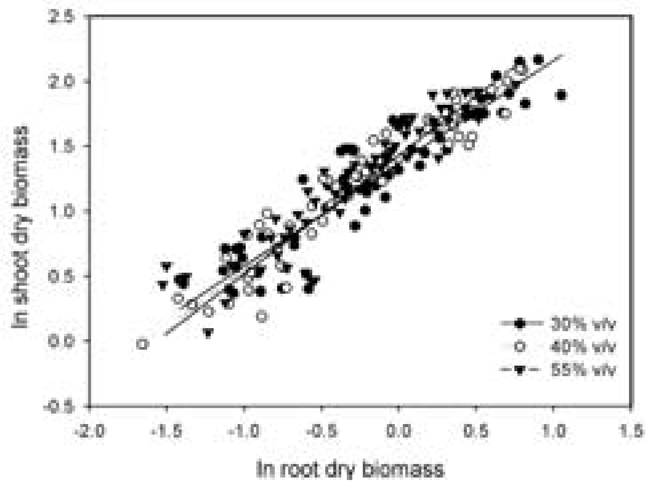

***Figure 8.** Allocation of carbon between root and shoot tissues of (2+0) white spruce seedlings grown under three irrigation regimes.*

now have two choices when they learn of an impeding frost: (1) to run from sprinkler to sprinkler insuring that water is flowing and that a layer of ice is constantly being formed on the seedlings throughout the period of frost risk or, (2) to measure the dry mass ratio of the shoot apex on a regular basis and determine from the hardening schedules whether or not the seedlings will be able to sustain the forecasted temperature without irrigation and water wastage.

Conclusions

Reducing volumetric substrate water content from 55% to 40% does not have a significant effect on seedling growth, carbon allocation, tissue nitrogen content, end of season morphology, or the acquisition of frost tolerance. However, this irrigation strategy will result in a 20% reduction in water usage and, more importantly, reduce the total leachate volume by 65% and quantity of N leached by 52%.

The water content of peat/vermiculite (3/1) substrate should be maintained at 40% v/v during the second growing season for (2+0) white spruce seedlings. This strategy does not compromise seedling growth or physiological processes, yet limits leaching of water and mineral nutrients, and reduces the risk of groundwater contamination. The best way of controlling substrate water content is to grow seedlings under sheltered conditions for both the first and second growing season. New tunnel covers are being developed that maximize the ratio of red to infrared radiation transmitted. This growing environment, which is currently being used on an experimental basis by Pampev Inc. in Alberta, not only facilitates the use of highly efficient irrigation systems, but it also moderates the vapour pressure around the plants and shelters them from wind and rain, two elements that complicate irrigation management.

Hardening schedules, specific to individual ecological zones, can be developed using routine morphophysiological assessments, and measurements of the dry mass ratio of shoot apices over the hardening period. The schedules will help forest nursery managers to determine the level of frost tolerance the seedlings have attained and, therefore, reduce the amount of irrigation water used during periods of autumnal frost risk.

References

Bergeron, O, Lamhamedi, M.S., Margolis, H.A., Bernier, P.Y. and Stowe, D.C. 2004.Irrigation control and physiological responses of nursery-grown black spruce seedlings (1+0) cultivated in air-slit containers. HortScience 39: 599-605.

Burger, P. 2003. Désertification et société civile: Repères pour comprendre et agir. CARI Centre d'Actions et de Réalisations Internationales, France.

European Community 1998. Official Journal JO L330 (05.12.98). Council Directive 98/83/EC on the quality of water intented for human consumption. Adopted by the Council, on 3 November 1998. http://www.lenntech.com/EU's-drinking-water-standards.htm. Consulted July 9, 2005.

Girard, D., Gagnon, J. and Langlois, C.G. 2001. Plantec: un logicel pour gérer la fertilisation des plants dans les pépinières forestières. Gouvernement du Québec, Ministère des Ressources naturelles. Forêt Québec. Direction de la recherche forestière. Note de recherché forestière No.111.

Health Canada 2003. Summary of guidelines for Canadian drinking water quality. April 2003. http://www.hc-sc.gc.ca/hecs-sesc/water/pdf/summary.pdf. Consulted July 9, 2005.

Juntunen, M.-L., Hammar, T. and Rikala, R. 2002. Leaching of nitrogen and phosphorus during production of forest seedings in containers. J. Environ. Qual. 31: 1868-1874

Juntunen, M.-L., Hammar, T. and Rikala, R. 2003. Nitrogen and phosphorus leaching and uptake by container birch seedlings (Betula pendula Roth) grown in three different fertilizations. New For. 25: 133-147.

Labbé, L. 2004. Analyse géostatistique de la variabilité spatiale des teneurs en eau du substrat en relation avec la croissance et la nutrition minérale des semis d'épinette blanche (2+0) irrigués par les asperseurs. Mémoire de matrîse. Faculté de foresterie et de géomatique. Université Laval. 93p.

Lambany, G., Robidas, L. and Ballester, P. 1996. Measurement of soil water content in a peat-vermiculite medium using time domain reflectometry (TDR): a laboratory and field evaluation. Tree Plant. Notes. 47: 88-93.

Lamhamedi, M.S., Labbé, L., Margolis, H.A., Stowe, D.C., Blais, L. and Renaud, M. 2005a. Spatial variability of substrate water content and growth of white spruce seedlings. Soil Sci. Am. J. (in press).

Lamhamedi, M.S., Lambany, G., Renaud, M., Veilleux, L., and Plamondon, S. 2000. Gestion de l'irrigation en pépinière et evaluation des semis d'épinette blanche produits dans les récipients à parois ajourées. Gouvernement du Québec, Ministère des Ressources naturelles. Forêt Québec. Direction de la recherche forestière. Mémoire de recherche forestière no. 138. 36p.

Lamhamedi, M.S., Lambany, G., Margolis, H.A., Renaud, M., Veilleux, L., and Bernier, P.Y. 2001a. Growth, physiology, root architecture and leachate losses in containerized Picea glauca seedlings (1+0) grown in air-slit containers under different irrigation regimes. Can. J. For. Res. 31: 1968-1980.

Lamhamedi, M.S., Margolis, H.A., Renaud, M., and Veilleux, L. 2003. Effets de différentes régies d'irrigation sur la croissance, la nutrition minérale et le lessivage des éléments nutritifs des semis d'épinette noire (Picea mariana) (1+0) produits dans les récipients à parois ajourées Can. J. For. Res.33 : 279-291.

Lamhamedi, M.S., Renaud, M. and Margolis, H.A. 2002. La réflectométrie dans le domaine temporel : une technique d'optimisation de l'irrigation et de réduction du lessivage en pépinières forestières au Québec. Cahiers Agricultures 11: 275-283.

Lamhamedi, M.S., Renaud, M. and Veilleux, L. 2005b. Élaboration des seuils de tol érance au gel des plants d'épinette blanche 1+0 en pépinièere forestièere selon les régions écologiques du Québec. Gouvernement du Québec, Ministère des Ressources naturelles et de la Faune. Direction de la recherche forestière. Mémoire de recherche forestière no. 147. 52p.

Nienstaedt, H. and Zasada, J.C. 1990. *Picea glauca* (Moench.) Voss. *In* Silvics of North America Volume 1. Conifers. Agricultural Handbook 654. *Edited by* R.M. Burns and B.H. Hankala. USDA Forest service, Washington, DC. Pp. 204-234.

Saucier, J.-P., Bergeron, J.-F., Grodin, P. and Robitaille, A. 1998. Les régions écologiques du Quebec mériodional (3º version). Supplement to L'Aubelle, no. 24. 12p.

Stowe, D.C., Lamhamedi, M. S. and Margolis, H. A. 2001. Water relations, cuticular transpiration, and bud characteristics of air-slit containerized Picea glauca seedlings in response to controlled irrigation regimes. Can. J. For. Res. 31: 2200-2212.

Topp, G.C. and Davis, J. L. 1985. Time domain reflectometry (TDR) and its application to irrigation scheduling. *In* Advances in Irrigation vol. 3. Academic Press. New York, pp. 107-127.

USEPA 2004. Drinking water standards. http://www.epa.gov/safewater/standards.html. Consulted July 9, 2005.

World Health Organization 1993. WHO's Guidelines for Drinking-water Quality. Geneva, 1993. http://www.lenntech.com. Consulted July 9, 2005.

Improving Root Development: Genetic Selection, Cultural Practices or Both?

S.A. Carles[1], J. Beaulieu[2], M.S. Lamhamedi[3], D.C. Stowe[1], H.A. Margolis[1]

[1] Centre de recherche en biologie forestière, Faculté de foresterie et de géomatique, Pavillon Abitibi Price, Université Laval, Sainte Foy, QC G1K 7P4
[2] Natural Resources Canada, Canadian Forestry Service, Laurentian Forestry Centre, 1055 rue du P.E.P.S., Box 3800, Sainte Foy, QC G1V 4C7
[3] Direction de la recherche forestière, Forêt Québec, ministère des Ressources naturelles et de la faune, 2700 rue Einstein, Sainte Foy, QC G1P 3W8

White spruce (*Picea glauca* (Moench) Voss) is a highly variable species with a great potential for genetic improvement. Being one of the most commonly reforested species in Quebec, a local breeding program was set up during the 1960s. Selective criteria exploit the variability of above-ground growth and wood characteristics. To date, no detailed studies have been made with regards to the genetic variability of root system morphology (topology) in conjunction with forest nursery cultural practices.

In this study, we investigated genetic variation in the morphological characters of (1+0) seedlings grown under two substrate fertilities *(optimal or low)* for 75 open-pollinated white spruce families. Particular attention was paid to root systems. An experimental design was installed in an unheated production tunnel at Centre de production de Plants Forestiers du Québec Inc. (CPPFQ, Sainte Anne de Beaupré, QC) in May 2004. A destructive sampling on October 25, 2004 allowed us to measure the morphological characters (height, root collar diameter, root and shoot dry mass,…) and calculate their genetic parameters (heritabilities and genetic correlations).

Given a family heritability estimated to be 0.42 (± 0.18), under optimal substrate fertility, genetic control of root dry mass is strong enough to permit genetic selection for larger root systems. Moreover, root dry mass has a strong, positive genetic correlation with root collar diameter (0.91 ± 0.09). Thus, by selecting families having the greatest root collar diameters, we can attain 71.4% of the potential improvement of a direct selection for the largest root systems. Meaning that genetic selection for greater root collar diameters favours larger root systems. Finally, some families performed very differently under the two different substrate fertility regimes. Some of these families lost their growth superiority under lower substrate fertility. This is an indication that growth capacity under different environmental conditions should be taken into account when families are selected for seedling production.

A thorough examination of root system morphology for the first year of growth (length, diameter, surface area, …) is yet to be completed. The entire study will be repeated at the end of the second growing season.

Root Form of Jack Pine Seedlings Grown in a Variety of Containers

S.J. Colombo[1], K.A. Chapman[2]

[1]Ontario Forest Research Institute, c/o Centre for Northern Forest Ecosystem Research, 955 Oliver Road, Thunder Bay, ON P7B 5E1
[2]Ontario Forest Research Institute. Current address: Great Lakes Forest Centre, 119 Queen Street East, Sault Ste. Marie, ON P6A 2E5

Stability of trees grown in containers is an economic and ecologic concern as instability owing to root system form can make trees susceptible to stem defects. Jack pine grown in Rigi-pots and Ventblocks had many vertically oriented roots after the first season, and fewer lateral roots distributed evenly around the plug after planting (Fig. 1, Table 1). Seedlings grown in Jiffy pellets, Starpots, and Copperblocks had high proportions of horizontal roots at lifting and more evenly-distributed roots after the second season, which should lead to greater stability. Asymmetric distribution of first-order lateral roots resulted from off-centre placement of seed in the cavity, either from sowing or from seed shifting to the container edge during handling or by irrigation water before germination. It is feasible to cull seedlings with asymmetric root forms, as the off-centre stem is easily seen. Pruning Jiffy seedlings substantially reduced root mass and sometimes ripped or scarred the taproot, but this may be minimized by earlier pruning. Although root mass of Jiffy seedlings was lower than other containers at lifting, they increased the most after planting, ending within the range of those grown in other containers.

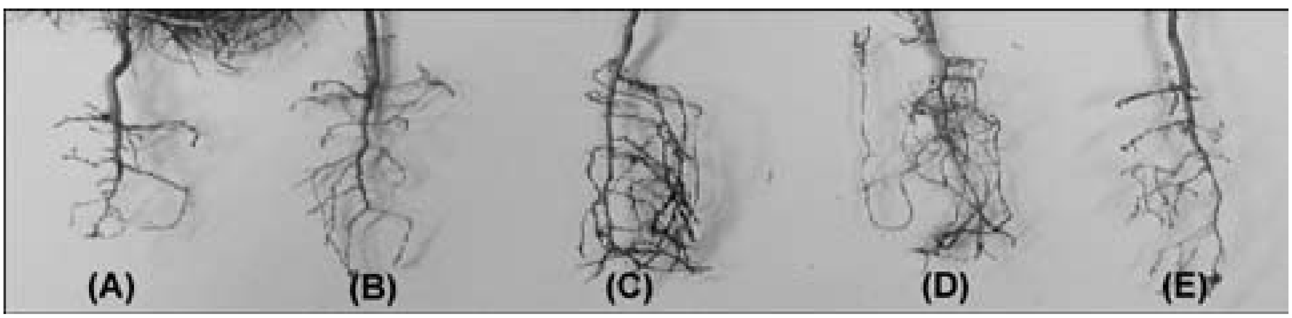

***Figure 1**. Root forms observed at time of lifting. (A) ladder (soft-walled type), (B) ladder (hard-walled type), (C) sinker, (D) elevator and (E) asymmetric.*

***Table 1.** Root forms produced in seven container types. The three Jiffy pellet types each had two pruning dates, 'E' early (September) and 'L' late (November).*

Container type	Root form (% of seedlings)				
	Ladder	Sinker	Elevator	Truncated	Asymmetric
Jiffy E28-140	70	0	0	15	15
Jiffy L28-140	95	0	0	0	5
Jiffy E28-165	80	0	0	5	15
Jiffy L28-165	95	0	0	5	0
Jiffy E30-140	85	0	0	15	0
Jiffy L30-140	95	0	0	0	5
Rigi-pot	0	30	65	0	0
Starpot	95	0	0	0	5
Copperblock	67	0	0	13	20
Ventblock®	0	40	45	5	5

Nursery Technology Cooperative: 20-Year Evolution of a Research Program to Optimize Seedling Quality and Reforestation Success in the Pacific Northwest

D.L. Haase, R. Rose

Department of Forest Science, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331

Since its inception in 1982, the Nursery Technology Cooperative (NTC) has conducted applied nursery and reforestation research in the Pacific Northwest. The NTC consists of members from state, private, and federal forestry sectors. Membership has grown significantly over time as we have gained national recognition for our innovative and valuable contributions to nursery culture and forest regeneration practices. With an integrated program of coordinated scientific studies, information exchange, and technical support, the NTC is instrumental in meeting both immediate and long-range goals to develop techniques that maximize seedling quality and outplanting performance. Having members from both nursery and field operations provides a broad spectrum of input and allows us to incorporate both pre-outplant and post-outplant components into our projects. Periodic meetings, reports, newsletters, conferences, and refereed publications ensure that the data generated through NTC projects is rapidly disseminated to the reforestation community.

NTC projects investigate numerous elements of nursery and reforestation practices. Each project is designed to statistically quantify the issue in question. These have included nutrition and fertilization, integrated pest management, morphological quality, physiological processes, site preparation, nursery culture, restoration ecology, environmental conditions, stocktype and species comparisons, new product evaluations, storage and handling procedures, etc. Seedlings are measured for variables such as chlorophyll fluorescence, starch, foliar nutrients, growth and survival. The breadth and depth of NTC projects has contributed significantly to improved seedling quality and performance from the nursery to the field.

This presentation will focus on the structure of the co-op and its research priorities along with highlights of project results which have influenced seedling quality, nursery production, and reforestation success.

Maximizing Nutrient Storage in Nursery Culture to Promote Retranslocation and Growth of Outplanted Seedlings

K.F. Salifu, D.F. Jacobs, Z. Birge

Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907

Introduction

Newly outplanted seedlings depend highly on remobilization of internal nutrient reserves to support new growth because initial poor root soil contact, root restriction and slow development limit uptake from the soil (Burdett et al. 1984, Burdett 1990, Nambiar and Sands 1993). Although exponential nutrient loading promotes nutrient storage and remobilization to facilitate early establishment success in tree seedlings, mechanisms to explain an increased or decreased retranslocation with pre-plant nutrient reserves (van den Driessche 1991, Millard and Proe 1993) has yet to be elucidated. Improved field response of exponentially loaded over non-loaded seedlings on a variety of site types (Timmer and Munson 1991, Quoreshi and Timmer 2000) and on simulated soil fertility gradients (Xu and Timmer 1999, Salifu and Timmer 2001) have generated interest in exponential nutrient loading, but more insight into optimizing fertilizer prescription for this practice are needed to refine intensive tree seedling culture. These concepts have been successfully examined in conifers (Quoreshi and Timmer 2000, Salifu and Timmer 2003b) and in tropical species (Imo and Timmer 1992, Xu and Timmer 1999). However, little is known about how exponential nutrient loading might influence nutrient storage and remobilization processes in deciduous tree species. Exponential nutrient loading may benefit deciduous species since significant quantities of nutrients are not lost from foliage but are resorbed into root and shoot tissues (Aerts 1996, Tagliavini et al. 1998, Duchesne et al. 2001, Yuan et al. 2005) prior to senescence. For example, foliar nutrient resorption can account for about 50-90% of the nutrients in stem and root tissues (Aerts 1996, Tagliavini et al. 1998, Yuan et al. 2005). Consequently, roots and shoots serve as important sinks for N storage during senescence and sources of N for new growth in spring (Dickson 1989, Tagliavini et al. 1998).

A proposed model of exponential nutrient loading (Fig. 1) suggests that plant growth and nutritional response to increased fertilization conforms to a curvilinear pattern depicting phases of nutritional states in plants ranging from deficiency to toxicity which aid in rationalizing fertilizer prescriptions to improve nutrient diagnosis (Timmer 1997).

Traditionally based on biomass alone (van den Driessche 1974, Grossnickle 2000), this model has been configured to include plant nutrient status as well in order to improve diagnostic capacity. Its application has been demonstrated in black spruce (*Picea mariana* [Mill.] BSP) container production systems (Salifu and Timmer 2003b), but has yet to be extended to deciduous species. We tested application of this model across a broad spectrum of soil fertility ranging from nutrient deficiency to toxicity in container and bareroot production systems to quantify optimum fertilizer prescriptions for northern red oak (*Quercus rubra* L) seedlings. We hypothesized that (1) plant growth and nutritional response will conform to a curvilinear pattern

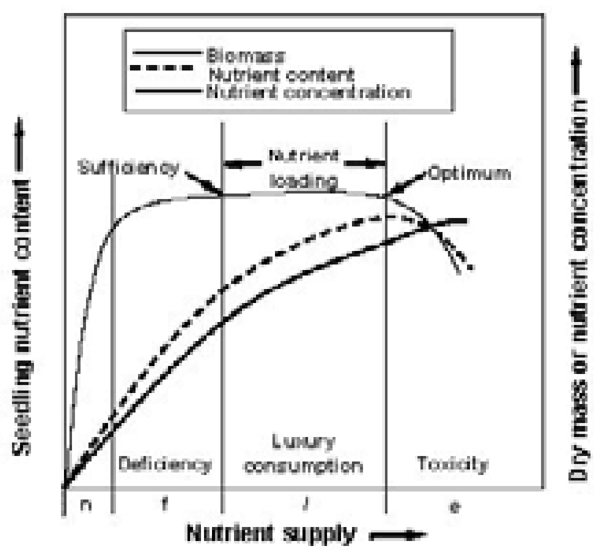

Figure. 1. *Plant growth and nutrient status conforms to a curvilinear pattern with increased fertilization. Fertilizer f supplements native fertility (n) to maximize growth at sufficiency. Extra high fertilization or nutrient loading (l) induces luxury uptake in excess of growth demand, which are stored as reserves for later utilization. Excess fertilization (e) may induce toxicity signified by diminished plant growth and N content at increasing tissue N concentration (Adapted from Salifu and Timmer 2003b).*

with increased fertility consistent with trends depicted in the proposed model, (2) exponential nutrient loading will induce luxury uptake to increase internal nutrient reserves in cultured plants, and (3) higher pre-plant nutrient reserves and increased sink strength will explain greater retranslocation in outplanted seedlings. We focused on N and P in the present study because these elements most commonly limit plant production (Chapin 1980), and because their important role in controlling plant growth and metabolism is well understood (Epstein 1972).

Materials and Methods

Greenhouse trials

Black spruce seedlings were reared for 18 weeks in styro-block trays filled with uniformly screened peat and vermiculite (3:1 v/v) mixture at the University of Toronto greenhouses using the same seed source and peat substrate. Each styro-block tray, representing an experimental unit contained 40 mL cavities (209 cavities per tray). Seasonal dose rates (Fig. 2) ranged from 0-80 mg N plant^{-1}, applied conventionally (10 mg seedling^{-1}) or exponentially (30-80 mg plant^{-1}). These fertility treatments were randomly assigned to trays and arranged in a randomized complete block design (RCBD) with four replications, which were then placed on raised benches in a heated and ventilated greenhouse at temperature 18-25 ^{o}C, humidity 65-85%, and an extended 20 h photoperiod supplemented with sodium vapor lamps at a light intensity of 250 µmol m^{-2} s^{-1}. A commercial water-soluble fertilizer 20N-20P_2O_5-20K_2O plus microelements (Plant Products Co Ltd., Brampton, Ont.) was applied in solution. Further details can be found in Salifu and Timmer (2003b).

Northern red oak container plants were germinated using an equivalent seed source and seedlings grown for 16 wk in 2.8 l Treepots™ (Stuewe and Sons, Corvallis, OR, USA). An experimental unit was represented by 18 pots. Seasonal dose rates ranged from 0-50 mg N plant^{-1}, applied conventionally (25 mg N plant^{-1}) or exponentially (25-150 mg N plant^{-1}). The conventional treatment was chosen to represent the average rate generally used for production of container red oak seedlings (Beckjord et al. 1980, Struve 1995). The eight fertilizer treatments (Fig. 2 and 3, left) were installed as a RCBD and arranged on a greenhouse bench (mean day/night temperature of 24/20 °C) under ambient light conditions in the Department of Horticulture and Landscape Architecture Plant Growth Facility at Purdue University, West Lafayette IN, USA (40°25'N, 86°55'W). A commercial water-soluble fertilizer (Miracle Gro® Excel® 15N-5P_2O_5-15K_2O plus other macro- and micro-elements [The Scotts Company, Marysville, OH, USA]) was applied in solution. For all container trials, each pot was irrigated to container capacity determined gravimetrically at planting (White and Mastalerz 1966). Supplemental irrigation was supplied twice weekly by periodic weighing of pots to determine amount of water to be added to bring pots back to container capacity.

Bareroot northern red oak seedlings were grown under operational conditions (Jacobs 2003) for 18 wk at the Vallonia State Nursery (38°85'N, 86°10'W) south of Indianapolis, Indiana, USA (Jacobs 2003). Seeds were mechanically sown in the fall of 2003 to obtain about 54 seedlings m^{-2} after germination. Fertilizer rates ranged from 0-3.2 g N plant^{-1} season^{-1}. The ten treatments (Fig. 3, right) were laid-out as a RCBD with 4 replicates. The standard practice at this nursery is to supply a total of 0.84 g N seedling^{-1}season^{-1} at seven equal amounts (bi-weekly), which was chosen as the conventional (C) treatment in this study. Ammonium nitrate (34-0-0) in crystal form was broadcast manually on treatment plots. For all trials, weekly applications for exponential treatments followed exponential functions (Timmer and Aidelbaum 1996, Timmer 1997) designed to synchronize fertilizer supply with exponential growth and nutrient uptake of seedlings (Ingestad and Lund 1986, Ingestad and Agren1995). Seedlings were harvested at the end of nursery culture and processed according to standard protocols detailed in Salifu and Timmer (2003b).

Outplanting trials

Nursery reared black spruce seedlings were outplanted in the field or grown under controlled greenhouse environments to examine importance of prior nursery culture in promoting retanslocation and seedling growth. Transplanted seedlings received either 0 [control] or N ranging from 200-400 kg N ha^{-1} simulating a range of soil fertility from poor to rich (Salifu and Timmer 2001, 2003a). N was supplied as 20N-20P_2O_5-20K_2O plus micro-elements (Plant Products Co Ltd., Brampton Ont.) to field seedlings. For the greenhouse trial, N was supplied with the irrigation as $^{15}NH_4$ $^{15}NO_3$ enriched to 5 at. % ^{15}N (34-0-0, ISOTEC Inc. USA) in sand culture. Thus, current uptake was labeled with ^{15}N which could be distinguished from retranslocation (unlabeled N) in new growth. Chelated (EDTA 42% and DTPA 13%) micronutrients were applied at the rate of 0.03 g L^{-1} and phosphorus (P) supplemented by KH_2 P_2O_5 (0-52-34, Plant Products Co Ltd., Brampton Ont.) at the rate of 60 kg P ha^{-1} to avert deficiency of other nutrients. Net N retranslocation was estimated for field seedlings as detailed in Salifu and Timmer (2001). The greenhouse experiment was conducted to directly quantify retranslocation to confirm higher retranslocation by loaded seedlings under field conditions (Salifu and Timmer 2003a). Further details on experimental protocols and statistical procedures can be found in Salifu and Timmer (2001, 2003a, 2003b).

Results and Discussion

Greenhouse response

Plant growth and P response increased with nutrient supply in the deficiency range, remained stable during luxury uptake, but declined at higher N addition (Fig. 2), which appears consistent with trends shown in the conceptual model (Fig. 1) for container black spruce. Similar trends were observed with N for black spruce (Salifu and Timmer 2003b) and for container (Fig. 3, left) and bareroot (Fig. 3, right) red oak seedlings. Fertilization increased (*p* = 0.0001) red oak seedling dry mass by 113-260% in bareroot culture and by 34-65% in containers.

Seedling dry mass production was maximized at sufficiency, which corresponded to 30 and 25 mg N plant^{-1} season^{-1} for container black spruce and red oak, respectively, and 0.84 g N plant^{-1} season^{-1} for bareroot red oak seedlings. Red oak seedling N content increased (*p* = 0.0001) by 184-397% in bareroot culture and by 14-77% in containers in response to increased N supply. Nutrient loading induced luxury nutrient uptake, which increased N and P storage by 175 and 48% in black spruce, 27 and 45% for container red oak and 39 and 32% for bareroot red oak, demonstrating capacity of this practice to build internal nutrient reserves in plants. Optimum loading

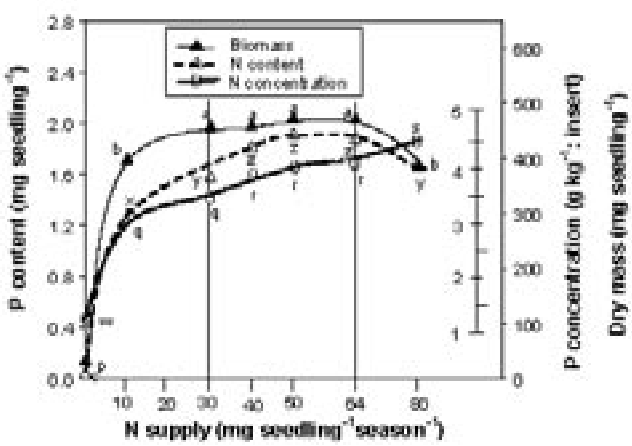

Figure. 2. Growth and P response to increasing nutrient supply for black spruce seedlings grown for 18 wk in a greenhouse environment. Points marked with different letters within each parameter differ significantly according to Tukey's highly significant difference test α = 0.05.

occurred at 64 and 100 mg N plant^{-1} season^{-1} for container black spruce (Fig. 2) and red oak (Fig. 3, left), respectively, and at 1.62 plant^{-1} season^{-1} for bareroot red oak seedlings (Fig. 3, right). Toxicity associated with reduced growth and N content at higher fertility (Haynes 1986, Salifu and Timmer 2003b) occurred beyond 80 mg N seedling^{-1} season^{-1} dose rate for container black spruce, and beyond 1.62 g N plant^{-1} season^{-1} for bareroot red oak (Fig. 3, right).

Nutrient toxicity decreased growth and N content by 69 and 44%, respectively, for bareroot red oak and by 81 and 56%, respectively, for container red oak. Toxicity reduced growth (17%) and P content (13%) in black spruce seedlings. Exponential delivery schedules (0.84E or 25E) were more effective in promoting nutrient acquisition, which increased N uptake by 16% for container (Fig. 3, left) and bareroot (Fig. 3, right) red oak seedlings than when applied conventionally (0.84C or 25C). These results are in general agreement with published information (Xu and Timmer 1999; Salifu and Timmer 2003b). The general similarity of experimental data with trends depicted in the conceptual model demonstrate model suitability for rationalizing and quantifying optimum fertilizer prescriptions for raising high quality forest tree seedlings for field planting. Induced luxury uptake in red oak seedlings should not be lost through leaf fall because of resorption. This important nutrient conservation mechanism by deciduous tree species can recover about 50-90% of the nutrients from senescing leaves, which are conserved as stored reserves in stem and root tissues for later utilization (Aerts 1996, Yuan et al. 2005). Thus, outplanted red oak seedlings with higher internal nutrient reserves as conditioned by loading may readily draw on these stored resources for new growth (Aerts 1996, Tagliavini et al 1998, Yuan et al. 2005) to facilitate early establishment success.

Field response

Although similar in dry mass at outplanting, loaded black spruce seedlings contained 22 mg N compared with 8 mg N in non-loaded plants. Nutrient loading increased growth on the poor and rich soils by 100 and 35%, respectively, in the field (Fig. 4, top left) and by 100 and 23%, respectively, in the greenhouse (Fig. 4, top right) when compared with non-loaded plants. Nutrient loading also increased net N retranslocation 7 and 4 fold on the poor and rich soils, respectively (Fig. 4, bottom left). Increased sink strength (Fig. 4, top) and higher pre-plant nutrient reserves (22 vs. 8 mg N) explained greater retranslocation in loaded seedlings as previously noted elsewhere (Salifu and Timmer 2001, Nambiar and Fife 1991). It was difficulty to discriminate between tree and soil derived N in plant

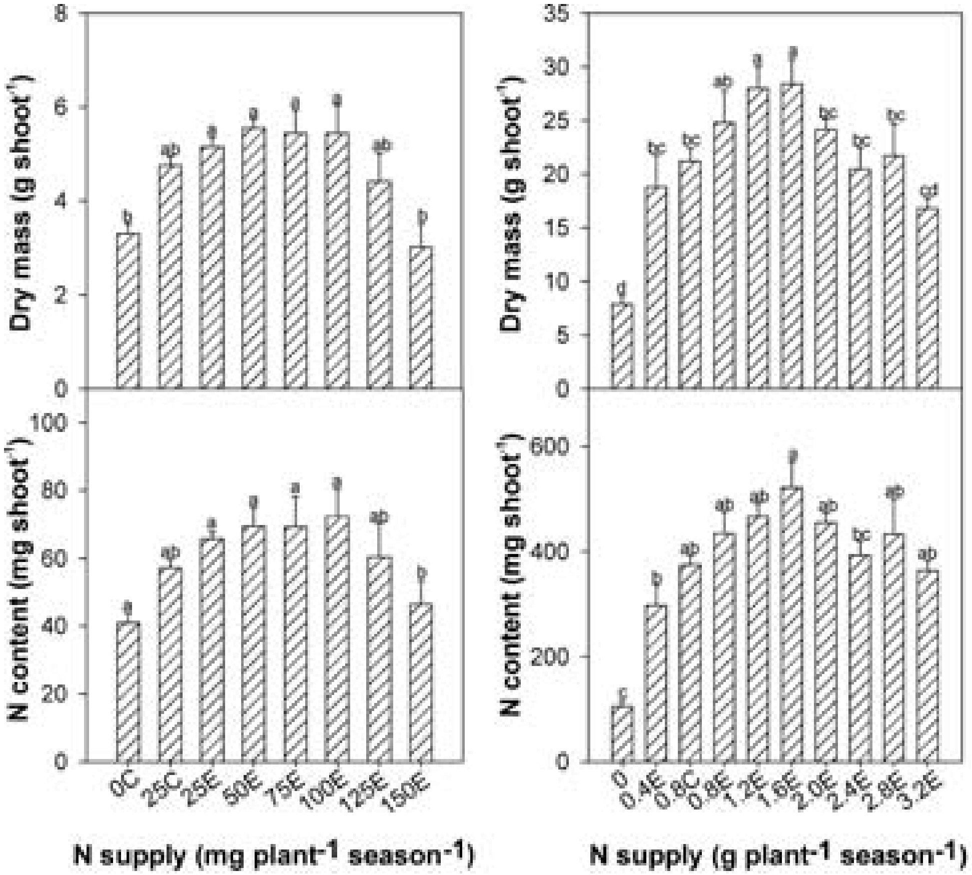

Fig. 3. *G*
Bars marked with different letters differ significantly according to Tukey's highly significant difference test α = 0.05.

tissues using net estimates, which resulted in erroneous conclusions that rates of retranslocation diminishes with soil fertility (Salifu and Timmer 2003a). Consequently, the stable isotopic technique was used to discriminate between tree (unlabeled N) and soil (labeled N) derived N in new growth, which addressed limitations associated with the net approach (Salifu and Timmer 2003a). Direct retranslocation estimates (unlabeled N) in new growth (Fig. 4, bottom right) confirmed improved retranslocation after nutrient loading previously observed with net estimates (Salifu and Timmer 2001).

Nutrient loading also promoted nutrient acquisition. For example, non-loaded seedlings accumulated 17 and 34 mg N in new growth on the poor and rich soils, respectively, compared with 36 and 74 mg N for loaded plants under field conditions. For the greenhouse study, similar comparisons results in 3 and 19 mg N acquired by non-loaded compared with 8 and 28 by loaded seedlings on the poor and rich soils, respectively. Internal cycling accounted for 6% of the N in new growth of non-loaded plants and 20% of the N demand for new growth of loaded seedlings in the field study. Similarly, retranslocation met 16 and 32% of the N demand for new growth of non-loaded and loaded plants, respectively, in the greenhouse trial. However, when no N was supplied on the poor soil, plants relied entirely on internal cycling to meet seasonal growth demand (100%). This suggests plants can rely entirely on retranslocation for growth, a capacity enhanced by nutrient loading. Other studies have also shown that internal nutrient cycling can meet up to 40-60% of the annual N demand for new growth in plants (Miller 1984, Lim and Cousens 1986, Cheng and Fuchigami 2002). The loading response persist in time as exemplified by 62% increase in dry mass by day 120 (Salifu and Timmer 2001) and by 50% four years after outplanting (Malik 1998). Study results suggest exponential nutrient loading could be more successful in promoting early seedling establishment success than conventional silvicultural methods such as broadcast fertilization at outplanting (Burdett et al. 1984), which may increase brush competition (van den Driessche 1991, Staples et al. 1999).

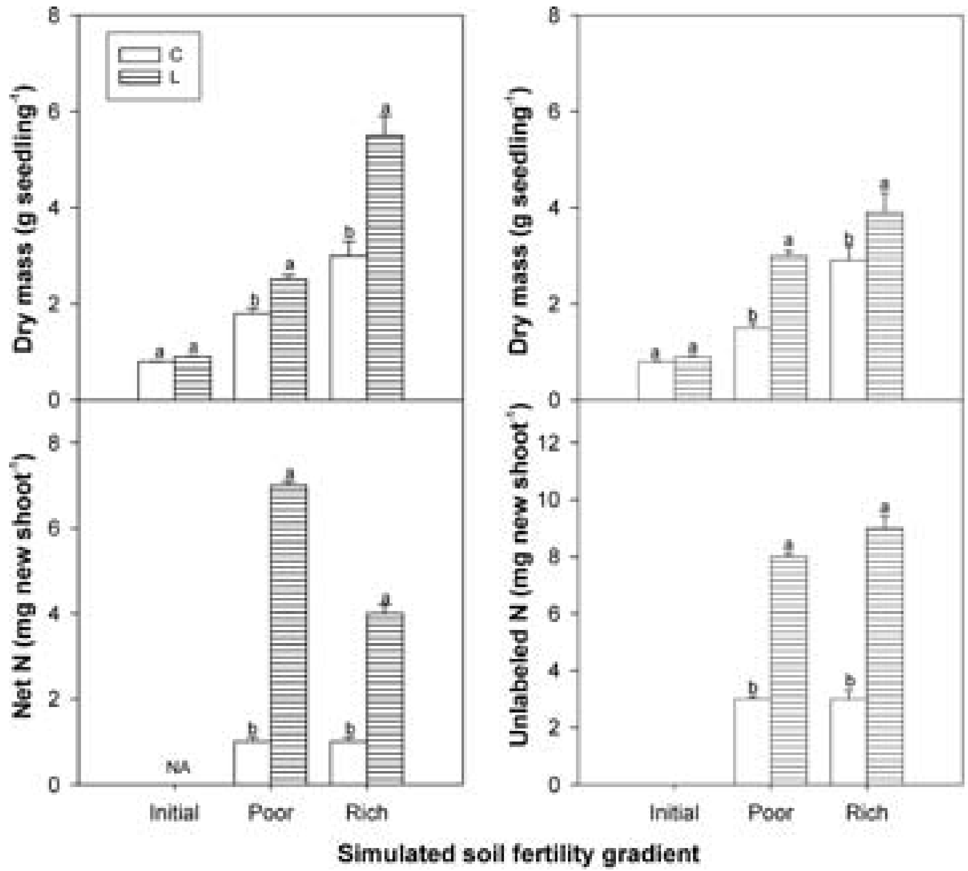

Fig. 4.
seedlings planted on simulated poor and rich soils in the field (left) or under greenhouse environments (right) for 120 days. Paired bars marked with different letters differ significantly according to Tukey's highly significant difference test α = 0.05.

Conclusions

For each species and growing system, plant growth and nutritional response to increased fertilization appeared consistent with trends shown in the conceptual model. These findings demonstrate suitability of the exponential nutrient loading model for rationalizing and quantifying optimum fertilizer prescriptions for forest tree seedlings. Black spruce seedling biomass was maximized at sufficiency (30 mg N plant^{-1} season^{-1}) while N and P content of tissues peaked at the optimum loading rate (64 mg N plant^{-1} season^{-1}). Nutrient loading induced luxury uptake that raised plant N content (175%) and P content (48%) in black spruce seedlings. Optimum plant dry mass production and nutrient toxicity for red oak seedlings occurred at 100 and 125 mg N plant^{-1} season^{-1}, respectively, in containers and at 1.6 and 2.0 g N plant^{-1} season^{-1}, respectively, for bareroot culture. Higher pre-plant N reserves increase net retranslocation 4-7 fold in loaded black spruce relative to conventional plants. Direct retranslocation estimates using tracers in a controlled greenhouse confirmed nutrient loading promotes retranslocation as observed with net estimates under field conditions. Isotopic determinations also addressed limitations associated with net estimates (Salifu and Timmer 2003a). Higher pre-plant nutrient reserves and increased sink strength explained greater retranslocation in loaded seedlings. Exponential nutrient loading demonstrates potential to improve plant nutrient diagnosis and can be applied to other species or cultural systems. This new approach will help refine and optimize fertilizer recommendations to produce high quality seedlings for field planting.

Acknowledgements

This research was financially supported in part by a Van Eck Post-Doctoral Research Scholarship, USDA Forest Service State and Private Forestry and Purdue University. Additional financial support from the Natural Sciences and Engineering Research Council (NSERC) of Canada is acknowledged. B. Wilson, J. Mckenna, R. Goodman and M. Selig assisted with the greenhouse work.

References

Aerts, R. 1996. Nutrient resorption from senescing leaves of perennials: are there general patterns? J. Ecol. 84: 597-608.

Beckjord, P.R., Adams, R.E., and Smith, D.W. 1980. Effects of nitrogen fertilization on growth and ectomycorrhizal formation of red oak. For. Sci. 16: 529-536.

Burdett, A.N. 1990. Physiological process in plantation establishment and development of specifications for forest planting stock. Can. J. For. Res. 20: 415-427.

Burdett, A.N., Herring, I.J., and Thompson, C.F. 1984. Early growth of planted spruce. Can. J. For. Res. 14: 644-651.

Chapin, F.S., III. 1980. The mineral nutrition of wild plants. Annu. Rev. Ecol. Syst. 11: 233-260.

Cheng, L., and Fuchigami, L. 2002. Growth of young apple trees in relation to reserve nitrogen and carbohydrates. Tree Physiol. 22: 1297-1303.

Dickson, R.E. 1989. Carbon and nitrogen allocation in trees. Ann. For. Sci. 46: 631-647.

Duchesne, L., Ouimrt, R., Camire, C., and Houle, D. 2001. Seasonal nutrient transfers by foliar resorption, leaching, and litter fall in a northern hardwood forest at Lake Clair Watershed, Quebec, Canada. Can. J. For. Res. 31: 333-344.

Esptein, E. 1972. Mineral nutrition of plants: principles and perspectives. John Willey and Sons Inc., NY.

Grossnickle, S.C. 2000. Ecophysiology of Northern Spruce Species: the performance of planted seedlings. NRC Res. Press. Ottawa, Ont. Canada.

Haynes, R.J. 1986. Uptake and assimilation of mineral nitrogen by plants. *In* Mineral nitrogen in the plant soil system. *Edited by* R. J. Haynes. Academic Press Inc. Orlando Florida, USA. pp 303-378.

Imo, M., and Timmer, V.R. 1992. Nitrogen uptake of Mesquite seedlings at conventional and exponential fertilization schedules. Soil Sci. Soc. Am. J. 56: 927-934.

Ingestad, T., and Agren, G.I. 1995. Plant nutrition and growth: basic principles. Plant and Soil 168-169: 15-20.

Ingestad, T., and Lund, A.B. 1986. Theory and techniques for steady state mineral nutrition and growth of plants, Scan. J. For. Res. 1: 439-453.

Jacobs, D.F. 2003. Nursery production of hardwood seedlings. Purdue University Cooperative Extension Service, Department of Forestry and Natural Resources, FNR-212. 8 p.

Lim, M.T., and Cousens, J.E. 1986. The internal transfer of nutrients in Scot pine stand. I. Biomass components, current growth and their nutrient contents. Forestry 59: 1-16.

Malik, V. 1998. Growth and nutrient dynamics of nutrient-loaded black spruce seedlings in relation to neighbouring vegetation on boreal mixedwood sites. P.hD. Thesis. University of Toronto, Canada. 135 p.

Millard, P., and Proe, M.F. 1993. Nitrogen uptake, partitioning and internal cycling in *Picea sitchensis* (Bong.) Carr. as influenced by nitrogen supply. New Phytol. 125: 113-119.

Miller, H.G. 1984. Dynamics of nutrient cycling in plantation ecosystems. *In* Nutrition of Plantation Forests. *Edited by* G.D. Bowen and E.K.S. Nambiar. Academic Press London. pp 53-78.

Nambiar, E.K.S., and Fife, D.N. 1991. Nutrient retranslocation in temperate conifers. Tree Physiol. 9: 185-207.

Nambiar, E.K.S., and Sands, R. 1993. Competition for water and nutrients in forests. Can. J. For. Res. 23: 1955-1968.

Quoreshi, M., and Timmer, V.R. 2000. Early outplanting performance of nutrient-loaded containerized black spruce seedlings inoculated with *Laccaria bicolor*: a bioassay study. Can. J. For. Res. 30: 744-752.

Salifu, K.F., and Timmer, V.R. 2001. Nutrient retranslocation response of *Picea mariana* seedlings to nitrogen supply. Soil Sci. Soc. Am. J. 65: 905-913.

Salifu, K.F., and Timmer, V.R. 2003a. Nitrogen retranslocation response of young *Picea mariana* to nitrogen-15 supply. Soil Sci. Soc. Am. J. 67: 309-317.

Salifu, K.F., and Timmer, V.R. 2003b. Optimizing nitrogen loading of *Picea mariana* seedlings during nursery culture. Can. J. For. Res. 33: 1287-1294.

Staples, T.E., Van Rees, K.C.J., and Van Kessel, C. 1999. Nitrogen competition using ^{15}N between early successional plants and planted white spruce seedlings. Can. J. For. Res. 29: 1282-1289.

Struve D.K. 1995. Nitrogen. phosphorus and potassium recovery of container-grown red oak and blackgum seedlings under different fertilizer application methods. J. Env. Hort. 13: 169-175.

Tagliavini, M., Millard, P., and Quartieri, M. 1998. Storage of foliar-absorbed nitrogen and remobilization for spring growth in young nectarine (*Prunus persica* var. *nectarina*) trees. Tree Physiol. 18: 203-207.

Timmer, V.R. 1997. Exponential nutrient loading: a new fertilization technique to improve seedling performance on competitive sites. New For. 13: 279-299.

Timmer, V.R., and Aidelbaum, A.S. 1996. Manual for exponential nutrient loading of seedlings to improve outplanting performance on competitive forest sites. NODA/NFP Tech. Rep. TR25. Nat. Res. Canada. Canadian Forest Service, Sault Ste Marie, ON, Canada.

Timmer, V.R., and Munson, A.D. 1991. Site-specific growth and nutrient uptake of planted *Picea mariana* in the Ontario Clay Belt. IV. Nitrogen loading response. Can. J. For. .Res. 21: 1058-1065.

Van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. The Bot. Rev. 40: 347-394.

van den Driessche, R. 1991. Effects of nutrients on stock performance in the forest. *In* Mineral nutrition of conifer seedlings. *Edited by* R. van den Driessche. CRC Press, Boca Raton, Ann Arbor, Boston. pp 229-260.

White, J.W., and Mastalerz, J.W. 1966. Soil moisture as related to container capacity. Am. Soc. Hort. Sci. 89: 758-765.

Xu, X.J., and Timmer, V.R. 1999. Growth and nitrogen nutrition of Chinese fir seedlings exposed to nutrient loading and fertilization. Plant and Soil 216: 83-91.

Yuan, Z.Y., Li, L.H., Han, X.G., Huang, J.H., Jiang, G.M., and Wan, S.Q. 2005. Soil characteristics and nitrogen resorption in *Stipa krylovii* native to northern China. Plant and Soil 273: 257-268.

A Root-Bound Index for Container-Grown Pines

D.B. South[1], R.G. Mitchell[2]

[1]School of Forestry and Wildlife Science, Auburn University, AL 36830
[2]Sappi Forests Research, P.O. Box 372, Ngodwana, Sout Africa1209

Introduction

Root-bound seedlings have been a concern of nursery managers for more than four decades. When container-grown seedlings are root-bound (or pot-bound), survival, growth or stability might be reduced after outplanting (van Eerdin and Kinghorn 1978; Hulten 1982). In some cases, root-binding might not affect survival or early growth but it might adversely affect stability (Lindgren and Orlander 1976). Initially, the concern over root-binding was concentrated on root-spiraling which could result in "root-strangulation" and early toppling.

One source defines root-bound as: adj: of a potted plant; grown too large for its container resulting in matting or tangling of the roots. Our definition is broader and defines root-bound as: a plant grown too large for its container resulting in a reduction in field performance or root growth potential (RGP). The dictionary definition focuses on the appearance of the roots while our definition concentrates on plant performance. We contend field performance of pines will be reduced before the roots become tangled or matted and that nursery managers need a method to estimate when this begins to occur.

Only a few indexes have been proposed to evaluate root-binding in the nursery. Hiatt and Tinus (1974) proposed a "strangle-angle" index to evaluate the degree of root spiraling in container-grown seedlings. Due to concern over root spiraling, changes were made in container design and now most solid plastic containers have ridges which greatly reduce the amount of root spiral. For this reason, the "strangle-angle" index is rarely used as a predictor of seedling quality. However, there still is a need for a simple, easy-to-use "root-bound index" (RBI). A RBI would be useful when nursery managers and regeneration foresters evaluate stock quality prior to outplanting.

A RBI can be based either on a subjective score (based on the appearance of the root-plug) or on an objective value (such as root mass). In addition, the RBI could be determined with destructive or non-destructive measures. We wanted to develop a RBI that was both objective and non-destructive, therefore, root-collar diameter (RCD) was selected as the seedling attribute to measure (since it is often related to root mass). We calculated RBI as a ratio of either container diameter or volume. The objective of this study was to develop a RBI that would help nursery managers estimate the percentage of root-bound seedlings prior to shipping. We wanted to test the hypothesis that: (1) RBI was related to outplanting survival; and (2) independent of RCD, outplanting survival is related to the length of time stock is kept in the hardening phase.

Materials and Methods

Four separate studies were used to test the effects of RBI on survival in this paper. The first study was conducted in the United States on *Pinus palustris* (seedlings) whilst the other three studies were conducted in South Africa on *P. patula* (seedlings and cuttings) and the *P. elliottii* x *P. caribaea* hybrid (cuttings).

P. palustris

Seedlings from a southern Mississippi seed source were grown in six container types at the USDA Southern Forest Experiment Station research nursery in Pineville, Louisiana (31º 19' N, 92º 26' W). Container types included styroblock® (Beaver Plastics, 12150 - 160 Street, Edmonton, Alberta, Canada T5V 1H), Multipot® (Stuewe & Sons, Inc. 2290 SE Kiger Island Drive, Corvallis, Oregon 97333-9425) , Hiko® (BBC AB, Profilgatan 15, SE-261 35, Landskrona, Sweden) and Jiffy® (Jiffy Products of America, Inc., 600 Industrial Pkwy, Norwalk, Ohio 44857). The styroblock® tray was model 112/95 (112 cells per block and 95 cc/cell) and the cell walls were treated with SpinOut® (Griffin LLC, P.O. Box 847, Valdosta, GA 31603-1847). Although two types of Multipot® trays were used (M3 and M6), the cavity size was the same for both containers (Table 1). The difference was in number of cavities per m^2 (441 for M3 vs. 581 for M6). The Hiko® tray (H) had the widest cell diameter of any container type. The two Jiffy® Pellets included short (JPs) and standard (JP) versions.

Containers were filled with a peat:vermiculite (V:V=1:1) medium that contained a slow-release fertilizer (Osmocote® 18-6-12; Scotts Company, Marysville, OH) at a rate of 3.56 kg/m^3. Seeds were sown on April 24, 2000 and seedlings were grown using procedures described by Barnett and McGilvary (1997). The containers were covered with a 10% shade cloth until seed germination was complete. About 3 weeks after sowing, the shade cloth was removed and seedlings were exposed to full sunlight. All of the containers received thiophanate-methyl and metalaxyl fungicides on an approximate 2-week interval during the growing phase. Times of fungicide application varied due to rainfall that delayed treatment. Irrigation was applied during dry periods

***Table 1.** The sizes and shapes of containers used to raise pines.Figure 1. The relationship between root-collar diameter, root bound index (diameter or volume) and seedling survival of P. palustris seedlings in Alabama. Numbers above each mean represent the number of seedlings in that class.*

Container type	Shape of top	Cavity volume (ml)	Cavity diameter (top section) (mm)	Density (#/m^3)
Unigro 128	Square	61	32	587
Unigro 98 side slits	Square	95	37	450
Unigro 98 solid	Square	95	37	450
Sappi 49	Round	80	39	423
Styroblock + Spinout	Round	93	35	530
Multipot-441	Round	98	38	441
Multipot-581	Round	98	38	581
Hico – V93	Round	93	41	526
Jiffy-pot-super	Round	120	38	588
Jiffy-pot-short	Round	60	33	735

to prevent medium from drying out. Seedlings were given additional applications of a water soluble fertilizer (Peters Professional 20-19-18 - Water Soluble Fertilizer, Scotts Company, Marysville, OH) late in the growing period to green-up the seedlings. Seedlings were extracted from containers on 6th November 2000 and culls and diseased seedlings were removed. The plantable seedlings were packed in boxes and placed in a cooler at 2^{o}C.

P. elliottii x P. caribaea

The hybrid cuttings were set in four tray types (three Unigro containers plus the Sappi container) (Table 1). The Unigro 98 side-slit tray was the same dimension as the Unigro 98 solid tray but contained slits in the side walls to air prune lateral roots. All Unigro and Sappi container types contained internal ribs or ridges to prevent root spiralling. Cuttings were set on three different occasions (24/03/2000, 27/07/2000 and 28/09/2000) in order to produce plants of different ages at planting (13, 8 and 6 months). At each setting, cuttings were harvested from the same donor plants from four families. The cuttings were harvested from hedges that were growing in 10-litre black potting bags. Once set, the cuttings were left to root for a period of 3 months in a greenhouse where they received intermittent mist, before being placed on a raised bed underneath 30% shade cloth. Plants received water and fertilizer for the remainder of the nursery period. This trial was planted on the 17/05/2001 to determine the effect of raising cuttings in four different container types available for nursery use in South Africa.

P. patula

Cuttings were rooted from two elite families for this trial and seedlings were obtained from a mix of several elite families from a breeding seed orchard. The cuttings were raised in the nursery for a period of 9 months while seedlings were raised for a period of 7 months. These raising periods were considered optimal for each plant type and plants did not appear root-bound at planting. The *P. patula* cuttings were produced in the Unigro 98 solid tray whilst the seedlings were raised in the Sappi 49 tray.

The cuttings and seedlings were planted in separate but adjacent trials. The site chosen for the two trials can be described as cool temperate and suited to growing *P. patula*. Compared with other lower altitude *P. patula* sites, this site is expected to receive frost during the winter months and may experience insufficient rainfall in some years which can result in environmental stresses that can lead to increased field mortality. Cuttings were planted on the 6/06/2003 and seedlings were planted on the 8/06/2003. These two trials form part of a series of four trials. As with the case of the *P. elliottii x P. caribaea* trial, these trials were planted to test experimental factors not reported on in this paper but are being reported elsewhere (Mitchell and Jones 2005).

RGP trial

A RGP study was initiated in January in a greenhouse at Auburn University's Pesticide Research facility. Five aquariums (37.8 liters per aquarium) equipped with aerators were double wrapped with black plastic and filled with tap-water. Plywood tops with thirty drilled holes about 2.5 cm in diameter were placed on the top of the aquariums. New, white roots were removed from the bareroot seedlings and from the outer edges of the root plugs for container-grown seedlings. Initial RCD was measured and recorded for each seedling. Each aquarium served as a replication and each contained four seedlings from each of the seven treatments (28 seedlings per aquarium). Each seedling was placed in a hole in the plywood at random and the root plugs were suspended in the water below the plywood top. Water temperature and air temperatures were recorded weekly during the study to ascertain laboratory growing conditions. Low temperatures were observed around 2300 hours and high temperatures were observed around 1300 hours. After five weeks, all new roots were excised and dried at 65° C for 36 hours, and then weighed.

RBI

All plants were measured for RCD using a digital calliper prior to planting. For each plant, a RBI was calculated. A total of 3376 *P. palustris* seedlings were evaluated. In the case of the hybrid trial, a total of 2304 plants were assessed. For *P. patula*, 3000 cuttings and 3000 seedlings were assessed.

RBI was determined using two techniques and expressed as a percentage. To avoid confusion, the RBIdia value is expressed as a percentage while RBIvol is expressed as a whole number.

(a) RBIdia = (RCD in mm ÷ Cavity diameter in mm) x 100
(b) RBIvol = (RCD in mm ÷ Cavity volume in cc) x 100

Field assessments

The effect of RBI on survival was assessed using the most recent survival count conducted in each of the four trials. The *P. palustris* study was last measured two years after planting, the pine hybrid trial three years after planting, and the two *P. patula* studies, one year after planting. In each case each tree planted in the field was recorded as being either dead or alive.

Statistical analyses

A General Linear Model was used for each analysis. For the *P. palustrius* study, the factors included site, replication and seedling class. For the remaining analyses, factors only included replication and class. Therefore, factors such as container type were not included in the model. Contrast statements were included in the model to determine if the relationship between class and survival was linear or quadratic. Survival data were not transposed prior to analysis.

An additional analysis was conducted to test the effect of age on survival of *P. elliottii x P. caribaea* cuttings (independent of differences in RCD). Therefore, stock with diameters larger than 3.5 mm or smaller than 3.1 mm were deleted prior to analysis.

Results

Survival of *P. palustris* seedlings was related to diameter class (P = 0.0001) and the relationship was similar to a bell-shaped curve (Fig. 1). There was a significant quadratic relationship (P=0.034). Seedlings with RCD values less than 7 mm or greater than 10 mm did not survive as well as seedlings with intermediate diameters. The lowest survival was observed for the seedlings with the largest diameter. Survival of *P. palustris* seedlings was also related to RBIdia (P = 0.0001) and RBIvol (P = 0.0001). In this case, the quadratic relationship was slightly stronger for RBIvol (P=0.0001) than for RBIdia (P=0.0017).

Survival of *P. elliottii x P. caribaea* cuttings was high (Fig. 2) but there still was a relationship between diameter class and survival (P=0.082). Contrast statements revealed a quadratic (P=0.034) relationship. The lowest survival was observed for stock with the largest diameter. In contrast, survival of hybrid cuttings was not related to either RBIdia (P=0.83) or RBIvol (P=0.55).

Seedlings of *P. patula* were also related to both diameter and RBIvol (P=0.0001) and the relationship was similar to the left half of a bell-shaped curve (Fig. 3).

There was a significant quadratic relationship (P=0.0001). Seedlings with RCD values less than 1.6 mm did not survive as well as seedlings with greater diameters.

Survival of *P. patula* cuttings was related to diameter class and RBIvol (P = 0.0001) and the relationship was generally positive (Fig. 3). There was a significant quadratic relationship (P=0.0014).

The RGP of container-grown *P. palustris* seedlings increased as average diameter increased from 5 mm to 9 mm. However, 10 mm seedlings produced 8 new roots per seedling while 9-mm seedlings produced 10 new roots.

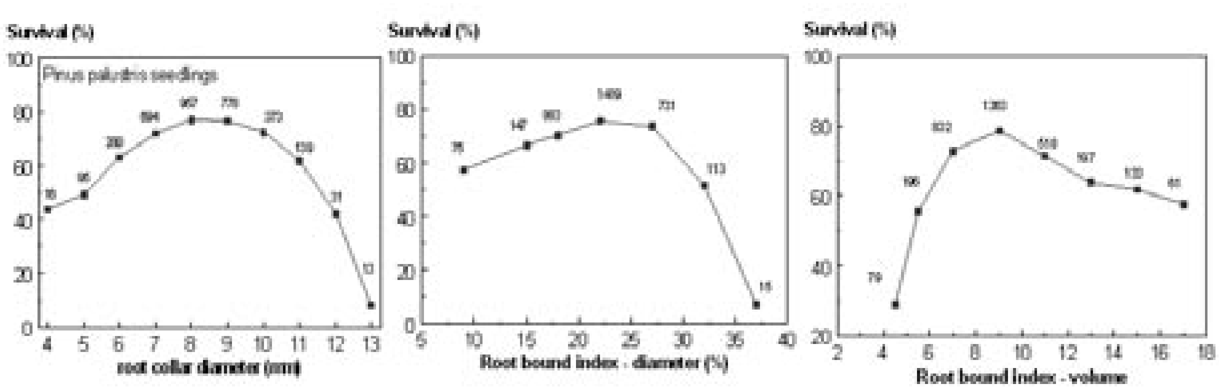

Figure 1. *The relationship between root-collar diameter, root bound index (diameter or volume) and seedling survival of* P. palustris *seedlings in Alabama. Numbers above each mean represent the number of seedlings in that class.*

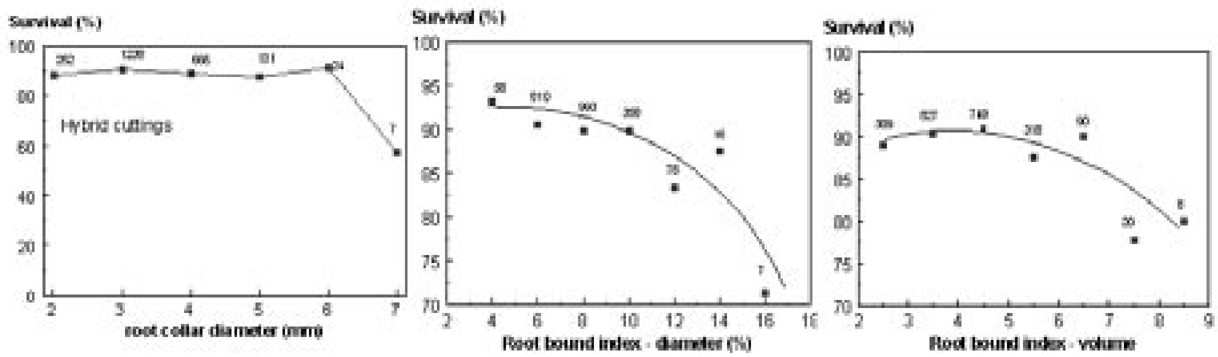

Figure 2. *The relationship between root collar-diameter and survival of* P. elliottii x caribaea *cuttings. Numbers above each mean represent the number of cuttings in that class.*

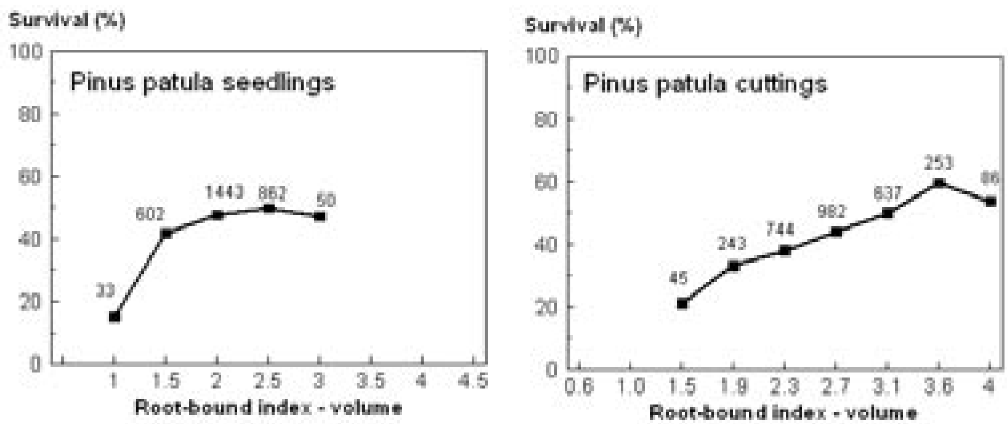

Figure 3. *The relationship between root-bound index (volume) and survival of container-grown P. patula in South Africa. Numbers*
x-axis values will change.

Discussion

Overall, the largest-diameter stock in the *P. palustris* and *P. elliottii* x *P. caribaea* study did not survive as well as pines that were closer to the median size. These findings suggest that a small proportion of operationally produced container stock may suffer symptoms of root-binding. For example, survival of the large container-grown *P. palustris* seedlings (RCD of 12-13 mm) exhibited much lower survival than seedlings with a RCD of 8-9 mm (Fig. 1). These findings cast doubt on the belief that only small diameter container-seedling need to be culled.

A bell-shaped curve was apparent for *P. palustris* seedlings and the curve for *P. patula* seedlings could be considered to be a truncated bell-shaped curve. This study may be the first to demonstrate this bell-shaped, survival-response curve for container-grown pine seedlings. Previous authors have warned against root-binding of seedlings but data showing the relationship between root-binding and field performance are rare. In some cases planting date and plant age are confounded, which casts some doubt on the conclusions.

Age or size?

Some warn against growing seedlings too long in the container (Dickerson 1974, Zwolinski and Bayley 2001, Salonius et al. 2002). For example, 6-month old pine seedlings grown in paper-pots survived better than 18-month old seedlings (Alm et al. 1982). Brisette and others (1991) say that “Adverse root forms increase rapidly with the length of time seedlings are grown in containers.” They suggest that if *P. palustris* seedlings are kept in containers only 3 to 4 months, there should be no problem if the containers are properly designed. Others say the optimum seedling age in South Africa is between 5 and 7 months (Zwolinski and Bayley 2001). However, stock size and stock age are confounded. As a result, RBI increases as seedling age increases (Fig. 4).

Since root-binding is a function of both seedling size and container size, then plant age should not be the sole

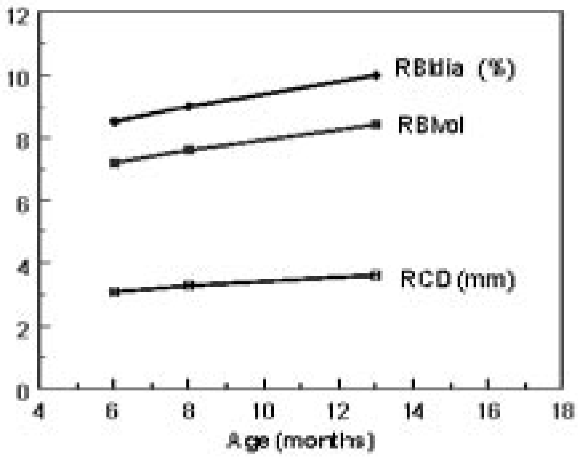

Figure 4. The relationship between age and RBI values for cuttings of P. elliottii x P. caribaea*. RBIdia = RCD/cell diameter. RBIvol = RCD/cell volume.*

criterion for determining stock quality (Barnett 1974a). The *P. palustris* data suggest that 26-week-old seedlings may perform satisfactorily in >90 ml containers if the RBIvol is within the 8 to 10 range (Fig. 1). Of course young, 1-month-old *P. palustris* seedling do not survive in the field as well as 2-month-old seedlings (Barnett 1974b).

McCubbin and Smith (1991) examined the relationship between age and growth of *Eucalyptus grandis* seedlings. Older seedlings did not grow as well as 13-week-old seedlings. However, it was not clear if this was a function of age or was a function of size. The data from the hybrid pine trial suggest that age may have an effect on survival. Young seedlings had higher survival than 13-week-old seedlings. For bareroot *P. palustris* seedlings (where root-binding is not a factor), seedling performance was reduced if the seedlings were a year older than normal (Lyle et al. 1958).

Reduced RGP

The mechanism which explains why root-bound seedlings have lower survival is not known. Lower survival from root-bound seedlings might result due to a reduced RGP and a lower root-weight ratio. Our data along with data by others suggest the older root-bound seedlings have lower RGP than smaller non-bound planting stock. Smith and McCubbin (1992) found RGP of *E. grandis* seedlings was cut in half as seedlings increased in age from 16 weeks to 21 weeks. We observed a 20% reduction in RGP when comparing 10-mm diameter *P. palustrius* seedlings with 9-mm seedlings. When hybrid cuttings with a limited RCD (3.1 to 3.5 mm) were selected, age still had a significant effect on seedling survival. In this analysis, six-month-old cuttings had 94% survival while 13- week-old cuttings only had 84% survival. This suggests a decline in RGP may occur after hardening practices are initiated to slow root development.

When top-pruning is not employed, seedlings held too long in the nursery will sometimes produce an unbalanced seedling. Even when hardening techniques are employed, the growth in root mass is sometimes limited by the container while shoot mass continues to increase (McCubbin and Smith 1991). Therefore, the root-weight ratio will sometimes decline over time.

RCD, RBIdia or RBIvol?

If a single container type is used in the nursery, there will be no need to calculate a RBI index that has only one value in the denominator. RBI will be directly related to RCD (Fig. 1). However, if several types of containers are used, then a single RBI value might be useful. Otherwise separate RCD limits would need to be developed for each container type.

The size of the container determines how long the plants can remain in the nursery without being root-bound. Therefore, stock grown in a 600 ml container can remain in the nursery for a longer time than seedlings grown in a 60 ml container.

Which RBI method is preferred? For *P. palustris*, survival of seedlings in the 60-ml Jiffy-pot was less than the 120-ml Jiffy-pot (South et al. 2005). The reduced survival might be a result of either use of smaller seedlings or might be a result of root-binding. To address this question, an analysis was conducted using trees within a limited diameter range (RCD 6.8-7.8 mm). This analysis indicated that survival of similar-sized seedlings in the 60-mm container was 18 percentage points lower than trees in the 120-mm container. In this case there was only a slight change in container diameter but the rooting volume was doubled. The RBIdia was 19% for the 120-ml pot and 22% for the smaller 60-ml pot. Likewise, the RBIvol was 6 for the large pot and 12 for the small pot. According to the curves in Fig. 1, a RBIdia of 22% should not have reduced survival. Therefore, these findings favor the use of RBIvol over that of RBIdia. A decline in survival would be expected for a RBIvol of 12 but survival should have been high for a RBIdia of 22% (Fig. 1).

Operational considerations

In South Africa, one company uses a subjective ranking of root-binding (values of 1 to 5) which are based on the visual appearance of roots on the outside of the seedling plug. Until now, there has been no objective definition of root-binding. In the past, many container nursery managers have used plant age as a surrogate for root-binding. Now managers can use RCD or RBIvol as an indicator of plant quality.

The RBIvol values will vary with species. For example, the performance limit for *P. palustris* seedlings might be 11 while the value for *P. patula* seedlings is about 3. To effectively determine the value may require researchers to conduct RGP tests on plants that cover a range of diameters. Only a few RGP over container size studies exist (e.g. South et al. 2005). Stock could also be planted in sand and subjected to moisture stress to obtain a robust survival-over-RBI curve (e.g. Fig. 1). Favorable environmental conditions might mask potential differences in survival if tests are conducted on sites where adequate rainfall is likely.

Once researchers have determined a RBIvol value for a given species, then the nursery manager can, at lifting, determine the percentage of plants that exceed this value. For example, 6% of *P. palustris* stock exceeded a RBIvol value of 11. By culling these root-bound seedlings, the average survival on one site would have increased by 4 percentage points.

Conclusions

Root-binding of container stock can result in reduced survival of both seedlings and cuttings of pine. As pine and eucalyptus roots become root-bound, their ability to produce new roots decline. To avoid root-binding, most managers ship seedlings by a certain age. Is some situations, they will reduce water and fertilization to slow root growth and prolong the time before many roots become root-bound. Keeping seedlings too long in the hardening phase can reduce RGP and seedling performance.

Some tree planting guides provide minimum specifications for the diameter of planting stock but do not include a maximum RCD limit. We propose that RBIvol maximums be determined for each species. When planting guides cover a range of container types, a maximum RBIvol value can provide some indication of when root-binding might reduce plant quality. At time of shipping, nursery managers could report both the percentage of plants that exceed the RBIvol value and the number of weeks the stock has remained in the hardening phase (since both can affect outplanting survival). Additional research needs to be conducted to determine if RBIvol will be useful for non-pine genera.

Literature Cited

Alm, A., Olsen, D., Lacky, M. 1982. Comparisons after planting of jack pine grown for varying time periods in different container systems. Minnesota Forestry Research Notes. No. 279, 4 pp.

Barnett, J.P. 1974a. Growing containerized southern pines. In Proceedings North American Containerized Forest Tree Seedling Symposium. Edited by R.W. Tinus, W.I. Stein, and W.E. Balmer. Denver, CO. Great Plains Agricultural Council Publication No. 68. pp. 124-128.

Barnett, J.P. 1974b. Tube lengths, site treatments, and seedling age affect survival and growth of containerized southern pines. USDA Forest Service Research Note, Southern Forest Experiment Station. No. SO-174.

Brissette, J.C., Barnett, J.P. and Landis, T.D. 1991. Container seedlings. Chapter 7. In Forest Regeneration. Edited by M.L. Duryea and P.M Dougherty. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 117-141.

Dickerson, B.P. 1974. Seedling age influences survival of containerized Loblolly Pines. USDA Forest Service Research Note, Southern Forest Experiment Station. No. SO-171.

Hiatt, H.A. and Tinus, RW. 1974. Container shape controls root system configuration of ponderosa pine. In Proceedings North American Containerized Forest Tree Seedling Symposium. Edited by R.W. Tinus, W.I. Stein and W.E. Balmer. Denver, CO. Great Plains Agricultural Council Publication No. 68. pp. 194-196.

Hulten, H. (Editor). 1982. Proceeding of a symposium on root deformation of forest tree seedlings. Institutionen for Skogsproduktion, Sveriges Lantbruksuniversitet. Report No. 11.

Lyle, E.S., Gilmore, A.R. and May, J.T. 1958. Survival and growth of 2-0 Longleaf and Loblolly seedlings in the field. Tree Planters' Notes 33:26-28.

McCubbin, P.D. and Smith, I.E. 1991. The influence of four seedling tray types over time on root growth and other growth parameters of *Eucalyptus grandis* seedlings. In Proceedings Intensive forestry: The role of eucalypts. IUFRO Symposium P2.02-01 Productivity of eucalypts, Sept. 2-6, 1991, Durban, South Africa. Edited by A. P. G. Schonau. pp. 143 - 155

Mitchell, R.G. and Jones, N.B. 2005. A comparison between *Pinus patula* seedling and cutting re-establishment success with specific focus on disease control, shoot morphology and site quality. Sappi Forests research document 06/2005. Shaw Research Centre, South Africa.

Salonius, P., Hallett, R., Beaton, K.I. and French, C. 2002. Extended nursery rearing compromises field performance of container-reared conifer seedlings. Canadian Forest Service, Fredericton, New Brunswick. Information Report M-X-214E.

Smith, I.E. and McCubbin, P.D. 1992. Effect of copper tray treatment on *Eucalyptus grandis* (Hill ex Maiden) seedling growth. Acta Horticulturae 319:371-376.

South, D.B., Harris, S.W., Barnett, J.P., Hainds, M.J. and Gjerstad, D.H. 2005. Effect of container type and seedling size on survival and early height growth of *Pinus palustris* seedlings in Alabama, U.S.A. Forest Ecology and Management 204:385-398.

Sutherland, D.C. and Day, R.J. 1988. Container volume affects survival and growth of white spruce, black spruce and jack pine seedlings: a literature review. Northern Journal of Applied Forestry. 5:185-189.

Van Eerden, E. and Kinghorn, J.M. (Editors). 1978. Proceedings of the root form of planted trees symposium, Victoria, British Columbia, May 16-19, 1978. British Columbia Ministry of Forests/Canadian Forestry Service Joint Report No. 8. 357 pp.

Zwolinski, J. and Bayley, A.D. 2001. Research on planting stock and forest regeneration in South Africa. New Forests 22: 59-74.

Root-Zone Electrical Conductivity Monitoring for Nutrient Loading and Spiking of Container Tree Seedlings

V.R. Timmer[1], Y. Teng[1], D.F. Jacobs[2]

[1]University of Toronto, Faculty of Forestry, Toronto, ON M5S 3B3
[2]Purdue University, Department of Forestry and Natural Resources, West Lafayette, IN 47907-2601

Container planting stock is commonly reared in small plugs or cells with limited substrate volume relatively low in buffer potential and nutrient reserves. Consequently, root-zone nutrient status changes rapidly in response to cultural manipulations and crop nutrient demands. These factors are particularly critical under intensive fertilization since plants are sensitive to extreme alterations in nutrient supply. Thus, it is important to monitor root-zone nutrient status frequently during the growing cycle to track and maintain desired growing media fertility. Substrate electrical conductivity (EC), usually determined from a saturated media extract, is the standard method of assessing growing media nutrient status during container tree propagation. In this paper, we address the need for EC testing to optimize substrate nutrition under two intensive fertilization techniques that promote early outplanting performance of conifer seedlings. We also report on the press extraction approach as a rapid, low cost alternative for routine monitoring of root-plug EC.

Nutrient loading builds up reserves in seedlings by inducing luxury consumption of nutrients. This is often accomplished through exponential fertilization, whereby nutrient inputs match exponential plant growth. The enhanced reserves are tapped internally after outplanting, and more effectively meet growth demands than external soil pools often limited by supply and competition from surrounding vegetation. Forcing luxury nutrient consumption on nursery seedlings is controversial because of concerns of plant stress associated with high fertilizer application. Our studies demonstrate that substrate EC can be a sensitive guide for regulating fertilizer applications. Periodic tracking clearly distinguished between conventional and exponentially driven delivery regimes and various dose rates applied. Trends accurately reflected substrate nutrient build up from loading and subsequent decline with fertilizer withdrawal at hardening. Potential toxicities were identified in time for remedial practices that minimized crop stress.

Nutrient spiking replenishes root-plug fertility of container stock before planting. The plug serves as an important reservoir of readily available nutrients for newly planted seedlings. Plug fertility is high during nursery culture, but is severely depleted during hardening and storage when fertilizer is withheld. Refertilization after storage is risky because of stock sensitivity. However, carefully controlled “spiking” of root plugs with liquid fertilizer to target EC status prior to planting markedly increased field survival and growth without stimulating neighboring weeds. Transplanting trials revealed maximum root-plug EC spiking capacity as high as 4.5 dS/m. Post-transplant growth performance declined after this target level, but nutrient accumulation increased suggesting that inhibition was associated with interactions of nutrient excess and reduced moisture availability.

Electrical conductivity readings derived from press-extracted and standard vacuum-extracted substrates sampled across a range of fertility showed strong correlations (r=0.96) between the two procedures. A small adjustment for differences in saturation moisture conditions may be required. Press extraction employs a kitchen potato press to expel soil solutions from peat-based growing media, and operationally offers a simpler, quicker and inexpensive approach to plug EC monitoring compared to standard laboratory-oriented vacuum extraction methods.

Theme 3

The Thin Green Line

Planting and Planting Site Treatments to Optimize Regeneration

Risks Related to the Extension of the Planting Period of Norway Spruce Container Seedlings: Drought – Growth Stage Dynamics and Handling Practices

P. Helenius, J. Luoranen, R. Rikala

Finnish Forest Research Institute, Suonenjoki Research Station, Juntintie 154, FIN-77600, Suonenjoki, Finland

Approximately 90 million Norway spruce (*Picea abies* (L.) Karst.) container seedlings (of which 50% are frozen-stored) are annually delivered from nurseries in Finland. To take advantage of high stress resistance of dormant seedlings and available soil water, seedlings are usually planted prior to budburst in spring. Consequently, the planting period lasts usually only 4 or 5 weeks (i.e. May and early June) before seedlings starts to grow and soil is considered too dry for survival and growth. Because it is problematic for nurseries and forestry organizations to deliver and plant all the seedlings during such a short period, we investigated would it be possible to extend the planting period to include also late June and July without risk of excessive mortality and growth restrictions due to drought. In addition, we tried to find operational ways to improve seedling outplanting performance under drought (e.g. prolonged frozen storage).

To investigate the effect of drought on outplanting performance, actively growing 1.5-yr old Norway spruce container seedlings were exposed to 0–12 day preplanting drying in the greenhouse followed by 0, 1, 2, 3, 4 or 6 week postplanting drought periods under the plastic rain shelter in the sandy nursery field in central Finland. Seedlings kept dormant by prolonged frozen storage until planting were also exposed to 0–4 week postplanting drought periods. After drought periods, seedlings were irrigated so that the drought period and irrigation lasted altogether 6 weeks.

Height growth and root egress of actively growing seedlings planted in late June-early July decreased when exposed to postplanting drought, depending on the water content of the soil at planting and atmospheric evaporative demand (VPD) during drought periods. Survival and growth under drought were also decreased by preplanting drying of root plugs and especially that of seedlings, i.e. when the water content of root plugs decreased to < 20% (v v^{-1}). In general, however, mortality of actively growing, well-watered seedlings planted in late June - early July was negligible when exposed to drought periods no longer than 2 or 3 weeks.

Prolonged frozen storage up to 34 weeks in cardboard boxes at –3.5 °C to maintain seedlings dormant until planting in late June had no observable negative effect on needle carbohydrate concentration and subsequent outplanting performance. Contrary to actively growing seedlings from the same seedling stock (storage duration 30 weeks), drought periods had no effect on root egress and chlorophyll fluorescence, and only moderate effect on xylem water potential of dormant seedlings. However, actively growing seedlings showed much greater root egress than dormant seedlings, except when exposed to very long (≥ 3 weeks) drought periods after planting.

The results suggests that no risk of excessive mortality occur due to drought when well-watered, actively growing Norway spruce container seedlings are planted in late June - early July, provided that soil is not dry at the time of the planting.

Effect of Plant Date on Stand Establishment

S. Kiiskila

New Forest Treeworks, 8640 Honeymoon Dr. S., Prince George, BC V2K 5J8

Introduction

The likelihood of successful reforestation via planting seedlings is influenced by many factors such as seedling quality, planting practices, and planting site environmental conditions. For the most part, planting dates are determined by the environmental conditions most likely to be encountered during planting and for the first few critical months thereafter. For while the planting site environment can be altered somewhat through site preparation, the prevailing climate can not. Any discussion on the current planting windows for container seedlings in British Columbia (B.C.) must also include seedling stock type, as different planting windows require the use of stock at different stages of phenological development.

There are currently two major planting windows used in the interior of B.C. Spring planting with overwintered stock, and summer planting with physiologically active stock. Spring planting begins in mid- to late April, finishing by June 21. There is some overlap between the spring and summer planting windows, as summer planting with active stock often begins as early as mid-June, although the majority is planted after July 1. In some areas there is also a fall planting window, beginning mid-August and running until early October. Preliminary numbers suggest that 264 million seedlings will be planted in B.C. in 2005. At 50 million (i.e.,19%), the percentage of summer plant seedlings has declined in recent years, partly due to replanting of lower elevation sites from the 2003 forest fires, where summer planting is not feasible due to environmental conditions. Also, recent summer droughts resulting in lower survival have decreased the summer plant's popularity, especially in the southern B.C. interior (S. Joyce, pers. comm., 2005).

Stock Types

With the advent of container stock and freezer storage, seedlings could be reliably harvested in the fall and held in frozen storage till planting the following spring. While bareroot seedlings could also be kept frozen over the winter, rainy weather during the fall often kept the harvesting equipment off the fields, thus delaying harvest till the following spring. Bareroot and/or plug-transplant field stock are currently used very little in B.C., thus this discussion will pertain to container stock, although some of the principles are applicable to planting bareroot seedlings. Seedlings harvested in the fall and stored over the winter are referred to as frozen stored or overwintered stock, and the planting window is referred to as a "spring plant". This refers more to the seedling stock type than the actual season, as a late spring plant can actually take place in the summer. As the nursery climate is in most cases quite different from that of the planting site, keeping the seedlings at -2°C until shortly before planting allows the seedlings to be in sync with the environment of the reforestation site at planting. Frozen stored one-year-old (1+0) seedlings such as interior spruce (*Picea glauca x engelmannii*) are commonly sown in a greenhouse in March or April, or in the case of lodgepole pine (*Pinus contorta*), outside in late April or May. Seedlings are grown over the spring and summer, and in most cases the naturally decreasing daylength is relied upon to induce budset and dormancy prior to lifting in the fall.

The "summer plant" with hot-lift, fresh or current stock was originally developed for high elevation, moist sites, which often had access problems due to a late snowmelt. This planting window has also gained popularity in northeastern B.C. and northern Alberta, areas which receive significant precipitation during the summer. Extending the planting window with hot-lift stock offers many logistical advantages such as spreading out the workload and eliminating stock overwintering frozen storage costs (Mitchell et al. 1990). While summer planting with hot-lift bareroot spruce was tried in an attempt to extend the planting window (Revel and Coates 1975), lifting the seedlings from the field during budflush reduced future growth potential. The use of container seedlings in conjunction with the horticultural practice of blackout, whereby the ambient photoperiod is artificially shortened, has allowed the operational production of stock phenologically suited to planting from mid-June onwards. Although hot-lift stock used in summer planting is still physiologically active, it has set a terminal bud, and has developed some degree of hardiness. Hot-lift stock is greenhouse sown in January or February, where it usually remains until the last month prior to lifting, at which time the greenhouse covers may be removed, exposing the crop to full sunlight. Hot-lift stock does not break bud the year of planting, instead it concentrates it resources on stem diameter and root growth.

While summer planting is a great tool for some sites which can not be spring planted, it is not feasible on all sites. In general, newly planted seedlings typically have restricted root placement and poor root-soil contact, resulting in limited water uptake and various levels of water stress, depending on the range of growth limiting factors present (Grossnickle 2000). Thus, sites that commonly experience root-zone water deficits and high atmospheric evaporative demand during late June and July should not be summer planted, as the seedlings will experience potentially severe stress levels. Thus, these sites must be spring planted when air temperatures are lower and soil moisture is higher. As an alternative, fall planting in interior regions such as the Sierra Cascade Mountains in California (Livingston 2000) and high elevation sites in the B.C. interior (Kiiskila 2004) have recently garnered renewed interest. However, in contrast to the current operational fall planting programs on the Pacific coast, current planting guidelines do not advise fall planting in the B.C. interior (Eastham et al. 1998). In the past, major problems with interior fall planting have included insufficiently hardened off stock (Revel et al. 1990), a high probability of frost heaving (Crossley 1956), and winter desiccation on sites with low annual snow cover (Krasowski et al. 1995, Krumlik 1984). Improvements in stock quality along with the switch to forest floor planting in conjunction with less "deep" planting have resulted in greater initial root growth in the organic/mineral soil interface (Heineman 1998), thus lessening the chances of frost heaving and winter desiccation (Krasowski et al. 1995). An interior "fall plant" is carried out with hardened off hot-lift stock.

Spring Plant

For the most part, the prevailing climate and environmental conditions at the planting site determine the planting window. While greenhouse growers now have close to total control over nursery stock, obviously the seedling must be at an appropriate phenological stage for the planting site and time of year. For example, although air temperature and soil moisture may be ideal for planting in early September, one would not want to plant a seedling in the boreal without some degree of frost hardiness. There are also logistical concerns, such as the availability of frozen storage and staff for thawing, and the availability of planters.

The general strategy with a spring plant is to get the seedlings in the ground early while soil moisture is adequate, to ensure the seedlings will have a chance to establish new roots prior to budflush. The start date of spring planting with frozen stored stock usually depends on access and when the ground is free of snow and/or frost, although it is recommended that soil temperature be above 4°C (Mitchell et al. 1990). With up to 100 million seedlings planted in the interior each spring, it is logistically impossible to plant all sites at the "optimum" time, with some cutblocks being planted simply because they are scheduled next. Another factor to consider when starting spring planting is the date of the last hard frost.

To ensure that frozen stored seedlings have sufficient time to flush and develop hardiness before the onset of fall frosts, it is currently recommended that spring planting be finished by June 21 (Eastham et al. 1998). While that calendar date may sound late, often planters are following the snow off north aspect, high elevation blocks which could not physically be planted any sooner. Lack of soil moisture at the later spring planting dates may also be a concern. It is recommended that soil moisture tension is less than 0.1 MPa (Mitchell et al. 1990), although it is doubtful that this parameter is actually checked during operational planting programs.

As frozen stored stock can be kept more or less in a state of suspended animation, site conditions and the length of the growing season are the primary determinants of initial field performance of frozen stored stock (assuming similar stock handling and planting practices). As the thawing method influences timing of budflush and root growth, the previous "slow" thaw procedure meant that the phenology of spring plant stock at the time of planting was variable, depending on how long and at what temperature it had been thawed. The "slow" thaw method consisted of raising the temperature of the entire refrigeration unit, which meant the last planted stock may have been thawed and exposed to warm temperatures for weeks at a time, sometimes resulting in stock flushing in the box. Seedling budflush in the spring is determined by the amount of exposure to warm temperatures (Grossnickle 2000); thus compared to a slow thaw the current practice of "quick" thawing stock a few days prior to shipping (Rose and Haase 1997) delays budflush, allowing time for new root development before budbreak. Therefore, when evaluating the field performance of a specific spring planting date, the thawing regime must also be considered.

Summer Plant

As summer planting takes place at a time of year with the potential for environmental extremes, several constraints have been recommended by Mitchell and others (1990). These include a soil moisture tension threshold of less than 0.1 MPa, a recommended air temperature of less than 18°C and a wind speed of less than 30 km/hr, along with consideration of the dryness of the air, or vapour pressure deficit. However, under operational conditions, summer planting is seldom suspended for these reasons, primarily due to the fact that the physiologically active hot-lift stock does not store well in boxes. Although on-site refrigerated units can keep the stock cool, the general rule of thumb is not to keep seedling boxes closed for greater than 48 hours. While not proven, some reforestation practitioners feel that a long dark period in a box may approximate a long blackout in the nursery, which has been shown to result in reduced stem diameter (Hawkins 1996). On the positive side, the use of container stock and improved stock handling practices have lessened the potential for seedling damage such as drying of the root tips when planting during hot, dry weather.

In comparison to frozen stored spring plant stock, which is basically kept dormant until planting, the morphology and physiology of hot-lift stock is changing rapidly during the summer lifting window (Grossnickle and Folk 2003). These changes occur primarily in response to a decrease in daylength, either naturally or more commonly via a blackout treatment, causing bud initiation. Seedlings are commonly shipped five to six weeks after blackout, although the criteria by which stock is judged acceptable for shipping is vague. Along with morphological height and root collar diameter (RCD) specifications, the only other parameter assessed is the subjective measure of shoot succulence (Eastham et al. 1998).

The start date of summer planting is determined more by logistical, rather than biological reasons. Depending on the location, the majority of spring planting is finished by early June, and the planting contractors want to start summer planting soon after, for fear of losing their planters. While planting contractors push for early summer planting with hot-lift stock, the nurseries usually struggle to produce stock ready for planting in mid- to late June. There are limits to how much a seedling can grow within the five to six month period between sowing and lifting. Due to low light levels in December and the cost of heating a greenhouse at that time of the year, there is not much gain in sowing trees much before the beginning of January. It is possible to produce a larger seedling earlier in the year by manipulating a two-year-old or reflush crop. However, by applying blackout even earlier in the year to initiate budset, you would be putting the stock even further out of sync from the normal phenological cycle of established spruce on the planting site. That is, blackout to initiate budset would be applied during a period of increasing daylength, when established spruce on the planting site may not have even broken bud yet.

No definite “must be completed by” calendar date has been defined for summer planting with hot-lift stock, although it is commonly felt by most B.C. reforestation practitioners that earlier planting dates are better, with most planting currently completed by the end of July. When discussing hot-lift planting dates, to ensure that you are not comparing apples to oranges, you should also be aware of the number of weeks since bud initiation. Five to six weeks after the start of bud initiation (i.e. blackout) is generally considered the optimum time to lift and plant hot-lift stock. Seedlings lifted earlier would have a higher root growth potential, although they would be less tolerant to frost, drought and handling, and their bud primordia would be less developed. Seedlings lifted later would have increased frost and drought tolerance and greater development of their bud primordia, but less root growth potential. To ensure the greatest likelihood of reforestation success, hot-lift stock should be lifted at the nursery and planted at the previously requested delivery date. Holding the stock in the nursery results in the seedlings moving further along their phenological cycle (i.e., moving towards dormancy), resulting in a further reduction in root growth potential and the chance for successful seedling establishment. However, a positive trade off of holding seedlings in the nursery is that stem diameter continues to grow, such that when planted these seedlings are usually more sturdy.

Considering that fall planting in the interior often begins as early as mid-August, the line separating hot-lift summer and fall plant stock is not clear. As seedlings are planted later into the fall, the need for a greater level of frost tolerance increases. However, frost tolerance increases as seedling move towards dormancy, during which time their root growth potential decreases. If the seedlings receive sufficient snow cover during their first winter, poor root growth during the first fall may not be as detrimental. However, if the snow cover is minimal or nonexistent, then seedlings with initially little or no root growth would be more subject to desiccation (Krasowski et al. 1995). Thus stock for fall planting should have just enough frost tolerance for the specific site and date, but no more — the trick is to reduce root growth potential no more than necessary.

Spring vs. Summer Plant

In comparing frozen stored spring plant with hot-lift summer plant seedlings, the frozen stored stock is initially larger at the end of the first planting season as its buds flushed and it grew in height and diameter. Also, frozen stored spring plant seedlings often have greater RCD than hot-lift summer plant seedlings grown in the same container size, as they are held in the nursery longer after budset allowing them more time to grow stem diameter. Needle primordia for the second season growth of the spring plant stock are developed in the field, usually under less than ideal conditions. In contrast, needle primordia development of hot-lift summer plant stock supposedly occurs under ideal nursery conditions, which in theory should allow the summer plant to “catch up” to the spring plant stock (Grossnickle and Folk 2003). However, current operational trials in B.C. (see Fig. 1) suggest that the hot-lift summer plant does not catch up to the frozen stored spring plant seedlings, which have actually been found to be much more vigorous. This may be partially due to the fact that rather than ideal conditions, nursery growers often stress the hot-lift crop by reducing water and fertilizer to encourage budset and/or prevent the buds from reflushing. It has also been noted in some cases that the terminal buds of hot-lift interior spruce do not flush and/or flush abnormally the first spring after planting, although the cause is not known (Hawkins 1998, MacDonald 1998). There is speculation that problems with the terminal buds may be due to the fact that in some cases artificially induced bud initiation via blackout takes

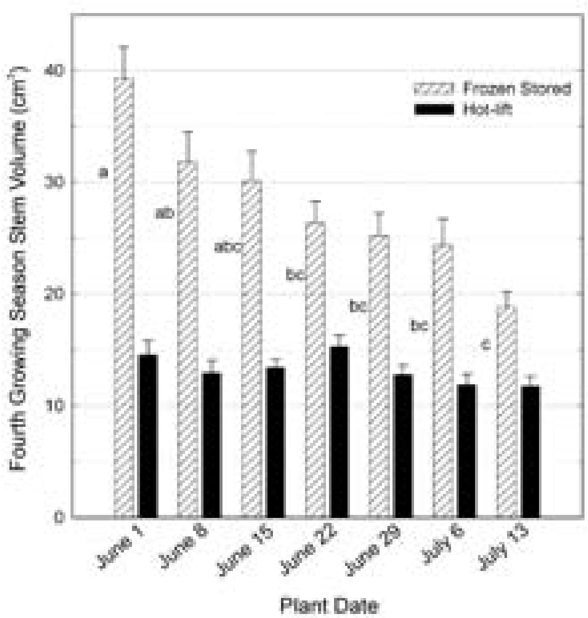

Figure 1. *Fourth season stem volume (cm^3) of frozen stored and hot-lift interior spruce planted once a week for seven weeks at 1,550 m elevation in the Montane Spruce dry mild biogeoclimatic subzone near Princeton, B.C. Means with the same letter are not significantly different (p=0.05) from one another. Vertical bars are standard errors of the mean.*

place at a time of the year when daylength is increasing and the seedlings would normally be actively growing. That is, they are receiving mixed signals. Another cause for relatively poor vigour with hot-lift summer plant seedlings is that they are sometimes planted much later than their optimum lifting date according to when the planned bud initiation took place. For seedlings held in the nursery past their originally scheduled delivery date would have reduced root growth potential and their establishment could suffer, especially under dry conditions.

Conclusions

The best time to plant depends of course on the site. With the use of quick thawing procedures, spring plant stock is now for the most part in better condition when planted later in the season. Thus it is worthwhile to examine the current rule of thumb stating that frozen stored seedlings should not be planted past June 21. The use of hot-lift summer plant seedlings is a great tool for extending the planting season on appropriate sites. However, the use of physiologically active hot-lift stock requires a greater level of coordination between the nursery, forester, and planting contractor. The growth benefits of early summer planting have not been proven, and in fact may be indirectly responsible for terminal bud abnormalities observed in interior spruce. It is suggested that as a guideline summer planting of hot-lift stock not begin prior to July 1, which would ensure that the planted stock is more in sync with the normal phenological cycle of established spruce on the planting site. Although millions of hot-lift summer plant seedlings have been planted to date, more questions still need to be answered regarding their field performance in relation to frozen stored spring plant stock. To ensure the best possible seedling establishment, it is also recommended that greater effort be made to plant hot-lift stock as close to the originally requested delivery date as possible.

Literature Cited

Crossley, D.I. 1956. The possibility of continuous planting of white spruce throughout the frost-free period. Dept. of Northern Affairs and Nat. Resour., For. Br., For. Res. Div. Tech. Note No. 32.

Eastham, A., Kooistra, C., Madill, M., McDonald, A., McClarnon, J., Trotter, D., van Steenis, E., Comeau, P., Courtin, P., Hawkins, C., and Carlson, M. 1998. Provincial seedling stock type selection and ordering guidelines. B.C. Min. of For., Silv. Br., Victoria, B.C.

Grossnickle, S.C. 2000. Ecophysiology of northern spruce species: The performance of planted seedlings. NRC Res. Press, Ottawa, Ont.

Hawkins, C. 1998. Some factors affecting spruce plantations at higher elevations (executive summary). In Proceedings of the 1995, 1996, and 1997 annual meetings of the Forest Nursery Association of British Columbia, Canada. Edited by Kooistra, C.M. For. Nur. Assoc. of B.C., Vernon, B.C. pp. 135-136.

Hawkins, C. 1996. Spruce blackout nursery culture in British Columbia: Operational Summary. Can. For. Ser. and the B.C. Min. of For., Victoria, B.C. FRDA Res. Memo No. 229.

Heineman, J. 1998. Forest floor planting: A discussion of issues as they relate to various site-limiting factors. B.C. Min. of For., For. Prac. Br., For. Site Manag. Sec., Silv. Note 16.

Kiiskila, S. 2004. Fall planting in the Interior Cedar-Hemlock and Montane Spruce zones: Two Year Report. Available from http://www.for.gov.bc.ca/hfd/library/FIA/HTML/FIA-03-04-0047.htm [cited July 10, 2005].

Krasowski, M.J., Letchford, T., Caputa, A., and Bergerud, W.A. 1995. Desiccation of white spruce seedlings planted in the southern boreal forest of British Columbia. Water, Air and Soil Pollution 82: 133-146.

Krumlik, G.J. 1984. Fall-planting in the Vancouver Forest Region. B.C. Min. For., Victoria, B.C. Res. Pap. RR-84002-HQ.

Livingston, T.J. 2000. Fall versus spring planting in the Sierra Cascade Region. In Proceedings of the 21st Annual Forest Vegetation Management Conference: Reforesting for the New Millennium. Redding, Calif., Jan. 18-20, 2000. Complied by Cooper, S.L. Univ. of Calif. Shasta County Cooperative Exten., Redding, Calif., pp. 60-62.

MacDonald J.E. 1998. Failure of terminal buds of Sx seedlings to break: What happened inside the bud? In Proceedings of the 1995, 1996, and 1997 annual meetings of the Forest Nursery Association of British Columbia, Canada. Edited by Kooistra, C.M., For. Nur. Assoc. of B.C., Vernon, B.C. pp. 131-134.

Mitchell, W.K., Dunsworth, G., Simpson, D.G., and Vyse, A. 1990. Planting and seeding. In Regenerating British Columbia's Forests. Edited by Lavender, D.P., Parish, R., Johnson, C.M., Montgomery, G., Vyse, A., Willis, R.A., and Winston, D. UBC Press, Vancouver, B.C. pp. 235-253.

Revel, J. and H. Coates. 1975. Planting of white spruce throughout the growing season on high site areas in the sub-boreal forest region of British Columbia. B.C. Min. of For., Prince George, B.C., Unpublished Rep. 37 pp.

Revel, J., Lavender, D.P., and Charleson, L. 1990. Summer planting of white spruce and lodgepole pine seedlings. B.C. Min. of For. and the Can. For. Ser., Pac. For. Cen., Victoria, B.C. FRDA Rep. No. 91.

Rose, R., and Haase, D.L. 1997. Thawing regimes for freezer-stored container stock. Tree Planter's Notes 48(1/2):12-17.

Growth of Aspen and White Spruce in Planted Mixtures

R. Man[1], K. Greenway[2], J. Rice[1]

[1]OMNR, Ontario Forest Research Institute, 1235 Queen St. E. Sault Ste. Marie, ON P6A 2E5
[2]Alberta Sustainable Resource Development, 9920 – 108th Street, Edmonton, AB T5K 2M4

Introduction

Mixedwood stands dominated by aspen and white spruce are the most common tree mixture in Canadian boreal forests, particularly in the west (Rowe 1972). The review by Man and Lieffers (1999) indicated that aspen and white spruce interactions in mixture could lead to a greater yield than in pure species stands, through competitive reduction and facilitation (Vandermeer 1989, Kelty 1992). The 'mixedwood productivity gain' likely depends on species interactions that not only differ with species involved, but also vary with composition and vertical and horizontal structure. While the ecological benefits of mixedwoods are well recognized (MacDonald 1995), little is known about the magnitude of productivity gain relative to stand structural attributes.

The objective of this study is to examine the early growth of aspen and white spruce in planted mixtures varying in species composition and to relative compare productivity (plot volume production). Results will help practitioners manage species composition and structure when creating and maintaining mixedwood stands.

Methods

Experimental design and treatments

The study site is located on the Alberta Research Council's research station at Vegreville, Alberta. The soil is Dark Gray Chernozem with good soil drainage (Soil Classification Working Group 1998).

A randomized block design was replicated three times. Twenty treatments resulted from combinations of 5 species compositions described based on proportions: from pure aspen (Aw100), mixed aspen and spruce (Aw83Sw17, Sw50Aw50, Aw17Sw83), and pure spruce (Sw100), two moisture regimes (irrigation and control), and two nutrient conditions (fertilization and control). Moisture was added through irrigation based on 30-year average growing season rainfall in the study area, while the control served as the scenario of reduced soil moisture resulting from climatic drought during the course of experiment. Each treatment plot is 5 x 4 m surrounded by metal sheets inserted vertically 60 cm deep. The soil was ripped to a depth of approximately 30 cm before planting and Propex 3919 landscape fabric was used to hinder development of competitive vegetation.

White spruce and aspen seedlings (provided by Smoky Lake Forest Nursery, AlPac seedlot and K & C Silviculture, Weyerhaeuser Drayton Valley seedlot) were planted in early June 1999. The one-year old aspen seedlings had been trimmed to approximately 15 cm and cold stored until planting. The white spruce seedlings were started from seed, field grown for 1.5 years and cold stored until the time of outplanting. Seedlings were planted on a 50 cm grid so that a total of 63 seedlings were planted in each plot. Aspen and spruce were interspersed in the mixed-species plots. The 25 seedlings in plot centre were used for growth measurements. A handful of forest soil from a natural mixedwood stand and Plant Starter Fertilizer 10-52-10 (Plant-Prod® Water Soluble Fertilizer) were applied to each seedling at the time of transplanting. Regular watering was carried out in the first year to improve the establishment of all seedlings.

Both moisture and nutrient conditions were differentiated among treatments from the second year. The fertilized plots received a split application each year in the second and third year after planting. The first application was shortly after the snow melted (mid-April) and the second was in early July. Fertilization rates in each application were ammonium nitrate (34-0-0) at 150 kg N (nitrogen)/ha and phosphorus pentoxide 0-45-0 at 50 kg P (phosphorus)/ha. The granular fertilizers were mixed and applied around the base of each tree and between rows, followed by immediate irrigation to all plots at approximately 100 litres per plot (5 mm depth).

The intensity and frequency of irrigation varied depending on weather. Rainfall was close to normal in the second year and spread evenly throughout the summer. Irrigation was not carried out until August when soil moisture was low based on Time Domain Reflectometry (TDR) readings. Plots were watered every two weeks, with approximately 5 mm of water delivered each time.

Manual irrigation was continued for the entire growing season in the third year, following the same intensity and frequency. In the fourth year, manual irrigation was replaced with a drip semi-automatic system installed at individual tree bases. Due to the extremely dry weather in 2002, a total of 180 mm water was added to the irrigated plots. Approximately 50 mm water was manually added to the non-irrigated control plots to reduce the risk of massive mortality.

Weeds and aspen suckers inside the plots were hand-cleared. Aspen roots that grew over the metal insulator were severed. Planted seedlings that died in the first summer and winter were replaced in spring of second year to maintain plot density and species composition, with spare seedlings of the same stock reserved in a nearby planting. Each year, snow fence was set up on the north side of the plots in late October and removed in late April to reduce the risk of winter desiccation. The entire study area was fenced to prevent deer browsing and rabbit damage.

Data collection and analysis

Data collection included individual tree growth of 25 trees in plot center, foliar chlorophyll fluorescence, leaf area index, foliar and soil nutrient levels, and soil moisture.

Annual growth measurements were conducted in late September and early October. Measurements included total height, RCD (root collar diameter), and crown width averaged from two directions, south-north and east-west.

Chlorophyll fluorescence of white spruce in *situ* was measured annually with a portable chlorophyll fluorescence meter (PAM 2000, Heinz - Walz GmbH, Germany) to examine the effects of different treatments on the integrity of the photosynthetic system. Readings were taken twice a year, in mid-summer between late July and early August and in the fall between late September and mid-October. Five seedlings were randomly selected from the growth measurement trees within each plot and individual tree readings were averaged by plot. The 'Yield" parameter, defined as the ratio of (Fm'-Ft)/Fm' and commonly determined under steady-state illumination, was chosen to reflect chlorophyll fluorescence yield. Dark cloudy days were preferred for fluorescence measurement, but late afternoon/early evening (when sampled foliage did not receive direct sunlight) measurements were also used.

Leaf area index (LAI) was determined annually starting in the second year. All treatment plots were assessed in mid-August using LAI 2000 Plant Canopy Analyzer. Readings were taken at five locations within each plot, four in the corners and one at the plot centre, and the values were averaged by plot.

Soil and foliar samples were collected in 2000, the second year after planting, to assess the nutrient status in soil and foliage. In mid-September, four soil cores were taken to a depth of 25 cm from each plot and bulked together. Soil samples were air-dried and analyzed for N, P, and K (potassium). Foliar samples from growth measurement trees were collected in mid-August for aspen and in mid-September for spruce. Collected foliar samples were freeze-dried and analyzed for N, P, K, magnesium, calcium, and sodium.

Soil moisture was monitored in all treatment plots with single diode TDR probes inserted vertically at plot center at three depths, top (0-20 cm), middle (20-40 cm) and bottom (40-60 cm) layers. Rod length was 16.5 cm. Volumetric soil moisture content readings were taken bi-weekly between early May and early October except for a two-month delay the first year. Two readings were taken each time and averaged for each probe using the TDR unit (Moisture Point TK-917, Environmental Sensors Inc., Victoria, BC).

Data were analyzed with Pro Mixed procedure available with SAS 8.02. The effects of treatments on height, RCD, crown width, and chlorophyll fluorescence were assessed by tree species and measurement time. All individual-tree measurements were averaged to generate plot-level means prior to statistical analysis. Trees replaced in the first year, from mortality not likely caused by experimental treatments (watering, fertilization, or species composition), were excluded from the plot average calculation for tree height, RCD, and crown width. A similar analytical approach was applied to determine treatment effects on soil moisture at three depths, soil and foliar nutrient content, and LAI.

Total volume by species at plot level was the sum of individual-tree stem volume calculated from height and RCD using a cone model and plot density and composition. Since volumes of mixes are not directly comparable due to different growth rates of aspen and spruce, a relative volume production by plot was used to facilitate comparisons. The relative volume production of spruce or aspen was defined as the total volume in mixture divided by the total volume in pure species plots (Kelty 1992). The relative volume total is the sum of relative volume production of both aspen and spruce in the mixed-species plots.

Results

Soil moisture and nutrient levels

A period of severe drought occurred during the experiment. Based on data from a nearby weather station in Vegreville, total precipitation was 305 mm in 1999, 386 mm in 2000, 238 mm in 2001, and 201 mm in 2002, compared to 374 mm, the 30-year normal from 1971-2000 (Environment Canada weather station data). Soil moisture was similar at different depths, ranging from 13-40% for the top layer, 11-38% for middle layer, and 11-42% for bottom layer. Mean soil moisture generally decreased with depth and over time (from year 1 to 4) as well as within years from beginning to end of growing season (Fig. 1).

Soil moisture tended to decrease with increased proportion of aspen in the plots, particularly in the first two years when moisture levels were relatively high (Fig. 1). Mean soil moisture averaged over the four years and three soil depths are 18% for mostly aspen plots (Aw83Sw17 and Aw100), and 20% for mostly spruce plots (Sw83Aw17and Sw100). Differences in soil moisture content among the five composition treatments decreased with increased soil depth and reduced soil moisture (Fig. 1).

Soil moisture was generally similar between the irrigated and control plots at all three depths, with an exception in the third year (2001) when higher moisture content from irrigation was measured in most middle layer and a few bottom layer observations during mid and late season. The average difference was 2% in the middle layer, but decreased to about 1.5% in the bottom layer.

Total soil N, P, and K in the second year were 3000, 700, and 140 µg/g and not affected by any treatments. The mean available ammonium was 2.67 µg/g in the irrigated plots and 2.45 µg/g in the control plots (P=0.0547). Irrigation treated plots also had higher available soil nitrate (49.02 vs 17.74 µg/g for irrigated and control plots, P<0.0001) and P (5.05 vs 4.04 µg/g for irrigated and control plots, P=0.0133). Among the five species mixtures, available P increased as the proportion of aspen decreased from 4.00 µg/g in Aw100 to 5.03 µg/g in Sw100 (P=0.0029).

Seedling growth

Average aspen trees were 11.2 mm in RCD, 75 cm in total height and 39 cm in crown width by the end of first year. The largest increment occurred in the second year, with an average increase of 13.0 mm in RCD, 113 cm in height and 57 cm in crown width. Aspen growth slowed down in the third year, particularly crown width, which remained unchanged in the fourth year (Fig. 2).

RCD in white spruce followed the same pattern as that in aspen, with the largest average increment (6.1 mm) in the second year, and the smallest (1.8 mm) in the fourth year. Mean total height of spruce trees was 40 cm by the end of first year, followed by increments of 14 cm, 21 cm, and 17 cm from second to fourth year. Mean crown width was 20 cm in the first year and increased 15 cm the second year, 14 cm the third year, and 12 cm the fourth year.

Both aspen and white spruce showed a general trend of reduced growth as the proportion of aspen increased in the plots. The only exception was crown width of white spruce with the best growth in the mixed-species of Aw50Sw50 or Aw17Sw83 (Fig. 2). The effect of composition became apparent in the second year and increased over time with tree size. By year 4 mean aspen trees were 46% bigger in RCD, 11% taller in total height, and 53% larger in crown width as aspen proportion decreased from 100% to 17%, while the corresponding changes in white spruce were 41%, 18%, and 3% with aspen proportion decreasing from 83% to 0%.

Irrigation did not affect seedling growth of either species until the fourth year. At the end of fourth year, irrigated aspen averaged 38.7 mm in RCD, 296 cm in height, and 107 cm in crown width, compared to 35.5 mm, 256 cm, and 98 cm for the non-irrigated control trees (P=0.005, 0.0001, and 0.0008 for the three growth parameters). By year 4, irrigated spruce trees averaged 21.3 mm in RCD, 95 cm in height, and 62 cm in crown width, while non-irrigated spruce averaged 20.5 mm, 88 cm, and 60 cm, respectively (P=0.0172, 0.0001, and 0.0103). Irrigation increased aspen growth by 9%, 16%, and 9%, and spruce growth by 4%, 8%, and 3%, respectively. The relation between growth and species composition was also significantly different between irrigated and controlled plots for spruce at year 4 (P=0.0004 for RCD, 0.0004 for height and 0.0005 for crown width for the irrigation and composition interaction).

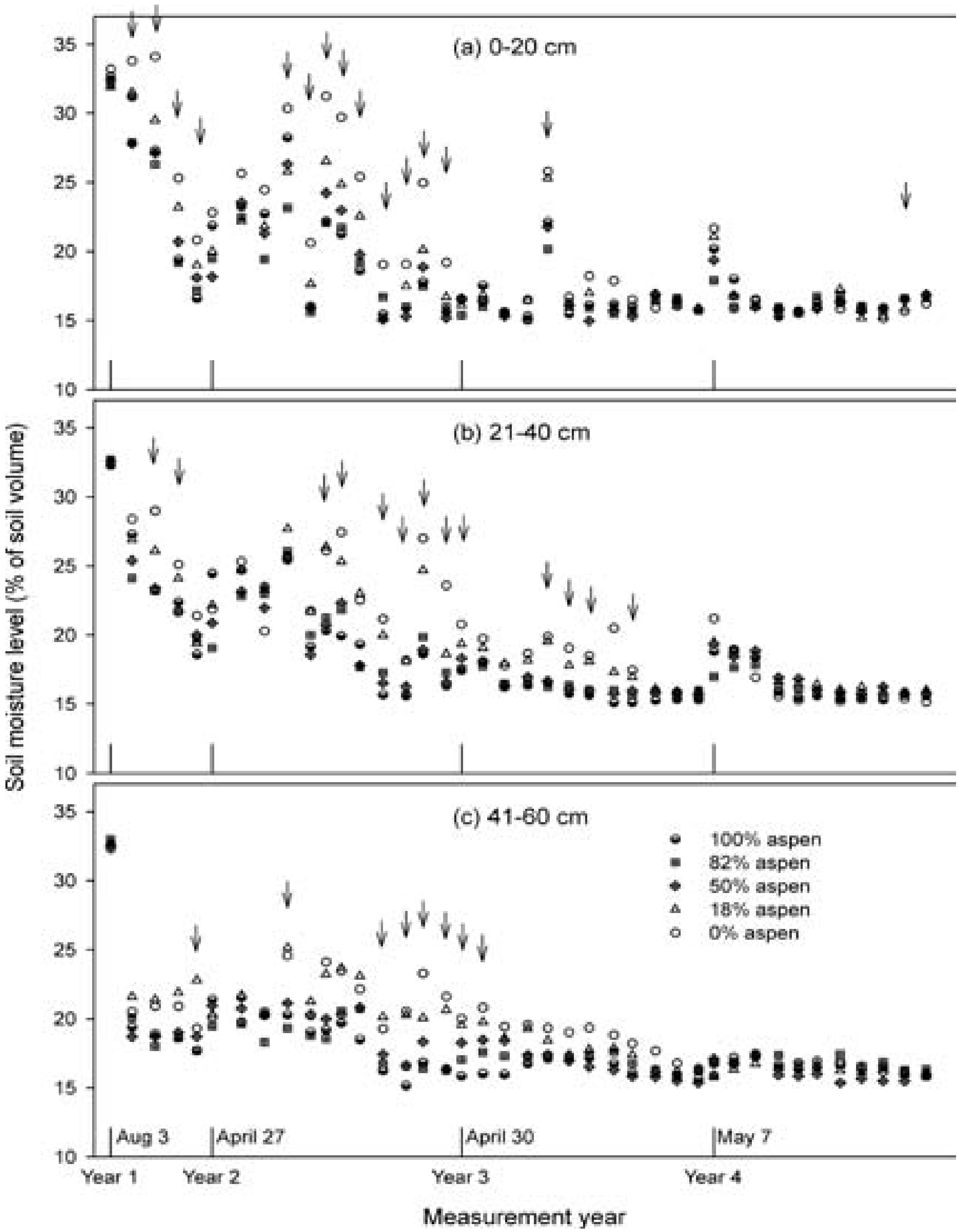

Figure 1. *Mean soil moisture by tree species composition at three depths in aspen - white spruce mixture study in Alberta (arrows indicate significance).*

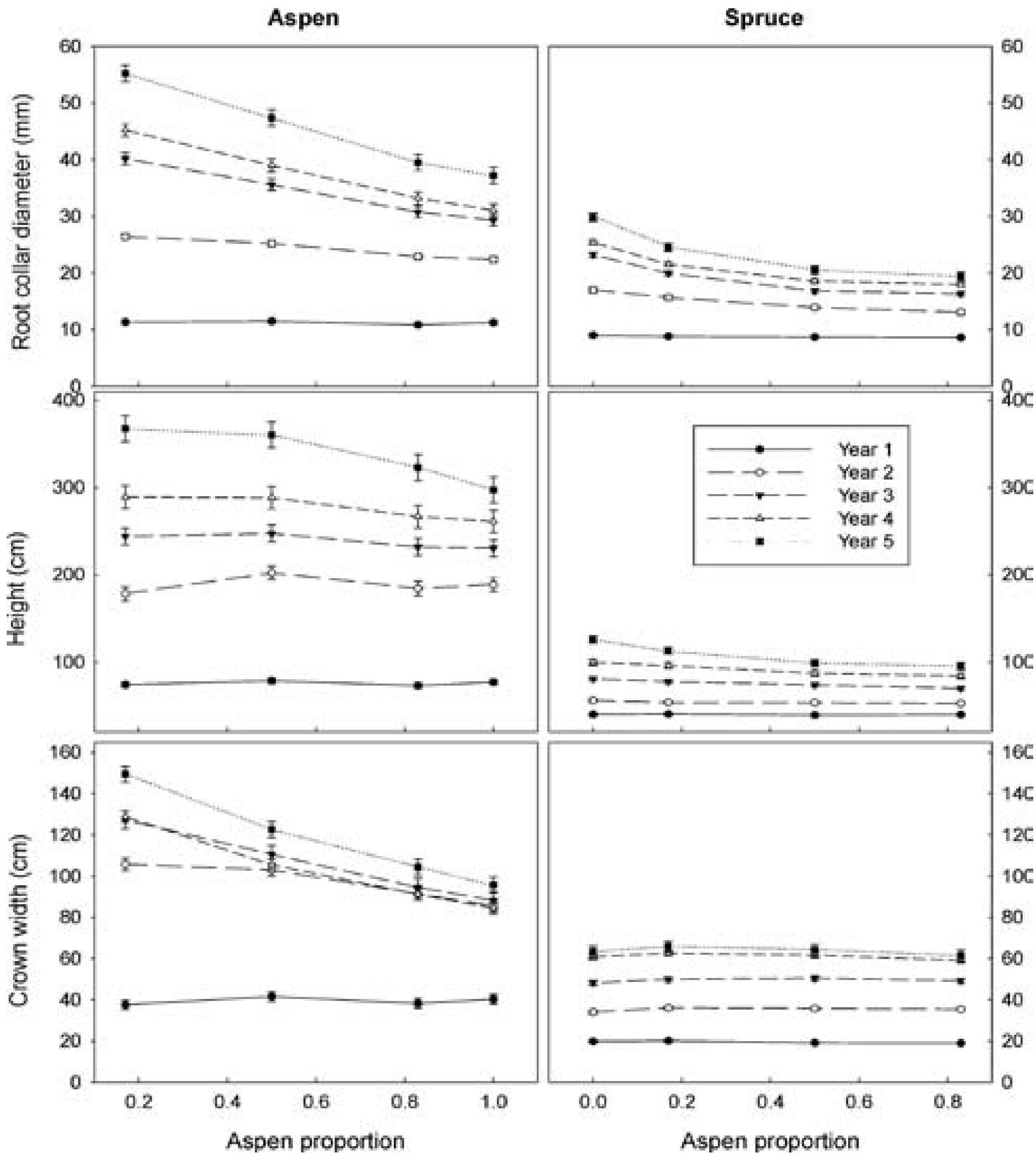

Figure 2. *Relationships between seedling growth and proportion of aspen in mixed plantings in the first four years after establishment in Alberta.*

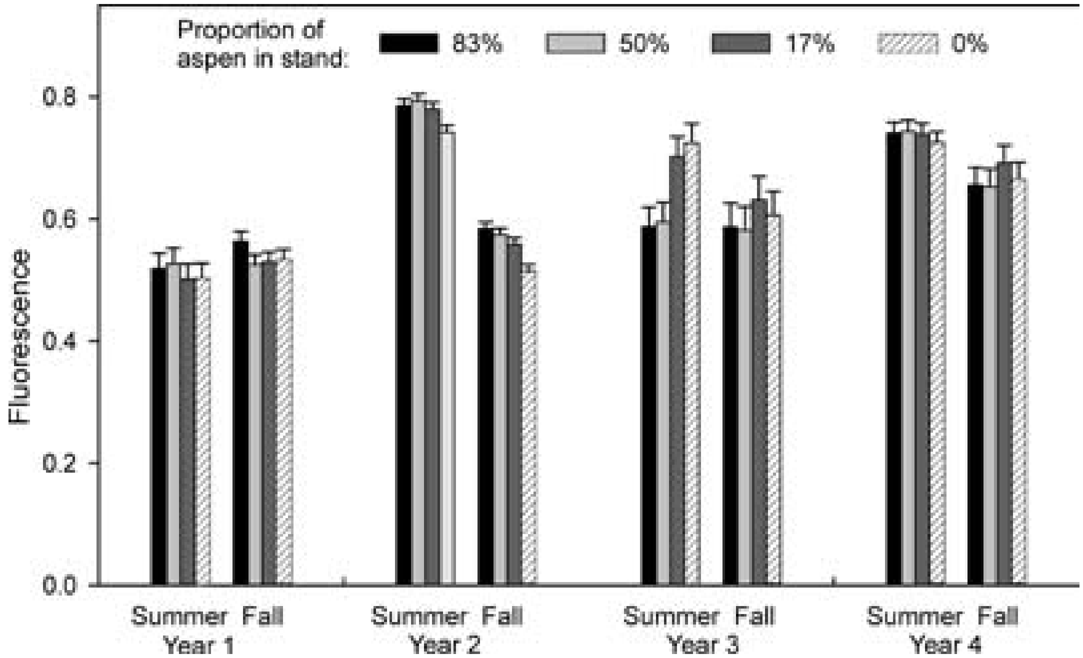

Figure 3. *Chlorophyll fluorescence of white spruce in mixtures by proportion of aspen, season, and years after planting.*

Fertilization did not change the growth of aspen, but reduced height and crown development of white spruce in year 3 and 4 (P<0.0001). By the end of year 4, fertilized seedlings averaged at 86 cm in height and 59 cm in crown width, which was 12% and 8% smaller than seedlings in the non-fertilized control.

Foliar nutrient and chlorophyll florescence

The calcium level increased proportionally with the decrease of aspen proportion from 0.81% in the Aw83Sw17 plots to 0.94% in Sw100 plots (P=0.0543), while magnesium level changed from 0.16% in the Sw100 to 0.19 in Aw83Sw17 plots (P=0.0267). Significant composition effect on foliar nutrient levels of aspen trees was only observed on sodium concentration, which was 0.11% in Aw100 plots and 0.02, 0.03, and 0.01% for the three mixed-species plots.

Irrigation treatment enhanced foliar P levels in aspen from 0.24% in the irrigated plots to 0.23% in the control (P=0.0019). In white spruce, irrigation increased the foliar total N from 1.76% in the control to 1.84% in the treated plots (P=0.0016), but decreased total P (0.19% and 0.17% for control and treated plots, P<0.0001) and K (0.70% and 0.65% for control and treated plots, P=0.0011) concentrations. Fertilization did not change the foliar nutrient levels for aspen or white spruce.

A significant difference in chlorophyll fluorescence of white spruce was evident among the four species compositions in the second (P<0.0001 for the summer and P=0.0002 for the fall measurements) and third years (P<0.0001 and P=0.0415 for the two measurements). Readings in the second year were higher in the high aspen proportion plots, particularly in the fall, while the opposite was observed in the third year when chlorophyll fluorescence appeared to be higher in the low aspen proportion plots (Fig. 3).

Plot volume and leaf area index

The relative volume production of mixed-species plots by irrigation treatment is presented in Table 1. The data indicate a general increase in aspen and a decrease in spruce relative volume production over time after planting. The increase of aspen relative volume is greater than the decrease of spruce volume, particularly in the Aw50Sw50 plots. As a result, the mixed-species plots produced more volume (greater relative volume total) than pure species plots on relative basis by year 4. The relative volume production gain in mixed-species plots differs with irrigation treatment and is generally higher for irrigated plots.

The greater volume production in the Aw50Sw50 is supported by the LAI measurements starting in the second year (Table 2). The LAI in year 4 was also increased by irrigation (4.02 vs 3.03 for irrigated and control plots, P<0.0001), but decreased by fertilization (3.43 vs 3.64 for irrigated and control plots, P=0.0255).

Table 1. *Relative volume production for mixed aspen (Aw) and white spruce (Sw) plots in the first four years after establishment.*

Year	Aw83Sw17			Aw50Sw50			Aw17Sw83		
	Aw	Sw	Total	Aw	Sw	Total	Aw	Sw	Total
Irrigated plots									
1	0.80	0.18	0.98	0.62	0.51	1.13	0.28	0.81	1.09
2	0.84	0.10	0.94	0.74	0.32	1.06	0.24	0.73	0.97
3	0.90	0.07	0.97	0.85	0.24	1.09	0.37	0.62	0.99
4	0.97	0.07	1.04	0.91	0.23	1.14	0.46	0.60	1.06
Control plots									
1	0.75	0.16	0.91	0.61	0.44	0.95	0.19	0.76	0.95
2	0.84	0.10	0.94	0.63	0.32	0.94	0.23	0.63	0.85
3	0.94	0.08	1.02	0.73	0.24	0.98	0.34	0.55	0.89
4	0.96	0.08	1.04	0.82	0.24	1.06	0.37	0.54	0.91

Table 2. *Leaf area index (means ± standard errors) of aspen (Aw) and white spruce (Sw) mixtures in the first few years after planting.*

Year after planting	Aw100	Aw83Sw17	Aw50Sw50	Aw17Sw83	Sw100
Year 2	2.45 ± 0.18	2.45 ± 0.18	2.36 ± 0.18	1.74 ± 0.18	1.07 ± 0.18
Year 3	3.66 ± 0.40	3.48 ± 0.40	3.63 ± 0.40	3.37 ± 0.40	2.15 ± 0.40
Year 4	3.38 ± 0.17	3.59 ± 0.17	3.91 ± 0.17	3.59 ± 0.17	3.22 ± 0.17

Discussion

Aspen leaves have less control of water loss than spruce (Jarvis and Jarvis 1963), which may explain why aspen were more sensitive to drought during the experiment. Mean growth increases of aspen in response to irrigation treatments were almost twice those of white spruce: 9%, 16%, and 9% versus 4%, 8%, and 3% for RCD, total height, and crown width, respectively. The greater response of height growth suggests that tree height is more sensitive to drought than RCD or crown width. The improvement of tree growth by irrigation may be the result of higher soil moisture and greater soil nutrient availability. For example, irrigation may have enhanced foliar concentration of total P in aspen and total N in spruce.

High water consumption by aspen on per unit leaf area basis (Peterson and Peterson 1992) may have resulted in lower soil moisture on the higher proportion aspen plots and reduced individual tree growth for both species. Again, aspen seems more sensitive to the change of aspen density, especially in crown width. Besides soil moisture, competition for light is also responsible for the strong response of RCD to the variation of aspen density in both species. In aspen, there was a close relationship between crown width and aspen density, while white spruce show little difference in crown width with aspen density. Species composition also affects soil P availability and foliar concentrations of total Ca and total Mg in spruce and total Na in aspen, likely due to the different demand for nutrients between aspen and white spruce (Peterson and Peterson 1992).

The lack of response to fertilization treatment in both aspen and spruce is likely attributed to the adequate soil nutrient supplies, as indicated by soil and foliar analysis and absence of visual symptoms for nutrient deficiency (Ballard and Carter 1983; van den Driessche 1989). Nutrient availability may have been reduced by low soil moisture from the drought. van den Driessche and Ponsford (1995) found that the increase of nitrogen availability through fertilization created requirements for other nutrients, which could induce nutrient deficiency. This may be the main reason for negative growth response of spruce to fertilization in this study.

The results of this study support current mixedwood practices that create mixedwood stands with equal proportions of hardwood and conifers. High initial density may result in the interaction between aspen and white spruce in the planted mixtures by year 4 being similar to that of 20- to 30-year-old stands established at 2- to 3-m spacing, based on LAI (Lieffers et al. 2002) and crown development. As species interaction in mixtures may intensify with the growth of crown width, the mixedwood productivity gain might shift to mixtures with a smaller proportion of hardwood and reach to a higher level with the reduction of stand density as trees age, as indicated by Man and Lieffers (1999) in examining unmanaged natural mixedwood stands in Alberta.

Both LAI and relative volume production show a similar trend among treatments and over time. LAI in pure aspen plots peaked at year 3 and started to decline by year 4, while LAI of pure spruce and mixed-species plots continue to increase (Table 2). At the end of year 4, mixed-species plots carried a greater LAI than pure species plots and the highest LAI was in the Aw50Sw50 plots.

Because of competitive advantage of aspen over spruce, relative volume production of aspen increased and that of spruce decreased from year 1 to 4 after planting (Table 1). However, the change in volume production is smaller in spruce, likely due to shade tolerance. White spruce may also photosynthesize during spring and fall when aspen is lacking leaves (Man and Lieffers 1997).

This study shows that species mixtures of aspen and white spruce can produce more volume. A similar volume production gain is expected for natural mixedwood stands under similar weather conditions. It is unclear from this study if non-irrigated control plots can achieve similar volume gains within a longer period of time.

In this study aspen and white spruce were grown in mixtures in the aspen parkland zone of Alberta. The weather in this zone is dry and restricts tree growth, compared to boreal forest zone (Hogg and Hurdle 1995). With a greater availability of rainfall and therefore soil moisture in the boreal mixedwood zone and eastern boreal forest, mixedwoods may provide a greater volume gain possibly at earlier stages of stand development.

Acknowledgements

This study was supported by Alberta-Pacific Forest Industries Inc. and Alberta Research Council. The authors thank Marie Gorda, Amar Varma, and Dave Kelsberg for their help with plot set-up and data collection, and Smoky Lake Forest Nursery and K & C Silviculture for providing seedlings.

Literature cited

Ballard, T.M. and Carter, R.E. 1983. Evaluating stand nutrient status. BC Min. For., Victoria. Land Management Report #20. 76 p.

Hogg, E.H. and Hurdle, P.A. 1995. The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? Water, Air Soil Pollut. 82:391-400.

Kelty, M.J. 1992. Comparative productivity of monocultures and mixed species stands. Pp. 125-141. *In* Kelty, M.J., B.C. Larson, and C.D. Oliver, eds. The Ecology and Silviculture of Mixed-Species Forests. Kluwer Academic Publishers. Dordrecht, Netherlands. 287 p.

Jarvis, P.G and Jarvis, M.S. 1963. The water relations of tree seedlings. IV. Some aspects of the tissue water relations and drought resistance. Physiol. Plant. 16(3): 501-16.

Lieffers, V.J., Pinno, B.D., and Stadt, K.J. 2002. Light dynamics and free-to-grow standards in aspen-dominated mixedwood forests. For. Chron. 78: 137-145.

MacDonald, G.B. 1995. The case for boreal mixedwood management: an Ontario perspective. For. Chron. 71:725-734.

Man, R. and V.J. Lieffers. 1997. Photosynthesis of *Picea glauca* and *Pinus banksiana* saplings in relation to season and temperature. Can. J. Bot. 75: 1766-1771.

Man, R. and V.J. Lieffers. 1999. Are mixtures of aspen and white spruce more productive than single species stands? For. Chron. 75:505-513.

Peterson, E.B. and Peterson, N.M. 1992. Ecology management, and use of aspen and balsam poplar in the prairie provinces. For. Can. Northw. Reg., North. For. Cent. Edmonton, AB. Spec. Rep. No. 1. 252 p.

Rowe, J.S. 1972. Forest regions of Canada. Dep. Environ. Can. For. Serv., Ottawa, Ont. Publ. 1300. 172 p.

Soil Classification Working Group. 1998. The Canadian system of soil classification. Third Edition. Res. Br., Agriculture and Agri-Food Canada. Publ. 1646. Ottawa, NRC Research Press.

Van den Driessche, R. 1989. Nutrient deficiency symptoms in container-grown Douglas-fir and white spruce seedlings. BC Min. For., Victoria. 29 p.

Van den Driessche, R. and Ponsford, D. 1995. Nitrogen induced potassium deficiency in white spruce (*Picea glauca*) and Engelmann spruce (*Picea engelmannii*) seedlings. Can. J. For. Res. 25: 1445-1454.

Vandermeer, J. H. 1989. The Ecology of Intercropping. Cambridge University Press. Cambridge, UK. 237 p.

The Influence of Mycorrhizal Inoculation and Site Preparation on the Extended Season Planting of Jack Pine (*Pinus banksiana* Lamb.) Seedlings in Northwestern Ontario

R.J. Murphy, J.R. Wang

Lakehead University, Faculty of Forestry and the Forest Environment,
955 Oliver Road, Thunder Bay, ON P7B 5E1

Since tree planting became a focus in Ontario in the 1960s it has been limited to early May through late June or early July each year. The suspension of planting efforts through July and August is considered necessary due to the drought and high temperature conditions in those months. Such conditions are not conducive to the successful establishment and growth of coniferous seedlings. Over recent years however, many advances in seedling cultural techniques have been developed which may increase the tolerance of seedlings to the stresses associated with summer planting. Among these is the use of mycorrhizal inoculation which results in a more branched root system with greater surface area. This facilitates the uptake of water and nutrients after outplanting, as well as increasing the seedlings stress resistance.

The overall objective of this project was to test the efficacy of mycorrhizal inoculation and mechanical site preparation treatments in successfully extending the operational tree planting season for jack pine in northwestern Ontario. In order to address the overall and other, more specific objectives, a large field trial was established over the spring and summer of 2001 and 2002. Morphological and physiological monitoring took place for three field seasons (2001 through 2003) and may continue again in future years to determine longer term results.

The results of this research project could be of significance to all those involved in the science and practice of silviculture. An extended planting season would allow nurseries and forest companies greater flexibility in scheduling and create the opportunity for more intensive reforestation efforts. Silvicultural contractors, nursery owners and industry would also be able to provide longer term contracts to their seasonal workforce.

Gap Planting In Conifer Pure Stand In Japan

Y. Ochiai, M. Ishizuka

Forestry and Forest Product Research Insititute, 1 Matsunosato, Tsukuba, 305-8687, Ibaraki, Japan

Introduction

Gap planting was introduced in Negara Brunei Darussalam for enriching the secondary forests degraded by a logging operation[1]. Gap planting resembles the regenerating process in the natural forests. In the cases of the natural forests, when a large mother trees falls, a gap is created and the seedlings in the gap start to grow quickly.[1][2][3]

One of the advantages of gap planting is the flexibility of the site. The site for gap planting can be selected at the site suitable for the quick growth. Each species has the site preference according to their own characteristics. In other words, the ecological site preference is closely related to the silvicultural site preference. If the site is properly selected, the seedlings grow quickly. Another advantage of gap planting is the micro-climate in the gap. The sunlight and soil water is more preferable in the gap than those in the surrounding forests. The seedlings in the canopy gap can grow faster than those under the forest canopy.

In Negara Brunei Darussalam, the gap planting is aimed to enhance the quality of the forests. In this report, the gap planting is carried out for enhancing the biodiversity of artificial forests of pure conifer stand. The four broad-leaved species are planted on the ridge, middle and lower slopes in both of gaps and forests. The gap planting as the method of under-planting and the silvicultural site preference of planted species will be discussed.

Experimental Site and Method

The experimental site is located in Tengakura experimental forest of Forestry and Forest Product Research Institute in Ibaraki prefecture, Japan (Fig.1). The altitude of the site is about 250m above see level. The upper trees were *Chamaecyparis obtusa* (Hinoki) on the ridge and upper part of the slope and *Cryptomeria japonica* (Sugi) on the lower part of the slope.

Three plots were set inside the site, March 2003. Those three plots were located on the different topography such as the upper, middle and lower plot (Fig. 2). The upper plot is located on the wide and flat ridge, the lower plot is at the foot of the slope and the middle plot is on the slope between the former two plots. The topography of the upper, middle and lower plot is flat, very steep and relatively flat. The size of each plot is 10 m x 20 m. Each plot contains a canopy gap and forest canopy. The seedlings of four species (*Quercus myrsinaefolia,*

Figure 1. *Location of experimental site in Japan.*

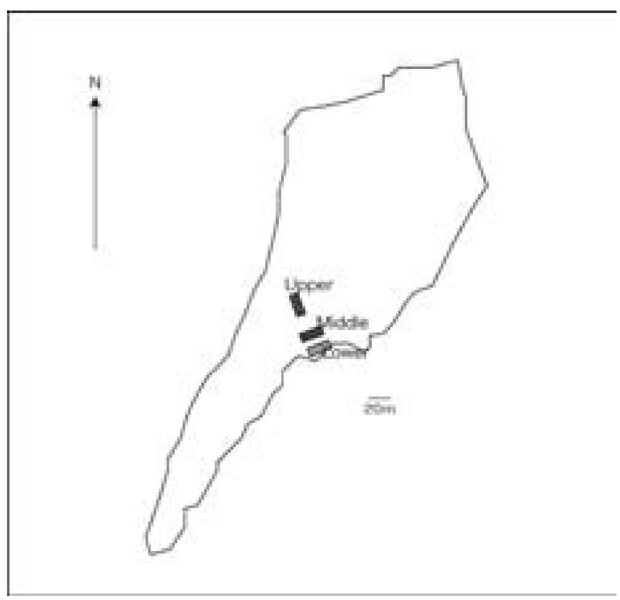

Figure 2. *Tengakura experimental forest and plots.*

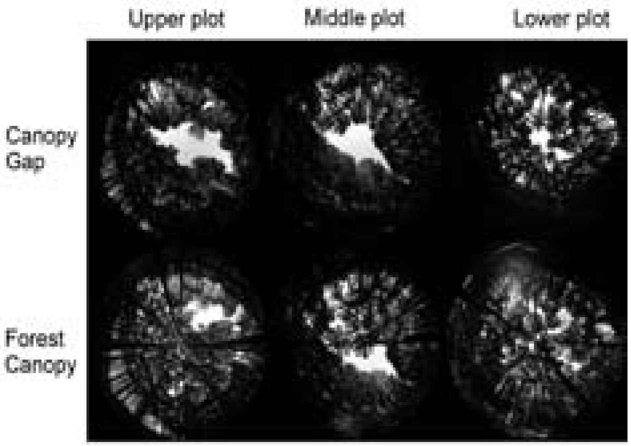

Figure 3. *Hemispherical pictures of canopy gap and forest canopy of three plots.*

Quercus serrata, Zelkova serrata and Zelkova serrata 'Musashino') were under-planted in each plot. In each plot, twenty seedlings of *Quercus myrsinaefolia, Quercus serrata* and *Zelkova serrata* and fifteen seedlings of *Zelkova serrata 'Musashino'*were under-planted with the spacing of 2 m. The diameter at breast height (DBH) and tree height of all trees inside each three plot. The diameter at ground level and height of all under-planted seedlings were measured March 2003, December 2003 and November 2004.

Results and Discussion

a. Upper trees

The DBH and height of the upper trees are shown in Table 1. The upper trees in the upper plot are *Chamaecyparis obtusa* of 57 years old. The average DBH and height are 22.6 cm and 16.1m. The upper trees in the middle plot are mixture of *Chamaecyparis obtusa* of 33 years old and *Cryptomeria japonica* of 57 years old. The average DBH and height of *Chamaecyparis obtusa* are 18.2 cm and 13.0 m and those of *Cryptomeria japonica* are 17.8 cm and 13.4 m. The upper trees of the lower plot are *Cryptomeria japonica* of 57 years old with 31.1 cm and 21.4 m of DBH and height. The growth of upper trees is not different from the trees growing the surrounding area.

b. Diameter growth of seedlings

The diameter increment of four species is shown in Fig. 4. The seedlings are divided into six categories of canopy gap and under forest canopy, in upper, middle and lower plot. The seedlings of *Quercus myrsinaefolia* show the least increment. The seedlings are assumed to have lower quality compared to the other three species. The seedlings of this species in canopy gap of upper and middle plots show the fastest growth in diameter.

Table 1. *Average diameter and height of upper trees in experimental site.*

Location	Species	DBH (cm)	H (m)	Age (year)
Upper	*Chamaecyparis obtusa*	22.6	16.1	57
Middle	*Chamaecyparis obtusa*	18.2	13.0	33
	Cryptomeria japonica	17.8	13.4	57
Lower	*Cryptomeria japonica*	31.1	21.4	57

Quercus serrata shows the largest increment in the canopy gap of the middle plot followed by the seedlings in the canopy gap of the upper plot. This species shows the least increment under forest canopy both of the middle and lower plot. This species is distributed on a ridge and upper part of the slope in undisturbed conditions. The ecological preference of this species is reflected to the silvicultural preference.

Zelkova serrata is famous for its high quality timber in Japan. The diameter growth shows the largest increment in the canopy gap both of the middle and lower plots. This species is distributed in the middle and lower part of the slopes. The ecological preference of this species is also related to the silvicultural preference.

Zelkova serrata 'Musashino' is one of the varieties of *Zelkova serrata*. Although *Zelkova serrata* has high quality timber, its defect is its multi-shoot. This subspecies has a up-straight trunk. *Zelkova serrata 'Musashino'* is planted for the possibility of straight timber. *Zelkova serrata 'Musashino'* shows the largest diameter increment in the canopy gap of the middle and upper plots.

c. Height growth of seedlings

The height increment is less stable (Fig. 5) than the diameter increment because the small animals disturb the growth, especially in the lower plot. They cut the trunk of planted seedlings. As the result, many seedlings decrease in height. Most of *Quercus myrsinaefolia* seedlings decreased in height during two years after planting. The only exception is the seedlings planted in the canopy gap of the middle plot. One of the reasons of decrese is low quality of the seedling.

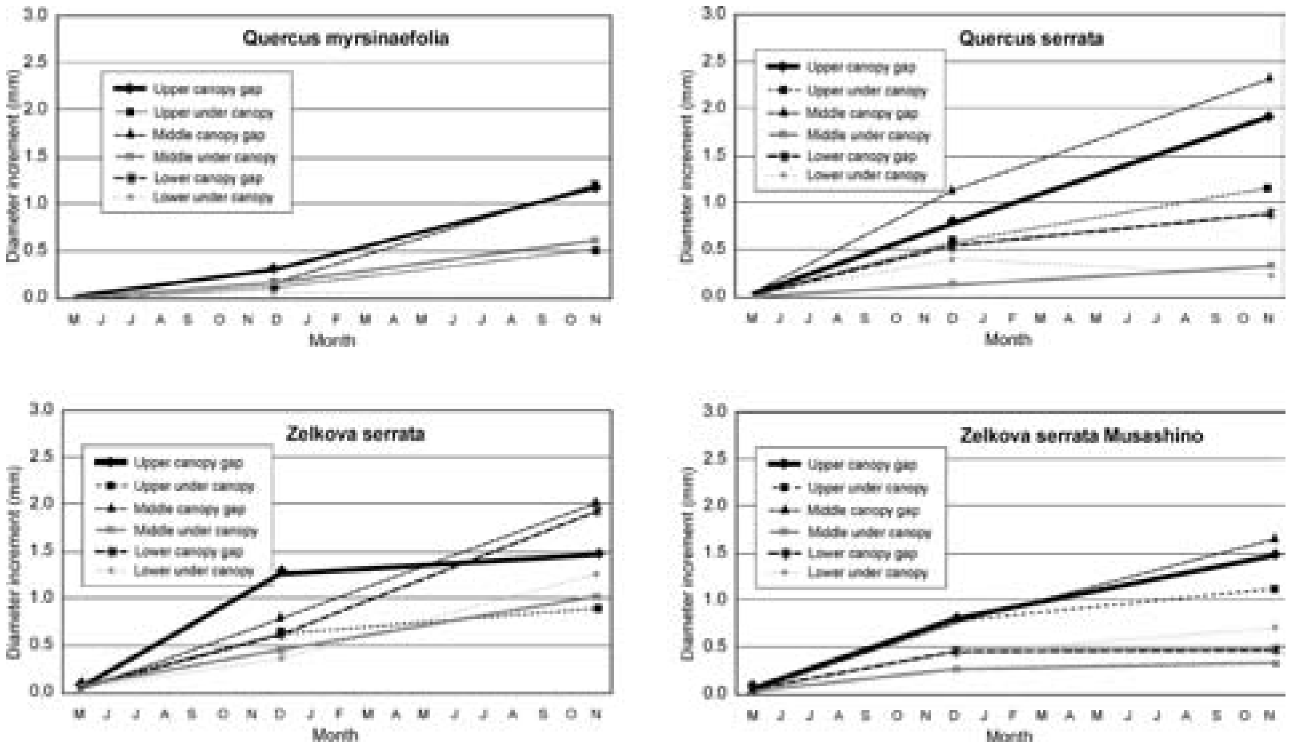

Figure 4. *Diameter increment.*

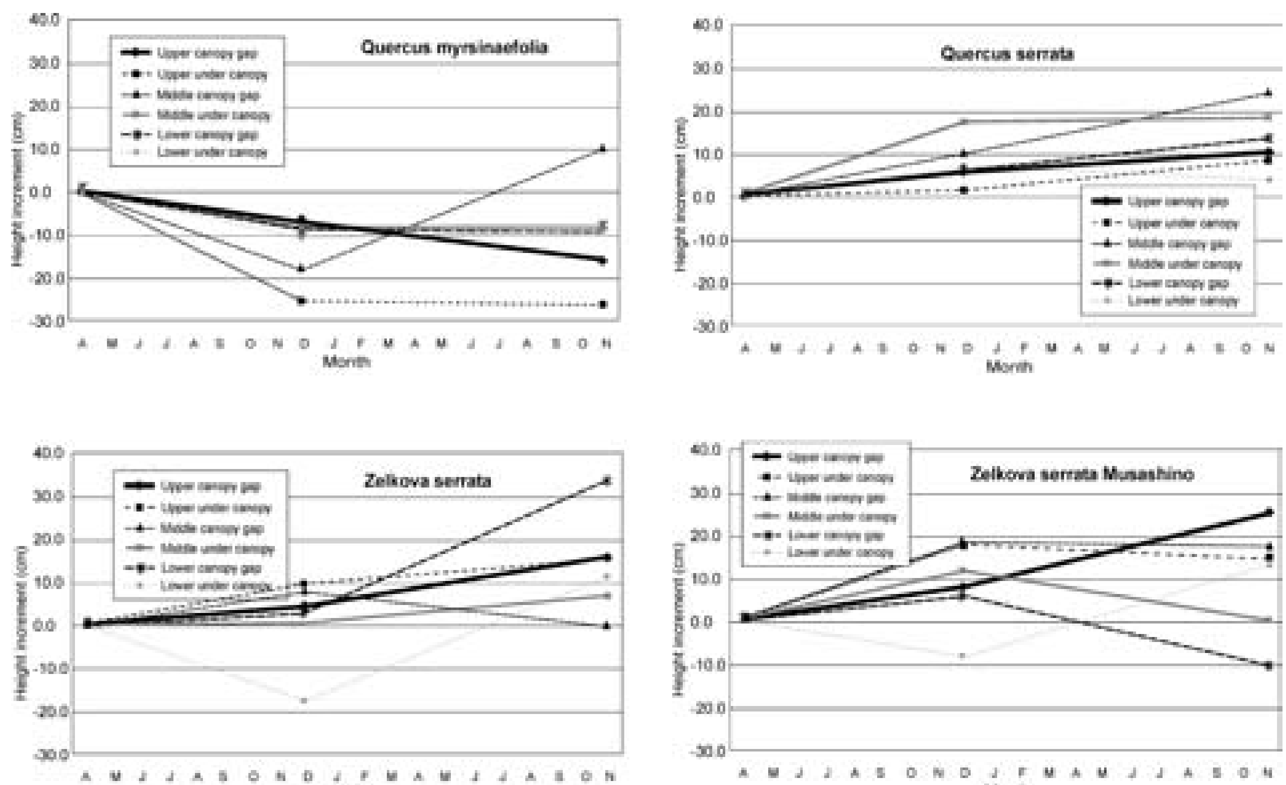

Figure 5. *Height increment.*

Most of seedlings of *Quercus serrata* show constant growth. The seedlings in canopy gap of the middle plot have the largest increment. The seedling height of *Zelkova serrata* decrease in the forest canopy of the lower plot first year because of the damage by the animal. The seedlings in the canopy gap of the lower part show the greatest height increment. *Zelkova serrata 'Musashino'* decrease in height in the lower plot. The height increment of this species is larger on the upper part of the slope.

The relationship of the height increment between the siilvicultural and ecological site preference is less clear than that of the diameter increment. The silvicultural site preferences of four species are slightly related to the ecological site preferences.

d. Site preference

These results are similar to those in Brunei Darussalam. *D. aromatica* which is distributed on the top of the ridge grow quickly on the upper and middle of the slope, *D. lanceolata,* which is distributed on the middle of the slope grow quickly only on the middle of the slope and *D. beccarii,* which distributed both on the ridge and middle of the slope grow quickly on the upper, middle and lower part of the slope. In this experiment, although more years of observation are necessary, it is obvious that when the site is decided, the silvicultural and ecological site preferences should be considered.

Although these are only second year results, the gap planting seems to be effective in enriching the biodiversity of the pure conifer stand in Japan. When carrying out the gap planting, the location of canopy gap is important. The ecological site preference should be considered at the decision of the location.

Literature cited

1) Ochiai Y., M. Alimanar and A.R. Yusop; Natural distribution and suitable method for plantation of two *Dryobalanops* species in Negara Brunei Darussalam, Bul. FFPRI, 31-56, 1994

2) Ochiai Y., Okuda S. and Sato A.: The influence of canopy gap size on soil water condition in a deciduous broad-leaved secondary forest in Japan, J.Jpn. For.Soc., 76(4), 308-314, 1994

3) Ishizuka M., Ochiai, Y., Utsugi, H.; Microenvironments and growth in gaps, Ecological Studies, Vol.158, 229-244, 2002.

Effects of Early Herbaceous and Woody Vegetation Control on Seedling Microclimate and Physiology of Eastern White Pine

W.C. Parker[1], D.G. Pitt[2], A. Morneault[3], A. Stinson[4], F.W. Bell[1]

[1]Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, ON P6A 2E5
[2]Canadian Forest Service, 1219 Queen St., E., Sault Ste. Marie, ON P6A 2E5
[3]Ontario Ministry of Natural Resources, 3301 Trout Lake Rd., North Bay, ON P1A 4L7
[4]Tembec, Canadian Ecology Centre, Box 430, #6905 Hwy 17 W, Mattawa, ON P0H 1V0

In 2000, an experiment was established to quantify the temporal and spatial effects of woody and herbaceous vegetation on seedling microclimate and physiology of planted eastern white pine (*Pinus strobus* L.) seedlings in a clearcut and a uniform shelterwood near North Bay, Ontario. Treatments included the continuous (i.e., 5 year) control of woody vegetation (W), herbaceous vegetation (H), both types of competition (B), and no competition control (0). On 3 replicate plots of each of these 4 treatments, seedling microclimate was monitored the first 3 (shelterwood) and 4 (clearcut) growing seasons after planting. Periodic, diurnal assessments of leaf gas exchange and seedling water status were conducted on these same plots, beginning in the second growing season after planting at the clearcut (growing seasons 2 through 4) and shelterwood (growing seasons 2 and 3) sites. Total daily photon flux density (PFD) did not differ among treatments at the clearcut until the second growing season, after which the 0 and H treatments had lower PFD than the W and B treatments, with comparative treatment differences increasing over time, as competing vegetation developed. In contrast, the shelterwood overstory reduced understory light levels to about 50% of full sunlight, the threshold for maximum height growth of white pine. Further reductions in PFD were exhibited only in the 0 and H treatments. Treatment effects on mean seasonal soil moisture content in the top 15 cm of mineral soil (SMC) were accentuated during periods of little rainfall at the clearcut, with the B treatment having higher SMC values than the 0 treatment. Competition for soil moisture during drought periods was more intense in the 0 and W treatments than in the H and B treatments. By comparison, vegetation management treatments had less influence on SMC in the shelterwood than the clearcut, even during periodic drought. In general, low PFD and SMC were associated with reduced photosynthetic potential of white pine seedlings in all 3 growing seasons. Herbaceous vegetation appears to be a greater competitor for soil moisture than woody vegetation during the first two growing seasons after planting. Thereafter, woody vegetation, with its rapidly increasing height and leaf area, become greater competitors for both light and moisture. Observations of seedling physiology and microclimate were strongly correlated with early growth responses.

Effects of Early Herbaceous and Woody Vegetation Control on Eastern White Pine

D.G. Pitt[1], W.C. Parker[2*], A. Morneault[3], L. Lanteigne[4], A. Stinson[5], F.W. Bell[2]

[1]Canadian Forest Service, Great Lakes Forestry Centre, 1219 Queen St. E., Sault Ste. Marie, ON P6A 2E5
[2]Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, ON P6A 2E5
[3]Ontario Ministry of Natural Resources, 3301 Trout Lake Rd., North Bay, ON P1A 4L7
[4]Canadian Forest Service, Atlantic Forestry Centre, P.O. Box 4000, Fredericton, NB E3B 5P7
[5]Tembec, Canadian Ecology Centre, Box 430, #6905 Hwy 17 W, Mattawa, ON P0H 1V0

Eastern white pine (*Pinus strobus* L.) is one of North America's most valuable softwood species. Historically, it thrived in regions characterized by frequent, low-intensity fires that created favourable regeneration conditions. Declining frequency of such fires, coupled with competition, insect, and disease problems, has seriously impeded white pine regeneration efforts. A greater understanding of the vegetation conditions favouring white pine survival, growth, and stem quality would enable more effective management of early stand conditions in the absence of fire.

In 2000, an experiment with 3 installations was initiated to quantify the temporal and spatial effects of woody and herbaceous vegetation on white pine seedlings. A response surface design is being used to combine and test different durations of herbaceous vegetation suppression (0, 2, and 4 years) with various timings of woody vegetation release (time of planting, after second growing season, after fifth growing season, and never). Four different hardwood densities are being studied: 0, 5000, 10000, and 15000 stems per ha. The research sites, situated near North Bay, Ontario, and Doaktown, New Brunswick, address the clearcut and 2 gradients of the shelterwood regeneration systems. After 4 growing seasons, white pine subjected to woody competition control had 1.2 to 1.4 times the stem volume of trees left untended, the earlier release providing the larger gains. In contrast, pine receiving 2 growing seasons of herbaceous competition control averaged 4.3-fold gains in stem volume over untreated trees. Two seasons of herbaceous control, coupled with woody vegetation control, after the 2nd growing season or at the time of planting, increased these gains in volume to 6.0- and 7.7-fold, respectively. These responses to early vegetation control challenge the current operational strategy of planting, waiting 2 growing seasons, and then broadcast releasing with glyphosate (i.e., providing both woody and herbaceous control after the second growing season), which provided 3.0-fold volume gains over untended pine. White pine height growth and weevil avoidance were greatest with either an aspen or a mature pine (shelterwood) overstory, suggesting that early herbaceous competition control and maintenance of a moderate overhead canopy may maximize white pine stem growth and quality.

Mycorrhizal Biotechnology for Reclamation of Oil Sand Composite Tailings and Tailings Land in Alberta

A.M. Quoreshi[1], D.P. Khasa[2], G. Bois[2], J.L. Jany[2], E. Begrand[1], D. McCurdy[3], M. Fung[4]

[1] Symbiotech Research Inc. # 201, 509-11 Avenue, Nisku, AB, T9E 7N5
[2] Forest Biology Research Centre, University of Laval, Quebec, G1K 7P4
[3] Bonnyville Forest Nursery, 5110-55th Avenue, Bonnyville, Alberta, T9N 2M9
[4] Environmental Affairs, Syncrude Canada, Fort McMurray, Alberta, T9H 3L1

Introduction

Reclamation of disturbed land in Alberta with tailings sand (TS) and composite tailings (CT) created by the Canadian oil sands industry is a high priority agenda. Surface mining of oil sands by the Canadian tar sands industry produces huge areas of degraded land in Alberta with composite tailings sand (CT) and tailing sand (TS) that requires reclamation (Fung and Macyk 2000). Over the last 30 years, it is estimated that oil sands extraction has produced over 3 x 10^8 m^3 tailings. Composite tailings are one of the most challenging materials for land reclamation and are generally known to be nutrient poor, with high alkalinity and salinity, extremely low in organic matter, and lack necessary biological activity. Because of prevailing poor soil conditions and lack of biological activity in disturbed land, establishment of vegetation has been challenging, and often requires repeated plantings to offset huge mortality. Mycorrhizal fungi are a crucial component in plant communities and play an essential role in ecosystem establishment and productivity of plant species (van der Heijden et al. 1998, Jonsson et al. 2001).

Improved reclamation of adverse sites has been achieved by inoculating conifer and hardwood tree species with beneficial mycorrhizal fungi (Marx 1991, Malajczuk et al. 1994). It is now an established fact that the presence of microorganisms, particularly mycorrhizal fungi, benefits the vegetation by increasing a plant's ability to survive in difficult sites. Therefore, the presence of mycorrhizae with seedling root system before outplanting must be a major consideration for successful reclamation of disturbed land.

In this summary report, we briefly describe the different types of mycorrhizae, which play an essential role in converting disturbed lands into productive lands. We will also describe several experiments on mycorrhizal inoculation techniques and procedures under commercial forest nursery conditions, different field trials conducted on oil sands tailings, and selection of appropriate species of mycorrhizal fungi for use in reclamation of tailings sands sites. A study on mycorrhizal inoculum potential of reclamation site is also briefly presented. Results are discussed in the context of application of mycorrhizal biotechnology to the revegetation of oil sand areas.

Benefits of Mycorrhizae on Mined Lands Sites

Mycorrhizas are symbiotic associations between plant roots and beneficial fungi, which greatly increase the efficiency of nutrient and water uptake of plants in exchange for carbohydrates (Smith and Read 1997). Other benefits include enhance resistance to pathogens (Duchesne et al. 1988, Krop and Langlois 1990), the ability to buffer plant species against several environmental stresses (Malajczuk et al. 1994), drought resistance, and they can also reduce transplanting shock (Molina et al. 1992; Smith and Read 1997). Mycorrhizal fungi can also improve plant growth and survival in soils contaminated by heavy metals (Jones and Hutchinson 1988) and salt (Azcón and El-Atrash 1997).

Mycorrhizal fungi are considered a necessary component of a self-sustaining ecosystem. The symbiotic association between plant-fungi sometime reduces growth of non-host weeds. Mycorrhizal associations are also known to increase soil biota by stimulating other beneficial microorganisms associated with the rhizosphere. Some mycorrhiza produce a substance called "glomalin" that acts as a soil aggregation agent. Furthermore, mycorrhizal fungi contribute toward carbon sequestration. Up to 30% of soil biomass is a result of mycorrhizal activity. The fundamental importance of the mycorrhizal association in restoration and to improve revegetation is well recognized but the use of inoculation technique in plantation forestry is not extensive in Canada. The primary reason could be the lack of availability of high quality commercial inoculum, improved technology for inoculation in commercial nursery setting, and lack of knowledge on mycorrhizal biotechnology.

In general, native mycorrhizal fungi are present in most healthy ecosystems, but are destroyed by different disturbances. When soil is disturbed, the populations of mycorrhizal fungi and other microorganisms that help plant roots in acquiring water and nutrients can be destroyed. The lack of mycorrhizal fungi on any disturbed areas is the basis of inoculation of seedlings. Furthermore, it is not just to make individual plants mycorrhizal, but it is important to establish the mycorrhizal network in soil that mediate ecosystem function. Therefore, re-establishment of symbiotic fungi should be considered as an essential constituent of any degraded land reclamation program.

Types of Mycorrhizas

Smith and Read (1997) recognize seven types of mycorrhizas depending on the plant and fungus involved. However, four main types of mycorrhizas; arbascular mycorrhizas (AM), ectomycorrhizas (ECM), ectoendomycorrhizas, and ericoid mycorrhizas are important for altering disturbed lands into productive agricultural and forested lands. This report is mainly directed toward ECM and AM (Fig. 1). The ECM, which are generally found on pines, spruces, firs, hemlocks, larches, poplars, beeches, eucalyptus, alders, hickories, and oaks, and formed by basidiomycetes, ascomycetes, also several species of zygomycetes comprising some 5,000 to 6,000 species (Brundrett et al. 1996). Ectomycorrhizas are characterized by the presence of hyphae between root cortical cells producing a net like structure called Hartig net and easily recognized by the presence of mantle or sheath of fungal mycelium that may cover the fine, short feeder roots.

The Arbuscular mycorrhizas (AM) are formed by a small group of fungi in the new phylum Glomeromycota and class Glomeromycetes (Schüβler et al. 2001) of eight known genera and characterized by the development of finely branched hyphae called arbuscules within root cortical cells, where the metabolic exchanges between the fungus and the host plant take place. Arbuscular mycorrhizas do not modify root morphology and the fungal part is invisible without a microscope. All AM fungal species are obligate biotrophs, meaning they depend entirely on the host plant for carbon. This means, unlike ECM fungi, AM fungi cannot be cultured in the absence of plants or artificial nutrient media. AM fungi are more common in agricultural crops, grasses, and some hardwoods (poplars, walnuts, maples, cedars, elms, willows, sycamore, redwoods, ashes, cherries, locusts, alders, oleasters, etc.).

Canadian Oil Sands Industry

Oil sands are naturally occurring deposits of bituminous sand -- a mixture of bitumen, which is a thick sticky form of crude oil, sand, clay and water (Fig. 2). Oil sands deposits are found in several locations around the world. In Canada, oil sands deposits are located in northern Alberta near Fort McMurray about 450 km north of Edmonton city (Fig. 3). Canada has ¾ of the world's oil sands deposits, which comprises 1/3 of the world's known oil reserves. It is estimated that 1.7 trillion barrels of oil in Alberta oil sands deposits and provides approximately 20% of Canada's oil needs.

Three large companies, such as Syncrude Canada Ltd., Suncor Energy Inc., and Albion Sands Energy Inc. are involved in commercially productive operations in Alberta's oil extraction process from oil sands deposits. The mining activity produced vast areas of land

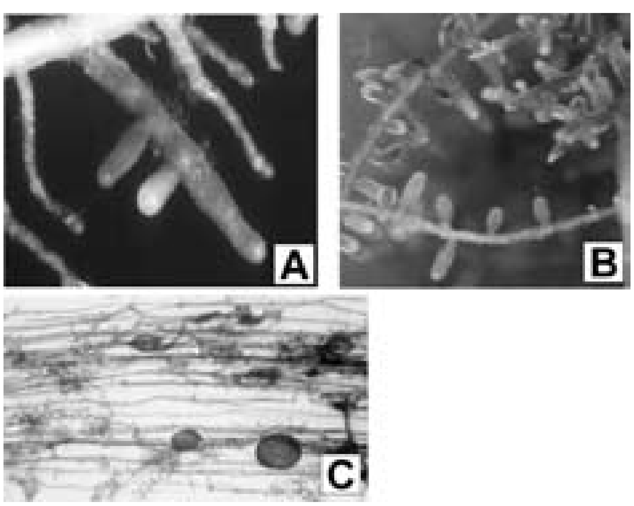

Figure 1. *Examples of morphological features of typical ectomycorrhizas (A, B) and Arbuscular mycorrhizas (C) formation.*

Figure 2. *Oil sand is a mixture of bitumen, sand, water and clay.*

unproductive with little or no biological activity due to production of composite tailings (CT) and tailings sand (TS) as byproducts of extraction process of the oil sands industry. These are a combination of course sand, fine silt and clay, some residual bitumen and water. Tailing sands are alkaline in nature, low in nitrogen and phosphorous, and very low in organic matter content. Development of oil sand industry has a major impact in the natural environment. Therefore, reclamation of these challenging materials is needed.

Briefly the processes in the oil sands industry include, mining the areas, removal of Muskeg and Overburden layers, extraction of raw oil (Bitumen), upgrading of bitumen into sweet light crude oil, returning tailings and overburden to areas, and finally land reclamation.

What is Reclamation?

Reclamation is the process of reconverting disturbed land to its former or any other productive uses. The main objective of reclamation is to reclaim disturbed land to a stable, biologically self-sustaining state as soon as possible. This means creating a landscape with productive capability similar, if not more so, to that before it was disturbed. The re-installation of microbiological activities to mining sites is known to enhance revegetation and reclamation success.

***Figure 3**. Oil sands deposits are found in Northern Alberta near Fort McMurray, Alberta, Canada.*

Inoculum Production

Effective utilization of mycorrhizal biotechnology in forest plantations and revegetation practices depends on the availability of high quality inoculum, improved technology for application of inoculum and an understanding of benefits of using mycorrhizal inoculum for plant development. Any mycorrhizal inoculation program cannot become a regular practice if adequate quantities of efficient inoculum are not available. Several methods of inoculation can be used in practice. Three types of inoculum (Fig. 4) are currently being used in nurseries to inoculate seedlings: (1) vermiculite-peat based solid-substrate inocula, (2) liquid/mycelial slurry inocula, and (3) spore inocula.

Pure vegetative inoculum of selected fungi is recommended as the most biologically effective materials for inoculation since harmful organisms are excluded (Marx and Kenny 1982). ECM fungi are generally grown in the laboratory using a fermentor for large-scale inoculum production. AM fungi cannot be grown on culture media. AM fungi must be cultured with a host plant. AM inoculum typically consists of root fragments, spores, fungal hyphae, and growth medium from the open pot culture method of inoculum production.

Solid-substrate inocula

It is easy to produce sufficient quantities in bag culture either for large trials or research purposes. We used Glucose Yeast Malt Extract (GYME) medium, excellent in producing huge fungal cultures using a fermentor. In

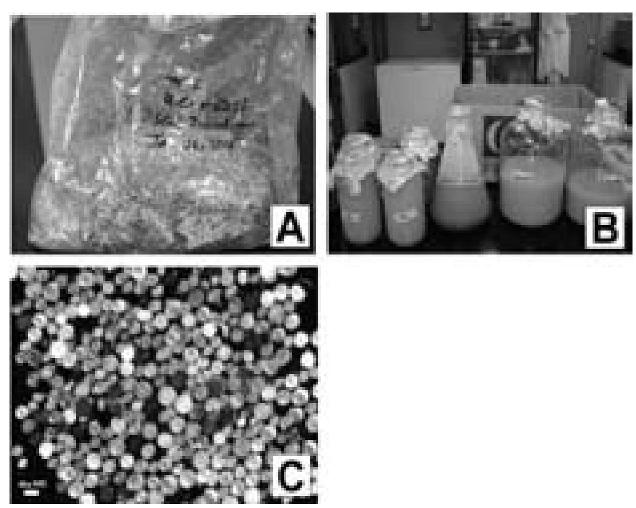

***Figure 4**. Different types of mycorrhizal inoculum can be used for inoculating nursery seedlings. Vermiculite-peat based solid vegetative inoculum in bag culture (A), liquid/mycelial slurry inoculum (B), and spore inoculum (C).*

this process, vermiculite and peat moss moistened with a nutrient solution is inoculated with liquid mycelial culture, produced by either a shake flask or in a fermentor and incubated in the dark for a certain period. The colonized solid substrate (vermiculite-peat) subsequently used as pure vegetative solid inocula mixed with a growing substrate.

Liquid inocula

The liquid inocula are grown from selected fungi on suitable liquid media using shake flask or fermentor. The mycelial suspension was continuously agitated on a mechanical shaker or in fermentor. Before using as liquid inoculum the mycelial suspension needs to be homogenized with a Waring blender. The suspension usually diluted before inoculation with water to obtain desired concentration of propagules/ml in the mycelial slurrey. The liquid inoculum can be mixed with growing substrate at sowing seeds.

The criteria of effective inoculum

The effectiveness of an inoculum is depends on its characteristics as a source of propagules. Fungal biomass should be produce under sterile conditions and must have an appropriate physiological state for high viability and storage capacity.

Mycelia carrier materials should be uniformly coupled with fungal propagules (biomass) and have the capacity to protect the fungal component during the production and handling process. Furthermore, inoculum should be in a form for which no problem in delivery in growing substrate or soil. Finally, a form of inoculum, which is practical and compatible to large-scale production and use, low in volume, easy to ship and handle, and cost effective.

Inoculation of Nursery Seedlings

Inoculation of nursery seedlings is required if the plants are mycorrhizal host species, and the seedlings need to be planted into soil with inadequate mycorrhizal inoculum potential, most importantly, revegetate any disturbed area caused by mining or other disturbances.

In order to obtain a better colonization of ectomycorrhizal fungi in nursery seedling, a slight modification of generous fertilization schedule practiced by commercial nursery is needed. Hunt (1992) recommended that nursery managers should limit application of soluble fertilizers with an upper limit of 80-100 ppm N and 30-35 ppm P.

Currently, inoculation of jack pine and white spruce is being done by our group using both liquid and solid vegetative inocula at Bonnyville Forest Nursery, Alberta. The fungal isolates were isolated from Canadian forests. Several techniques are available to apply inocula during seedling production. However, we found that the most convenient and practical way of inoculating seedlings under commercial nursery seedlings are mixing inocula either solid vegetative or liquid mycelial slurry, with growing substrate at the time of sowing the seeds. Our inoculation program showed successful ectomycorrhizal formation under commercial nursery conditions (Fig. 5). Our results showed that inoculation of jack pine seedlings with different inoculum types and different fungal species resulted in adequate ectomycorrhizal formation between 51 and 90% of short roots.

Application of Microbial Biotechnology in Land Reclamation

Several peer-reviewed research efforts focused on CT phytotoxicity, plant tolerance to saline conditions and establishment of soil microbial activity, and

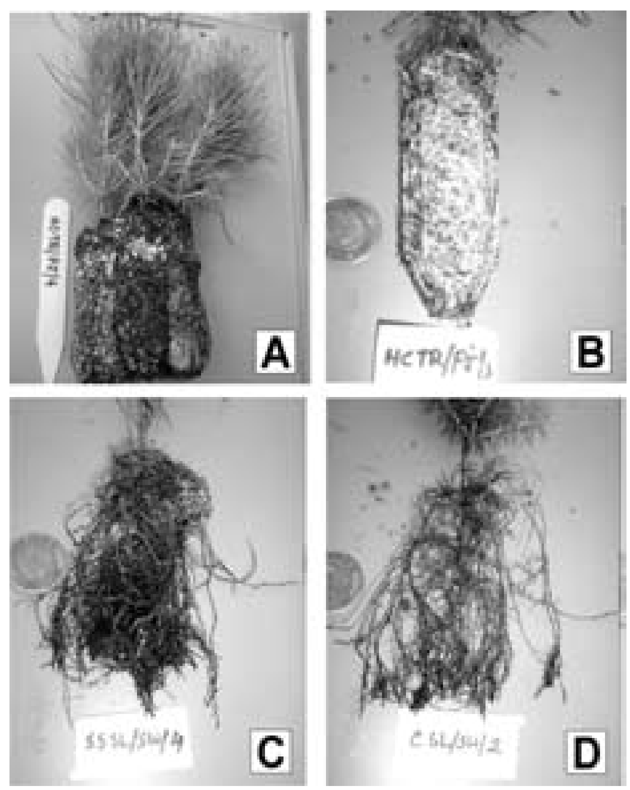

Figure 5. *Containerized jack pine seedlings successfully inoculated with Hebeloma crustuliniforme (A, B). Note white mass of fungal mycelia covered the root plug. Compare the root system of inoculated (C) with Suillus sp. and non-inoculated (D) white spruce seedlings.*

emphasized the use of mycorrhizal fungi to enhance plant establishment.

As an application of mycorrhizal biotechnology in reclamation of Canadian oil sands areas, our group has involved in several nursery and field trials. One of our efforts was to evaluate mycorrhizal inoculum (ECM and AM) potentials of reclamation materials and tailing sands from Canadian oil sand areas (source: Bois et al. 2005). In this study, jack pine, hybrid poplar and red clover plants were used in a greenhouse bioassay to evaluate the mycorrhizal inoculum potential of composite tailing sands (CT. The inoculum potential was also compared with three other reclamation materials, such as common tailing sands (TS), deep overburden (OB), and muskeg peat (MK) and with three sites reclaimed in different years. Results of this study indicated that CT was completely devoid of mycorrhizal propagules, while all other materials showed some level of inoculum potential. CT & TS were also devoid of ECM propagules. Controlled inoculation of seedlings in the nursery with selected strains could compensate for low natural inoculum potential and improve outplanting performance. Details of this study can be obtained from Bois et al. 2005.

In another experiment, in vitro selection of the most promising ectomycorrhizal fungi was obtained for use in the reclamation of saline-alkaline habitats (source: Kernaghan et al. 2002). The main objective was to identify appropriate ECM species for tolerance and use in saline-alkaline composite tailings (CT) sites. Pure cultures of several fungal species indigenous to the Canadian boreal forest were grown on media containing different levels of $CaCl_2$, $CaSO_4$, NaCl, Na_2SO_4, and on media containing CT release water. Among the fungal isolates tested, members of the Boletales, mainly *Suillus brevipes, Rhizopogon rubescens* and *Paxillus involutus*, and *Amphinema byssoides* (Aphyllophorales) were most sensitive to alkalinity and their growth was completely inhibited by CT release water. However, *Laccaria* and *Hebeloma* spp. showed tolerance to alkalinity and survived on the medium with CT release water. Calcium chloride proved to be the most toxic of the salt tested in this experiment. This study recommends inoculating seedlings with a combination of fungal species; each with its own beneficial characteristics is suitable for CT site. *Laccaria bicolor* is recommended for its rapid growth and overall salt tolerance, *Hebeloma crustuliniforme* is recommended for its excellent tolerance to the CT release water, as well as *Wilcoxina mikolae* for its tolerance to $CaCl_2$.

Syncrude Canada Inc. has been using several amending materials to amend the disturbed areas and reclamation. These include LFH, fresh peat, and stockpiled peat. One study by our group is in progress to evaluate the inoculum potential and ECM diversity of these three different amending materials. The aim of this experiment is to assess both quantitatively and qualitatively, and to draw an inventory of the ECM species present in these materials. The result would give us a clear picture of each site quality in terms of mycorrhizal status of amending materials. One-year-old jack pine and white spruce seedlings were used in bait plants experiment. Preliminary results indicate that at least 3-5 different ECM morphotypes were present in all three amending materials. Molecular analyses of root samples are in progress. However, based on presence of ECM morphotypes, it appears that fresh peat is the most suitable material for better amendment of the areas followed by LFH and stockpiled peat. The trial will be monitored over the next years to let plants grow further to see the stability of inoculum potential and diversity of reclamation materials as well as growth and survival of planted trees.

Another progress has been made by our group toward the application of mycorrhizal biotechnology in reclamation or revegetation work is the development of mycorrhizal DNA fingerprints. Microsatellite SSR markers were developed for *Hebeloma* species for the detection of introduced strains and molecular ecology applications (Source: Jany et al. 2003). This potent marker can be used as an efficient tool for monitoring the persistence of this fungus into the field.

Outplanting of inoculated seedlings

The success of any inoculation program depends upon sufficient demonstration of the advantages of inoculation in nurseries. In our recent field trials program established in spring 2005 at Syncrude oil sand areas, we intend to test the field performance of ECM inoculated jack pine and white spruce seedlings planted on highly disturbed saline alkaline sites. In this field experiment, we have selected one of the difficult sites that composed of mainly overburden materials, which is highly alkaline ($pH > 8$). We will monitor the field experiments for next three years to evaluate the growth and survival of inoculated seedlings as well as persistence of introduced mycorrhizal fungi in the field.

Conclusions

The potential benefits of the application of mycorrhizal biotechnology in revegetating Alberta's oil sand areas are promising. Mycorrhizal inoculation and secure development of mycorrhizas during seedling production in nurseries are particularly important for revetation of disturbed lands. Although there may be some sporadic mycorrhizal formation occurred in nurseries with nursery adapted fungal species, controlled mycorrhizal inoculation of tree seedlings assures a more rapid, efficient, and even mycorrhizal formation of whole nursery with targeted fungal species. In our studies, we found that tailing sand (TS) and composite tailing (TS) is devoid of active ECM propagules. All other amending materials tested have shown very low levels of mycorrhizal inoculum potential. The results suggest that pre-inoculation of nursery seedlings with appropriate mycorrhizal fungi would benefit revegetation of disturbed mined lands. In this process, not only improve survival and growth of individual plant but also we can re-establish the network of fungal mycelium in soil system, which is a particular goal of habitat restoration.

We have shown successful use of fermentor and effective method of large amounts of inoculum production and have demonstrated effective inoculation of forest tree seedlings under commercial nursery settings. We suggest that selection of appropriate plant genotype and their specific site tolerant microsymbionts is likely to maximize the success of land reclamation.

Acknowledgements

The research is supported by the Alberta Ingenuity Fund, Syncrude Canada Ltd., Bonnyville Forest Nursery, and Laval University, Quebec

References

Azcón, R., and El-Atrash, F. 1997. Influence of arbuscular mycorrhizae and phosphorus fertilization on growth, nodulation and N_2 fixation (^{15}N) in Medicago sativa at four salinity levels. Biology and Fertility of Soils 24: 81-86.

Bois, G.Y., Piché, Fung, M.Y.P., and Khasa. D.P. 2005. Mycorrhizal inoculum potentials of pure reclamation materials and revegetated tailing sands from the Canadian oil sand industry. 15(3): 149-158.

Brundrett, M., Bougher, N., Dell, B., Grove, T., and Malajczuk. N. 1996. Working with mycorrhizas in forestry and agriculture. ACIAR, Canbera, Australia.

Duchesne, L.C., Peterson, L.R., and Ellis, B.E. 1988. Interaction between ectomycorrhizal fungus Paxillus *invulutus* and *Pinus resinosa* induces resistance to *Fusarium oxyporum*. Can. J. Bot. 66: 558-562.

Fung, M.Y.P., and Macyk, T.M. 2000. Reclamation of oil sand mining areas. *In* Reclamation of drastically disturbed lands. *Edited by* R.I. Barnhisel, R.G. Darmody, and W.L. Daniels, American Society of Agronomy monographs, 2nd edn. 41: 755-744.

Hunt, G.A. 1992. Effect of mycorrhizal fungi on quality of nursery stock and plantation performance in the southern interior of British Columbia. For.Can. and Min. For. FRDA Report.

Jany, J.L., J. Bousquet and D. P. Khasa. 2003. Microsatellite markers for *Hebeloma* species developed from expressed sequence tags in the ectomycorrhizal fungus *Hebeloma cylindrosporum. Molecular Ecology Notes* 3: 659-661.

Jones, M.D., and Hutchinson, T.C. 1988. Nickel toxicity in mycorrhizal birch seedlings infected with *Lacterius ruffs* or *Scleroderma flaidum*. I. Effects on growth, photosynthesis, respiration and transpiration. New Phytol. 108: 451-459.

Jonsson, L.M., Nilsson, M-C., Wradle, D.A., and Zackrisson, O. 2001. Context dependent effects of ectomycorrhizal species richness on tree seedling productivity. Okios. 93: 353-364.

Kernaghan, G., B. Hambling, M. Fung and D. P. Khasa. 2002. *In vitro* selection of boreal ectomycorrhizal fungi for use in reclamation of saline-alkaline habitats. *Rest. Ecol.* 10: 43-51.

Kropp BR, Langlois CG (1990) Ectomycorrhizae in reforestation. Can. J. For. Res. 20: 438-451.

Leake, J.R. 2001. Is diversity of ectomycorrhizal fungi important for ecosystem function? New Phytol. 152: 1-8.

Malajczuk, N., Reddell, P., and Brundrett, M. 1994. Role of ectomycorrhizal fungi in mine site reclamation. *In* Mycorrhizae and Plant Health. *Edited by* F.L. Pfleger and R.G. Linderman. APS Press, St. Paul, MN. pp. 83-100.

Marx, D.H. 1991. The practical significance of ectomycorrhizae in forest establishment. *In* Ecophysiology of Ectomycorrhizae of Forest Trees. The Marcus Wallenberg Foundation. Symposia Proceedings No. 7, Stockholm, Sweden. pp. 54-90.

Marx, D.H., and Kenney, D.S. 1982. Production of ectomycorrhizal inoculum. *In* Methods and principals of mycorrhizal research. *Edited by* N.C. Scenck, Americal Phytopathological Society. St. Paul, MN. pp. 131-146.

Molina, R., H. Massicotte, and J.M. Trappe. 1992. Specificity phenomena in mycorrhizal symbioses: community-ecological consequences and practical implications. *In* Mycorrhizal Functioning: An Integrative Plant-Fungal Process. *Edited by* M.J. Allen. Chapman & Hall, New York, pp. 357-423.

Schüβler, A., Schwarzott, D., and Walker, C. 2001. A new fungal phylum, the Glomeromycota: phylogeny and evolution. Mycol. Res. 105: 1413-1421.

Smith, S.E. and D. Read. 1997. Mycorrhizal symbiosis. 2nd ed. Academic Press, London.

Van der Heijden, M.G.A., Klironomos, J.N., Ursic, M., Moutoglis, P., Streiwolf-Engel, R., Boller, T., Wiemken, A., and Sanders, I.R. 1998. Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. Nature (London). 396: 69-72.

Quality Control System for Regeneration Activities in Private Forests in Finland

T. Saksa, V. Kankaanhuhta, H. Smolander

Finnish Forest Research Institute, Suonenjoki Research Station

The annual forest regeneration area in Finland is about 185 000 ha. Of this area, planting Norway spruce (*Picea abies* L. Karst) and Scots pine (*Pinus sylvestris* L.) cover about 50%, direct seeding (mainly Scots pine) about 20% and the rest of the area is naturally regenerated (mainly Scots pine). According to the forest law, the forest owner is responsible for regeneration activities. Local forestry associations (covering one or several muncipalities in area) and its professionals act only as advisers, but can also offer a full service of regeneration activities to the forest owner.

During the last five years, quality work methods have been introduced in practical forest regeneration work in 30 different forestry associations in southern Finland. According to the main principle of quality work **Plan–Do–Check–Act** (PDCA –cycle), the targets of good regeneration results based on wood production facilities in future were decided first. Then the current regeneration results were measured trough a full-cover ground survey in young, 3-5 years old seedling stands. Inventory results in different regeneration chains were compared to the targets and analysed in order to find out the effects of different factors (site type, soil type, soil treatment, seedling type etc.) on the quality of seedling stands achieved.

In order to further develop the forest regeneration activities, the basic processes and factors behind them in different regeneration chains were analysed on forest association level. Using this kind of approach local professionals were obliged to consider the most critical points in the regeneration chain and to find the most important ‘bottlenecks’ to improve their own working habits. The results and manners of nearby associations were compared in order to find out the ‘best practice’ in a certain regeneration chain and to deliver it also to other users.

The quality work requires a new checkup of the regeneration results after 3-5 years, before a new cycle of development starts again. The efficiency of ‘quality control’ and the effect of feedback from own regeneration results will be evaluated in the coming years.

The variation in regeneration results among the forest associations was larger than expected. In planting (spruce or pine), direct seeding (pine) or natural regeneration (pine), the ‘best’ forest associations have reached the level of 70-90% of good regeneration results, but, at the same time, in some regions the corresponding level was 30-50%. For instance, in spruce planting the soil preparation methods and planting density were the reasons behind these differences but there were also some partly unknown factors related to the working manners etc. of the local forest association professionals.

Theme 4

Enhancing Timber Production and Non-Timber Values Through Stand Establishment

Benchmark Renewal Standards: What You See Is What You Get…. (NOT)!!

C. Bowling, R.G. White

Ontario Ministry of Natural Resources, Northwest Science and Information, Kenora, ON P9N 3X9

Currently, no standard procedure exists in Ontario for developing a regeneration standard using a common set of planning tools. While there has been general discussion and instruction on how various tools (i.e. density management diagrams (DMDs) and yield tables) may be used to help construct a regeneration standard, a formal procedure that provides a quantitative linkage between the renewal standard and the desired future forest condition has yet to be developed.

Problems identified with past and current renewal standards in Ontario include:

1. Variation in definition of terms

An example of (1) is the interpretation of what are considered ‘acceptable' species in a regeneration standard. In the most extreme cases, the list of species in the regeneration standard may include species that: (i) didn't occur in the original stand, (ii) are not listed in the proposed future stand composition, and (iii) are not being targeted for regeneration through silvicultural activities.

In addition, the string of species may include species that are traditionally considered to be competitors with one another. For example, where jack pine (Pj) is being regenerated with the objective of creating a future forest condition of Pj9Sb1 (Sb - black spruce), the renewal standard lists Pj, Sb, balsam fir (Bf) and poplar (Po) as acceptable species. There are no limits on the amount of ‘competitors' that may be permissible in the stand, yet there is an indication that, if required, tending will be used to release the Pj from hardwood competitors! So, what makes Po ‘acceptable' in this instance (or Bf)? Is it truly a measure of the success of regenerating the desired Pj stand?

2. Standards don't necessarily reflect management objectives.

Multiple treatment options listed in ground rules often achieve various levels of management intensity, yet are often given similar renewal standards. For example, planting, which is tied to more intensive yield projections, is often given the same renewal standard as a more basic or extensive treatment (e.g., 40% of stocked mil-acre quadrats may be listed as the standard for both planting and natural regeneration treatments, yet the stand development information may be quite different for each of these scenarios).

3. No formal direction on how a regeneration standard is to be developed.

The key overriding issue, however, is lack of formal direction on how a regeneration standard is to be developed. How should acceptable species be defined? How may long term stand objectives be quantified? How may stocking and/or density measures be used to predict stand development? These are areas that need to be clarified. Some of these areas fall into the area of “policy”, but current work is designed to help clarify the interaction of some of these components.

The basis of the idea surrounding the development of the **Objectives–Based Renewal Standards Project** came from reviewing renewal standards over a number of years and comparing these standards to various approaches used for developing objectives-based renewal standards presented in the literature (see examples below). The Objectives-Based Renewal Standards Project seeks to address the above problem areas by achieving the following objectives:

1. To outline a “model”[1] for the development of quantitative, site-specific, stand-level, objectives-based renewal standards. In this context, the word “model” is used in the broadest sense to describe the package of procedures and tools we may be generating (i.e., a toolkit).
2. To provide analytical procedures for incorporating silvicultural effectiveness monitoring data to calibrate renewal standards at the local level.

Objective 1:

This project seeks to develop a *stand-level* tool that is to be used with full regard to the fact that stand-level objectives must be developed within the context of forest-level objectives. As a consequence, the project was

[1]In this context the word model is used in the broadest sense to describe the package of procedures and tools we may be generating.

designed to develop a procedure where renewal standards could be developed locally. The process of developing the renewal standard should be completed in the context of a specific forest management plan and its forest level objectives. In a forest management plan, however, renewal standards are developed as part of a Silvicultural Ground Rule (SGR). The SGR is developed for a specific forest unit-site type combination and is applied to a 'stand' that fits the forest unit-site type description for that specific SGR.[2]

As the SGR is *site-specific*, it follows that the components of it, including the renewal standard, should also be site-specific. Due to the current scale of commercial forestry, treatments are often applied to 'blocks' which may include a number of 'stands' in actual practice. But this is not necessarily a practice that should be enshrined in our planning or operating procedures; the appropriate SGR should be applied to meet local site and stand conditions (and should come as a result of a pre-harvest inspection, but we are not there yet). Renewal standards should therefore be site-specific, while considering forest-level objectives (see below).

In light of these points, the development of a regeneration standard was viewed as a *stand-level* consideration and is included as part of the SGR. That is not to say that every SGR must have a unique regeneration standard. When objectives are similar for a series of SGRs, the regeneration standards may be the same as well, especially given the current level of precision (or lack thereof) that may be applied to linking a specific regeneration objective to a precise objective.

This project is aimed at improving the linkage between the desired Future Forest Condition (the desired forest unit, stand characteristics, and development information) and the regeneration standard. It seeks to do so by establishing a renewal standard (that may be assessed during early stand development) that is quantitatively linked to the management objectives (desired Future Forest Condition) for a stand at maturity.

It is proposed that the process of developing renewal standards involves defining the 'stand' level objectives first. The procedure for developing the regeneration standard that comes from this project may incorporate an iterative process of reconsidering objectives and corresponding standards, but it is clear that objectives must come before a regeneration standard may be developed.

Objective 2:

This objective addresses several important questions:

- Once a renewal standard has been defined, how often is it achieved?
- Is it realistic to expect certain treatments to achieve desired results consistently? In what percentage of times is the standard being achieved?
- If it isn't being achieved, what is the difficulty? Is it with the standard, with assumptions about local environmental conditions, or with the way in which silviculture practices are being implemented?

Silvicultural assessment may be used to address these questions. Local silvicultural assessment information is being collected, but the use of this information varies. The assessment procedures also vary from extensive to intensive approaches. The value of consistent, reliable assessment information could be demonstrated in a method to integrate this information into a silviculture decision support tool.

This method would involve various approaches to 'decision making under risk'. For example, one approach is the use of a 'decision tree' to calibrate the likelihood of various intensities of silviculture treatments resulting in particular regeneration results on a variety of sites/stand conditions (after Bergerud 2002). The probabilities of the decision points of the decision tree could be populated with the results of reliable silviculture assessments. A demonstration of this method in the context of this project might use plot networks which document historic regeneration assessment results and current stand conditions.

How This Project Might Fit Into the Bigger Picture

This project does not state that it will be producing specific regeneration standards because the whole premise of the proposal is that the regeneration standard must be linked to an objective and there are potentially a myriad of objectives that may be stated. Objectives are developed as part of the management planning process. Specific regeneration standards could, however, be generated through this project as part of a case study to illustrate the procedure.

For example, this project could help with the provincial initiative to generate 'minimum standards'. The province

[2]An SGR is composed of: (1) current forest condition (forest unit – site type); (2) future forest condition (forest unit; stand characteristics, development information (e.g., yield curves)); (3) silvicultural treatment package (harvest and regeneration treatments, etc.); and, (4) the regeneration standard.

would first define their objectives. For example, they may decide, on a regional or provincial basis, that they want to guarantee a minimum level of productivity for regenerating stands (e.g., 80% or better of Plonski's yield), or they want to ensure the species composition of the regenerating stand is consistent with the preharvest conditions. We could work with them to generate clear objectives, and then use our procedures to generate a series of 'minimum' regeneration standards that reflect their objectives.

The Province could then decide (these are policy decisions outside our mandate) that these standards would be the benchmark regeneration standards to be used (regionally?) in forest management plans. They could also decide that planning teams could customize these standards to meet local objectives if they rationalize the adjustments using the new "objective-based regeneration standards" procedure and have the adjustments approved through the forest management planning process. The objective is to develop a procedure to improve planning procedures. As someone suggested, for this aspect of the project we are not undertaking 'new science' as much as gathering together information and tools from the literature and through consultation and developing a procedure into a tool kit that may be used in the planning process.

An Example of a New Paradigm in Forest Renewal Standards

As a result of the current definition of a renewal standard in Ontario, success in developing a framework for (as well as successfully demonstrating and applying) objectives-based renewal standards will require a substantial paradigm shift. At the present time, forest renewal standards in Ontario primarily revolve around an arbitrarily set (at least very broad), fixed figure (i.e., a percentage-based approach) for stocking of both target or acceptable crop tree species (in most cases) on a regenerating site. This approach often has only a vague link to quantitative management targets or objectives such as stand composition, yield, site quality or management intensity. Essentially, the current standards are techniques-based rather than objectives-based. An objectives-based approach would likely do away with a fixed figure; if such a figure were required it would vary substantially with management objectives. One example of a quantitative method of deriving objectives-based renewal standards is presented by Newton (1998).

Deriving Site-Specific Regeneration Standards by Yield Objective – Newton's (1998) Approach

Newton (1998) examined the development of regeneration standards in terms of their practical application in answering two common operational questions often faced by silviculturists:

1. Given current juvenile stand conditions, what yield can be expected in the future from this stand/site?
2. What current juvenile stand conditions are required to obtain a target yield objective at rotation age?

To answer these questions, Newton (1998) developed a technique that quantitatively linked regeneration survey results to future stand yields using a stand density management diagram (DMD). In developing his approach, Newton (1998) noted the limited utility that stocking (i.e. a percentage-based approach) has in estimating future yields. In particular, it was noted that a single stocking figure for a regenerating stand could describe a multitude of variable stand conditions, from high-density clumps irregularly spaced throughout the stand to uniformly-distributed, evenly-spaced lower density trees across the site. These two situations would result in very different yields for the site due to the crop trees developing under different circumstances (Newton 1998).

Accordingly, Newton (1998) used an early stand development assessment based on mean-point density, adjusted for stocking, to get an idea of the true densities occurring in the stand. Development of the stands was then simulated using DMDs to obtain estimates of quantitative stand parameters such as diameter and volume at periodic intervals to rotation. Multiple regression models were then developed that predicted these stand parameters based on the assessment results (Newton 1998).

These models could then be used to obtain reliable, site-specific, quantitative estimates of future forest condition based on current stand assessment results; ***or***, a site-specific, required value for the stocking-adjusted density (juvenile stand assessment result) could be generated for a specific yield objective (Newton 1998). This required value could then serve as a regeneration standard for the site/stand. Stands not meeting this requirement could be targeted for remedial action to bring them up to the standard.

This approach is not without limitations, and Newton (1998) noted that it assumes stocked areas are contiguous, and that stocking levels will not change as the stand matures. These assumptions are not unique to Newton's (1998) approach; they reflect limitations of many stand development models.

Silvicultural Monitoring and Forest-Level Objectives

Silvicultural (and regeneration) success is typically investigated and viewed at the level of the individual cutblock or stand. Across a large area of forest such as an SFL or FMA, however, aggregates of stands are typically managed together for the achievement of one management objective. From the perspective of timber production, it is rare, or even unlikely, that a single stand in an FMA would be managed for the achievement of its own unique objective, independent of any other stand or aggregate of stands in the management area (though individual stands frequently have their own unique silvicultural prescriptions as a result of variation in site quality, composition and other concerns). Setting management objectives for groups of stands (i.e. Forest Units) is more efficient and is currently standard practice. It therefore makes sense that we should think of regeneration success at the stand aggregate [forest unit] level, rather than passing or failing individual stands (Martin et al. 2002), and summarizing these results to the forest or provincial level.

Thinking of stands at this level has the added advantage of allowing more productive or successfully regenerated stands within a forest unit to make up for shortfalls on less productive or successful stands, since regeneration success is viewed in terms of the achievement of a future management objective for an entire forest unit, not just a pass/fail approach for an individual cutblock (Martin et al. 2002). This could potentially allow for greater efficiency and effectiveness of silviculture (e.g. remedial action isn't necessary for a less productive stand if other, more productive stands are compensating for it at the forest unit level).

While the development of renewal standards at this level (and in this context) is not within the realm of this study, it is (and should be) of interest in terms of seeing how the stand-level toolkit being developed in this study might fit into the bigger picture. It is particularly interesting to examine how a similar approach can be taken with regulation and monitoring of renewal on a broader scale (e.g., SFL or even provincially) – see Martin *et al.* (2002) for an approach British Columbia is taking.

References

BC Ministry of Forests. 2003. Results-based FPC pilot projects – home page. http://www.for.gov.bc.ca/hfp/rbpilot/

Bergerud, W.A. 2002. The effect of the silviculture survey parameters on the free-growing decision probabilities and projected volume at rotation. Res. Br. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 50.

Martin, P.J., S. Browne-Clayton, E. McWilliams. 2002. A results-based system for regulating reforestation obligations. Forestry Chronicle 78(4): 492-498.

Martin, P., S. Browne-Clayton and G. Taylor. 2003. Assessing reforestation performance: A new approach. FORUM 10(1): 21.

Newton, P.F. 1998. An integrated approach to deriving site-specific black spruce regeneration standards by management objective. For. Ecol. Manage. 102: 143-156.

White, R.G. 2004. Developing and testing a model and analytical procedure(s) for establishing and calibrating objectives-based renewal standards. PROGRID project submission, July 14, 2004.

White, R.G. 2004. Objectives-based renewal standards. Introductory presentation at project team meeting, Natural Resources Centre, Thunder Bay, ON. August 24, 2004.

The Challenges and Accomplishments in Reforesting Boreal Sites in Northern Ontario

D. Bradley

Outland Reforestation, Thunder Bay, ON

Steve Colombo indicated that many conference goers may not have an understanding of the reforestation industry in Ontario. I have prepared this talk to paint a bit of a picture of how things work in Ontario. It struck me that in my 20 years in the industry, I had never been asked to deliver a talk to a conference such as this. Although reforestation has been going on for decades in Ontario, our industry in its current form had its beginnings in the early 1980s.

As I look around the room I see forestry professionals, scientists and business people all of whom had their own personal path and motivations leading them to their careers in forestry and seedling production.

For me, armed with my degree in history, my diploma in business and my penchant for coaching and working with youth, I stumbled into tree planting. In the mid-80s, I was headed toward a career in coaching alpine skiing. My plan was to use planting earnings not only to feed myself between seasons but also as seed money for other ski career building projects.

The early days were wild compared to today. I began supervising Outland planting projects in 1987. In 1988 I supervised the first 6 weeks of the Great Lakes Forest Products plant on the Black Sturgeon Forest with a cast on my left leg after reconstructive knee surgery. My boss at the time talked me into it and offered me his RV trailer to sleep in. In those days there was very little management capacity out there and I suppose we had no other person with experience to run the project other than myself.

I soon learned that we needed to build on every proven and keen staff member in our organization. The key to our success would be in maintaining a high quality product while increasing production; this would be done by increasing the level of experience in our company.

The true sign of a successful production piecework operation is that people at every level of the organization are making money. This is the basic fundamental that has allowed Outland and other successful planting companies to sustain profitability. Of course one does not continue to make money without addressing the key needs of clients, employees and owners alike. Certainly, for me, recognizing that my entrepreneurial bent could combine nicely with my coaching and people management skills within an organization like Outland was very exciting. Most people think those of us committed to the industry are crazy, but most people do not really understand what makes a successful tree planting company. My role within Outland as it evolves is vastly rewarding.

The act of planting a tree is a critical step in the process of regenerating the forest. The trees are selected, improved, grown, stored, shipped, watered and delivered to the site. Then we depend on a person to carefully select a microsite and properly plant a tree.

Yet, in our view tree planting is not a science. There are not randomized trials with different planters as there are with different stock types. But just because we cannot produce scientific abstracts on the subject does not mean that it should be overlooked when considering the current state of reforestation. We applaud the seedling production industry for making important technological contributions which are making planting more efficient and producing higher quality results. We also believe that it behoves the forest industry as a whole to understand tree planting from an operational perspective and in its broader contexts. The more forest managers understand about the human side of production planting, its challenges and opportunities, the more we can assure a thriving and competent tree planting industry exists to plant the trees this conference is all about.

In this talk I am going to:

- Have a look at how tree planting in Ontario has evolved in past 15 to 25 years
- Talk about some of the industries challenges and suggest a few ways that things might be streamlined on the ground through closer partnership between silviculture contractors and forest products companies
- Highlight the importance of attracting and maintaining a young, energetic workforce to undertake reforestation

There have been some major changes in the practical, on-the-ground approach to reforesting sites over the past 2 decades. Tree planting first became the industry that we know in Ontario about 25 years ago when the MNR gave up control of the tree plant programs and began tending reforestation out through the Forest Products Industry. This leap of faith from union workers paid by the hour to young students paid by the tree produced an astounding increase in productions rates.

Before the students arrived, the forest industry had daily tree plant production numbers of about 300 per person per day and the per seedling planting rate was effectively 60 cents a tree. When company supervision and overhead costs were factored in it cost well over $1.00 per seedling in 1978 dollars to plant a tree.

Once high production reforestation contracting companies arrived, the price fell rapidly and forestry companies realized they had made one of their best decisions ever. No more WCB claims, no more employee issues and planting costs of 25 cents a tree or less. New approaches to achieving higher production originated in BC where new planting techniques and land management systems paved the way for greater maximization of the pay-per-tree model.

For contractors tree planting prices have not moved much since then – if anything, they have slowly decreased in real terms. Yet behind the scenes, the tree planting industry continues to evolve. Production rates continue to climb. Our records show that twenty years ago a camp would average 1,200 seedlings per day over a season with average earnings of approximately $100 per day. Now an average Ontario camp is in the 2,000 seedlings/person/day range with average earnings of more like $175 per day.

In recent years, productivity gains can be largely attributed to a focus by the silviculture industry on a variety of factors: safety in the workplace, planting ergonomics – leading to reductions in lost time, more reliable crew transportation and access equipment allow planters to have longer and more consistent work days. On-site tree delivery is an ever-evolving art and particularly important with diminished road building of late. We have made steady improvements to our quadrunner configurations resulting in far less downtime and much better performance under load. In addition, most planting companies invest a great deal of time and money in hiring, informing, preparing and training the best people for the job to be efficient and productive workers.

Massive productivity increases are not the only significant changes in the modern planting camp. Planting life has changed a great deal from the early days of primitive infrastructure and haphazard quality control.

With the increased focus from the Ministry of Labour, WSIB and forest industry clients, reforestation contractors have improved bush camp facilities to comply with regulations, provide better accommodations and facilities to their workers and provide better service and reporting to forest products companies. Gone are the days of 10 to 15 person work camps, living in tents, drinking lake water and cooking their own meals on Coleman camp stoves. Today's tree planting camps have well structured and organized management teams and offer most of the amenities of home with a "rustic twist".

Visit a tree planting camp now and you will likely see functional combinations of the following elements:

- Fully functional bush camps with water purification systems, generators and propane cooking equipment
- Radios, cell phones, satellite phones, pagers and internet access.
- Handheld GPS Units, Laptops, Printers, ArcView and map making capability
- Televisions, DVD Players, Satellite dishes
- Garbage containment, Electric Bear Fencing
- 4x4 Crew Cabs, 15 Passenger Vans, Float Trailers, Quadrunners, Swamp Machines, Helicopters (and yes there are still a few battle scarred school buses plying the northern bush roads!)
- Adjustable, well-padded tree planting bags, ergonomically designed planting shovels, hard hats, Hi-Visibility vests, steel-toed boots, and Gortex raingear
- Silvicool tarps, shade tarps, tree-watering systems
- Contractors that are SWO safety certified, ISO certified and compliant with all Environmental Management Systems and Certifications in place with our clients

Operational changes in production, packaging and transport of tree seedlings represent another major contributor to improved productivity over the years.

The changes in stock types, packaging and transport have allowed silviculture contractors to move more seedlings from the nursery to the site in a shorter period of time, store trees on site for longer periods of time and spend less time in the field tending to seedlings prior to planting, ultimately resulting in an increase in planter productivity.

The move by the industry away from bare root planting stock, to container planting stock has simplified the process of planting a tree for planters. Bagging up and drawing trees from planting bags takes less time with bundled container stock than with bareroot. Shovel blades have reduced in size in response to a diminished need for a large planting hole to accommodate fairly large bareroot root systems. Loaded tree bags weight less, or carry more trees as the requirement to have water in the bottom of planting bags to maintain root moisture no longer exists. And tree planters are able to achieve quality specifications more easily now that putting the tree in the hole is one simple movement with no fussing with stray roots.

Most trees planted in northwestern Ontario are now extracted from their growing container, bundled, packaged in boxes or totes and put in cold storage awaiting delivery to the planting site. The delivery of seedlings to the site in their growing trays poses several hardships to the planting contractor. Trees transported in trays take up significantly more space than those packaged in boxes or totes – requiring more frequent deliveries from the nursery to the site and from the staging site to the planting blocks. Every load of trees to the site requires staff resulting in the loss of valuable production time unloading and loading trees. Movement of trays require heavy and cumbersome racks in reefers and on trucks, trailers and quads. Daily watering regimes mean watering equipment needs to be maintained at staging areas and planting sites.

Extracted, bundled and cold stored trees have provided planting contractors with a great deal of flexibility within their operations. Most trees can be packed in containers of 400 to 600 trees, allowing contractors to deliver more trees to the planting site per load and minimize delivery times. Seedling delivery to difficult access areas can be accomplished much more efficiently and with a lot less frustration with trees packaged and protected in easy-to-manoeuvre containers. Trees can be cold stored in on-site reefers for longer periods of time with no watering required. Most boxes and totes are collapsible or stackable for easier return of shipping containers to the nursery. All in all recent seedling packaging and storage technologies have contributed significantly to overall productivity gains and to keeping renewal costs down.

The ever-tightening business environment the forest industry has faced over the last 15 to 20 years has forced tree planting companies to evolve in order to survive. Gone are the days when planting company owners could sustain the business on planting work alone. We have utilized our core competencies and are always reaching out for other business opportunities. Ultimately, we have been able to streamline costs and provide greater earnings opportunities to our best staff. Outland has recognized the need to be a high volume producer in order to survive. Over the past two decades, just like the pulp and paper industry tree planting companies have undergone serious consolidation. Outland is now one of Canada's largest suppliers of planting services. We have spread our operations over many jurisdictions, which has allowed us to weather the tough times in certain market areas. As you can see at our booth in the display area, we are contracting our services in many facets of the silviculture industry including slash pile burning, juvenile spacing and herbicide applications. Further, we have become a large supplier of Type 2 forest fire fighting crews to various provinces. As well, our experience in running bush camps has led us nicely into Project Fire Basecamp services for several provinces. All of this growth and streamlining of cost inputs across all operations has ensured our ability to continue providing excellent value to the tree planting industry while maintaining overall profitability and extending employment opportunities for our seasonal employees.

Outland has done an excellent job of integrating FN workers into their operations. In fact, recognizing the growing population of First Nations in the north and recognizing the forest industry's looming shortage of skilled workers, Outland is working to increase involvement by First Nations in all aspects our business here in Northern Ontario. We have established capacity building partnerships with various First Nations and we conduct silviculture training programs on behalf of our clients. Consistent with the priorities of First Nation leadership, our focus has been largely on youth. Our workplaces and management teams are geared toward getting the best out of people. We have been most successful when we hire and train these workers with their own peer group – that is, young university students that are interested in training and teaching. A further benefit stems from the fact that silviculture contractors have been able to step-in to carry out this work without any previous conflicts or complicated relationships and have achieved some important successes on this front.

There have been many lessons learned in the tree plant contracting process. We believe that within the realm of project management, opportunities exist for new approaches that would further help streamline our tree planting business while maintaining desired results.

Perhaps the greatest challenge faced by planting contractors is the lack of consistency from licence to licence with respect to quality and density specifications.

After having planted trees for every major forest company in Ontario we are certainly qualified to make this assertion.

In our practical experience every client has a different take on what quality specifications are required to produce a good plantation. This is probably the most frustrating aspect of our business. Constant retraining from project to project hampers productivity and morale. Currently each company has slight variations on reporting procedures, quality sampling regimes, and different levels of experience among their on-the-ground company staff overseeing the tree plants. The differences we see often come from client preference. Differences that often result in costly slowdowns. Slowdowns that can seriously affect a planter's ability earn enough money for school. If quality specifications were consistent on the same site conditions from contract to contract re-training periods would be minimized contributing once again to controlling renewal costs.

As I have said earlier, planting contractors believe they have responded remarkably to industry's pressure to keep renewal costs down over the years. We understand the challenges the forest industry faces and believe we are doing our part. In spite of well known razor thin margins, best practices within our industry have improved steadily. Somehow, contractors have not been successful at getting the forest industry to look beyond the narrow framework of cost – to look at planting in a different manner. We believe various opportunities exist which would allow forest companies to get much more out of their renewal budgets.

First, look at contractors more as partners in the reforestation process. When we started in this business 25 years ago, MNR foresters ran tree planting. Now, our clients run the planting programs and are subsequently audited by government. We believe this evolution could be taken one step further. Planting contractors can run the entire planting program with appropriate and timely auditing to verify contract requirements are being met. Some of our clients are currently employing this contract management approach today. Our management staff have the experience to layout a planting project, coordinate stock shipments, care for the stock on site, coordinate project flow, assess quality & prepare all associated reports. The operational efficiencies found with this approach will further maximize the renewal dollar. Contractors will respond to the added responsibilities and contractor capacity to efficiently deliver other forestry services will grow as well.

Second, offer contractors longer planting seasons. From our perspective the industry should consider at least 2 to 2.5 months worth of planting work during the summer. If our industry wants the best labour force, we need to be able to offer enough work. There is a big difference between 3-5 weeks and 7-10 when it comes to hiring qualified planters. The vast majority of our seasonal workers participate in this industry because they are trying to make money to pay for school or travel. If we cut up their summer earnings window too much we inevitably lose good people who opt for steadier work. The $175 per day earned by average planters today does not go as far as the $100 per day 20 years ago. We all know how tuition and accommodation costs have risen dramatically over this period. The bottom line going forward: planting earnings must remain competitive with comparable work. Managing the planting windows with this consideration in mind will go a long way to attracting the most productive workers. This will lead to contractors hiring fewer people which will ultimately reduce risk. Rookie planters usually earn more in their last 2 weeks of a 6-week plant than they do in the first 4 weeks. Once planters are up to speed by mid June, this is the time contractors can offer more attractive pricing on projects.

Third, sign longer term deals. Most contractors operate at very tight margins. It is becoming increasingly difficult to operate on a year to year basis. A series of 3 to 5 year deals would guarantee exceptional pricing. Clients would also see how much easier it is on everyone when planters and management teams get to return to the same place for a few years in a row. Another hidden benefit companies feel is through the loyalty planters often develop for the sustainable forest license (SFL) holder they are planting for.

Reforestation companies are labour intensive operations that introduce a great number of people to the forest industry for the first time. How should this interaction be managed so that the young workers appreciate the forestry company priorities and challenges?

Forest industry professionals need to take advantage of the chance to meet our planters. It is a very interesting group that goes planting. They are generally all highly motivated. Today's crews are mostly a good mix of Northern Ontario and Southern Ontario college and university students. As well, we are seeing more and more First Nations planters joining our crews. This is an ideal chance for industry to "put out its message" to an open-minded and keen group – and a group that inevitably includes tomorrow's decision makers. Who has planted trees? You would be surprised at how many high profile professionals, artists, politicians and the like have spent a summer planting in Northern Ontario. Shania Twain is the extreme example we all love to refer to. No doubt, some of you in this room have planted trees!

Across Canada, upwards of 5,000 tree planters head to the bush each year to plant trees. Some foresters seize the chance to come and talk for half an hour about what their companies do – almost all of our staff comment about what a good session it is. Others do not ever come to the field – an opportunity lost in our view. We strongly believe the industry needs to do more to reach the community at large. Certainly, a willing group of planters who have gone through the blood, sweat and tears it takes to make it through a planting season deserve to hear the forest company's messages as well as have a chance to ask some questions.

There are no doubt many success stories that have come from reforestation contractors and forestry companies working closely together resulting in the general improvement of the caliber of the planting companies. The forestry world is full of SFL foresters who do care enormously about the reforestation workers and contractors. At Outland, we have been mentored by some excellent leaders from industry that have demonstrated to us the lessons that they have learned from working in their organizations:

- Lessons such as the benefits of taking an unwavering stand on safety and…
- The importance of standardized practices as one's organization grows and becomes more complex.

We know that we have a core competence that is different from that of our clients. We are labour management organizations. As this talk has hopefully shown we have grown in sophistication and ability over the past 20 years. We deliver excellent value for the dollars spent on our services and we have much more to offer.

On a final note, we believe the forest industry faces challenges which are changing the importance of the role of silviculture in providing a sustainable supply of willing and skilled forest workers. We will see much more involvement in our industry by First Nations as they build capacity to take back some of the economic opportunities they have been missing over the past decades. Our industry also provides a window on the north for many "southern Canadians". If the forest industry treats these workers well, we may see our northern colleges and universities filling up with young people who can see a future in sustainable forest management. Tree planting can be a first step in one's eventual decision to live, work and raise families in the north.

Tree planters want to play a role in renewing the environment. If they can pay for college while making this contribution it is a huge win for society. Compare this approach to our US neighbours who rely on low cost Mexican workforce to do its manual planting and tending. It is the job of all of us in this room to look for ways to keep interest high in piecework silviculture. Giving more and more people a positive experience in the north will help ensure the forest industry gather the support it needs to carry-on managing sustainably in the years to come. Going forward to 2010 and beyond the focus of reforestation companies such as ours along with our industry partners will be to balance economics with the very human opportunities we have before us.

Natural Regeneration With Shelterwood Silviculture in the Acadian Forest Region

J.C. Brissette[1], D.E. Swift[2]

[1]USDA Forest Service, Northeastern Research Station
PO Box 640, Durham, NH 03824, U.S.A.
[2]Natural Resources Canada, Canadian Forest Service, Atlantic Forestry Centre
P.O. Box 4000, Fredericton, NB E3B 5P7, CANADA

Two variants of uniform shelterwood are in a long-term study in Maine at the Penobscot Experimental Forest (PEF), which is in the southern part of the Acadian Forest Region. The experiment was established in the mid-1950s with replicates of two-stage shelterwood, in which the overstory was removed in two harvests 10 years apart; and three-stage shelterwood with overstory removed over a 17-year period. About the same time, four variants of shelterwood were established at the Acadia Research Forest (ARF) in New Brunswick, about central in the Acadian Forest Region. The four variants were: 3-stage uniform (similar to PEF), 4-stage uniform, 4-stage strip, and 4-stage group.

The first cuts in the shelterwood sequences were the disturbances that defined the beginning of stand initiation. The shelterwood harvests released advance regeneration and established a new cohort of seedlings. In both studies, regeneration was prolific and dominated by balsam fir and spruce seedlings. At the PEF, the number of fir and spruce seedlings (15 < ht < 30 cm) ranged from 2,750 to 10,500 per ha, with fir-to-spruce ratios between 6:1 and 27:1. Second- and third-stage harvesting operations destroyed < 50% of the seedlings and saplings in the PEF study. Seedlings continued to be present for up to 35 years after the first shelterwood harvests. Results from the PEF indicate that site characteristics, initial stand attributes, and treatment prescription all affect stand initiation and development. Site factors and/or previous stand composition largely determined total seedling density and species composition of the regenerating cohort.

Results of the ARF study support those from the PEF. Natural succession had more influence on species composition than did the various treatments. However, in the ARF study, spruce was generally more abundant than at the PEF, with 40 % of the stand composition 20 to 30 years after the final harvest in all except one treatment block. At both locations, precommercial thinning that favored spruce reduced the number that were suppressed by the initially faster growing balsam fir. However, at the PEF, the rate of mortality has been markedly higher for balsam fir than for spruce, so the necessity of favoring spruce with early treatments is not clear yet.

These experiments clearly show that shelterwood silviculture is effective for regenerating desired conifers in the Acadian Forest. The various shelterwood regimes did not have much effect on stand initiation; the impact of treatment was more evident on later stages of stand development. By comparing the results of these two independent long-term studies, forest managers throughout the region can have confidence in the shelterwood silvicultural system to successfully regenerate eastern spruce - balsam fir stands.

Reforestation of Surface Mined Lands in the Appalachian Coal Fields, USA

C. Cotton, C. Barton, P. Angel, D. Graves

University of Kentucky, Department of Forestry, 208A TP Cooper Building, Lexington, KY, 40546

Since the implementation of the Federal Surface Mining Control and Reclamation Act of 1997 (Public Law 95-87), many opportunities have been lost for the reforestation of surface mines in the eastern United States. Excessive compaction of spoil material, which occurs in the backfilling and grading process, is the biggest impediment to the establishment of productive forests as a post-mining land use. Cultural barriers that existed within the mining industry and the Federal and State regulatory authorities have also contributed to the failure of reforestation efforts under the federal law over the past 26 years. A mine land reforestation research project has been initiated in Kentucky in an effort to resolve these remaining cultural, technical and regulatory barriers to successful reforestation efforts. In this study, various methods are being employed to lessen both physical and chemical limitations of mined sites so that the establishment of forested species (hardwood and conifers) is possible. Metrics designated for the monitoring include: weather variables and site hydrology; vegetative biomass and growth parameters; plant tissue, litter and soil/spoil analysis; decomposition and CO_2 efflux; and chemical analysis of water from precipitation, runoff and infiltration. Initial planting of tree seedlings began in 1997. Over 600 ha (>1,000,000 seedlings) have been planted thus far with an additional 580 ha remaining for the project. Historically, the evaluation of reforestation efforts on mined lands has come from regional site indices (based on 50-year-old trees) and assessments of tree height and survival. Unfortunately, these methods fail to grasp the overall quality of the trees or site. With this in mind, a concurrent project is underway that will develop reference curves based on tree and soil variables measured on a chronosequence of sites for two species of trees: white oak (*Quercus alba)* and yellow poplar (*Liriodendron tulipifera)*. The goal of establishing the reference curves is to not only evaluate tree survival, but to also determine whether or not the stand is comparable to a naturally-regenerated forest on non-mined land. Through these extensive efforts we hope to restore the productivity potential of mined lands throughout the Appalachian Coal Fields for the purpose of re-establishing healthy and productive forests.

Cutting Versus Herbicides: Tenth-Year Cost-Benefit Analysis of Sub-Boreal Conifer Plantation Release

J.E.E. Dampier[1], F.W. Bell[2], M. St-Amour, D.G. Pitt[4], N.J. Luckai[1]

[1] Lakehead University, Faculty of Forestry and the Forest Environment, 955 Oliver Rd., Thunder Bay, Ontario P7B 5E1
[2] Ontario Ministry of Natural Resources, Ontario Forest Research Institute, 1235 Queen Street East, Sault Ste. Marie, Ontario P6A 2E5
[3] Forest Engineering Research Institute of Canada, Eastern Division, 580 boul., Saint-Jean, Pointe-Claire, Quebec H9R 3J9
[4] Natural Resources Canada, Canadian Forest Service, 1219 Queen Street East, Sault Ste. Marie, Ontario P6A 2E5

Although conifer release treatments must provide high economic returns on investment because treatments can be costly, few cost-benefit studies of vegetation management in conifer plantations have been reported. This study provides follow up cost-benefit analysis from research conducted at the Fallingsnow Ecosystem Project in northwestern Ontario, Canada with the objective of determining the relationship between planted white spruce (*Picea glauca* [Moench] Voss) stem volume and release treatment cost ($ m^{-3}) ten years after alternative release treatments. Individual treatment costs were inflated over the ten-year period to develop cost estimates for 2003. The most cost effective treatment was the herbicide Vision ($12.16 m^{-3}), followed by the herbicide Release ($12.18 m^{-3}), cutting with brushsaw ($38.38 m^{-3}) and cutting with Silvana Selective ($42.65 m^{-3}). No cost-benefit differences were found between the herbicide ($p = 0.998$) or cutting treatments ($p = 0.559$). The herbicide treatments were three-fold more cost effective than the cutting treatments ($p = 0.001$).

Positioning Forest Business to Capture Benefits of the Bio-Economy: A Role for Reforestation and Afforestation in Sustainable Forest Management

D. DeYoe, F.W. Bell, J. Maure

Ontario Ministry of Natural Resources, Sault Ste. Marie, ON

The past 150 years of human experience on this planet has brought to light some disturbing facts about our ability to manage the global system, environmentally, socially, and economically. That experience has also demonstrated that human ingenuity and innovation have enabled us to transcend adversity and capitalize on opportunities to grow…..so far. An overview of economic, social and environmental trends threatening the forest resource and industry will be explored in setting the stage to discuss how new technologies and processes can help achieve more effective and efficient use of forest resources for stimulating economic development while addressing uncertainty inherent within the global business and environmental climate. The focus will be on the use of forest biomass as bio-product alternatives for fossil fuels in production of bio-based fuels, energy, chemicals and polymers. Sustainable forest management strategies that employ intensive silviculture (reforestation and afforestation) and utilization practices will play a key role in optimizing the use and utility of forest biomass as a value-added resource. The attributes of forest biomass that make it useful, and the technologies and processes associated with biomass conversion and utility will be discussed in light of forest bio-refineries designed to optimize social, economic and environmental benefits. Linkages to carbon management and policy reform will be conveyed.

Seedling Size and Reforestation Success
How Big is Big Enough?

S.C. Grossnickle

NurseryToForest Solutions, 1325 Readings Drive, Sidney, BC, Canada V8L 5K7

Introduction

Foresters are frequently confronted with the option of planting seedlings that have a range of sizes. Most practitioners assume that larger planting stock has greater inherent performance capability to grow larger and faster, compete with vegetation for site resources under field site conditions and shorten the time to reach a desired size; thus meet management objectives (e.g., free to grow plantation status). For example, there are many reported historic (e.g., Dobbs 1976, McMinn 1978, Vyse 1982, Hines and Long 1986, Payandeh and Wood 1988, Sutherland and Newsome 1988) and current (e.g., Jobidon et al. 1997, 2003) studies that have shown larger spruce seedlings result in improved plantation performance. However, in some situations planting of larger seedlings might not make biological sense. This review examines available work on spruce seedlings size in relation to stock quality and stocktype size versus field performance from a biological perspective. The subsequent discussion tries to determine 'how big is big enough' when it comes to seedling size and reforestation success.

Stock Quality and Seedlings of Various Sizes

Stock quality characterization provides information on similarities and differences between stocktypes. This characterization allows one to have a better understanding of performance capabilities of nursery-grown seedlings and thus a better capability to forecast their field performance. Stock quality is a seedling's "fitness for purpose" as it relates to achieving specific silvicultural objectives (Lavender et al. 1980). In this instance, examples show variation in stock quality of seedlings from across a range of container cavity sizes and variation that can occur within a single container cavity size.

Seedling material attributes versus seedling size

In this first example, spruce seedlings grown in a range of container cavity sizes are compared for their stock quality material attributes. Material attributes are single-point measures of individual parameters that represent specific seedling subsystems (Ritchie 1984). Spruce seedlings grown in large-volume containers have greater shoot and root size, but maintain fairly comparable balance within their shoot system (i.e., height to diameter ratios), and between their shoot and root system (i.e., shoot to root ratios) (Table 1). Even though large-volume containers produced larger seedlings, all of these stocktypes met target specifications for 'plantable' container-grown spruce seedlings. Other work has also found that spruce seedlings grown in large-volume containers are taller, have larger root collar diameters, and greater total shoot and root dry weights (Lamhamedi et al. 1997; Paterson 1997). In addition to having a taller shoot, seedlings grown in large-volume containers have a greater number of branches and buds, but no greater potential for predetermined shoot growth (i.e., number of needle primordia found in the terminal bud) (Table 1). Nurseries can use large-volume containers to produce larger seedlings that can occupy a greater area within the planting spot, without compromising structural balance.

Spruce seedlings of all sizes have comparable physiological stock quality attributes (Table 1). This is reflected in the similar drought tolerance and avoidance for spruce seedlings grown over a range of container volumes. Photosynthetic capability was also comparable between seedlings of various container sizes. This indicates that producing a morphologically larger seedling does not confer any additional physiological stock quality attributes to enhance performance under optimum or limiting environmental conditions. If there is a benefit of a larger seedling in relation to physiological performance, it is that its greater foliar mass allows for greater seedling photosynthetic capacity. This capability could be critical in enhancing the ability of larger seedlings to grow quickly and occupy site resources during establishment (Grossnickle 2000).

Seedling performance attributes versus seedling size

In this second example, spruce seedlings grown in a similar container cavity size are compared for their stock quality performance attributes in relation to seedling size variation. Performance attributes reflect an integrated effect of many material attributes, are environmentally

Table 1. *Stock type material attribute characterization (mean + SE) of interior spruce seedlings (2+0 stock from the same seedlot) produced in three container Styroblock™ formats for the summer planting program (adapted from Grossnickle 2000).*

Attribute	415B†	415D†	615A†
Height	24.2 + 0.8 cm*	29.7 + 0.7 cm*	33.3 + 0.8 cm*
Diameter	4.4 + 0.1 mm*	5.0 + 0.1 mm	6.8 + 0.2 mm
Height to diameter ratio	5.6 + 0.2*	6.0 + 0.2*	5.0 + 0.2*
Shoot dry weight	2.8 + 0.1 g	4.5 + 0.2 g	6.4 + 0.3 g
Root dry weight	1.1 + 0.1 g	1.4 + 0.1 g	2.1 + 0.1 g
Shoot to root ratio	2.84 + 0.1	3.4 + 0.1	3.3 + 0.1
Number of branches	18 + 1	24 + 2	33 + 12
Number of buds	50 + 2	67 + 3	86 + 3
Number of needle primordia	193 + 35	164 + 36	147 + 38
Net photosynthesis (µmol m-2 s-1)	2.72 + 0.24	2.68 + 0.27	2.39 + 0.32
Drought tolerance Osmotic potential at turgor loss point (MPa)	-1.60 + 0.15	-1.64 + 0.09	-1.49 + 0.11
Drought Avoidance Cuticular transpiration (mg H2O (g DW)$^{-1}$ h^{-1})	435 + 72	364 + 42	415 + 60

† All stocktypes were grown in format 600 Styroblock® containers (Beaver Plastics Ltd.) in the following individual cavity volumes: 415B at 105 mL, 415D at 170 ml, and 615A at 340 mL.

* Meets or exceeds the accepted BC MoF target (Scagel et al. 1993).

sensitive seedling properties, and are measured under specific testing conditions (Ritchie 1984). Seedling root growth is the most commonly measured performance attribute used in operational programs throughout the world to define stock quality (Ritchie 1985, Sutton 1990, Simpson and Ritchie 1997). That is because root growth capacity (RGC) is a direct indicator of a seedlings ability to grow roots and is a general indicator that all systems in the seedling are functioning properly and thus provides a measure of seedling performance potential (Ritchie 1984, Burdett 1987). Shoot growth is also critical for recently planted spruce seedlings. New shoot growth allows the seedling to occupy the site and become dominant within the reforestation site vegetation complex. The shoot growth potential test defines the ability of seedlings to break bud and grow new shoots under defined environmental conditions (Folk and Grossnickle 2000, Grossnickle and Folk 2005). This assessment approach complements results of the RGC test and the combination of these tests provides a means of defining overall seedling growth performance.

Seedling size affected spruce seedlings ability to grow roots. Seedlings with greater initial root weight, in general, had greater root growth (Fig. 1A). Studies have shown that greater initial root mass is related to greater RGC in pine (Johnsen et al 1988, Williams et al. 1988) and spruce (Grossnickle and Major 1994) seedlings. Container-grown spruce seedlings have a high field survival potential when seedlings average at least ten new roots (>1.0 cm in length) per plant (Burdett et al. 1984, Simpson 1990). On the other hand, spruce seedlings with low RGC (<10 new roots) have the potential for poor field survival (Burdett et al. 1984, Simpson 1990). This is why the RGC threshold of at least 10 new roots is used as a batch culling guideline in British Columbia for container-grown seedlings (Simpson et. al. 1988). There is also a minimum accepted root weight (target root weight = 0.7 g) for container-grown spruce seedlings (Scagel et al. 1993). In general, as long as spruce seedlings root systems size exceeds this target root weight they have a sturdy root plug that can grow enough roots to ensure good seedling establishment within reforestation programs, though seedlings with greater root weight, in general, grow a greater number of roots.

Seedling size affected spruce seedlings ability to grow additional new shoot system. Seedlings with greater initial shoot size, in general, had greater total seedling new shoot growth (Fig. 1B). This occurs because larger

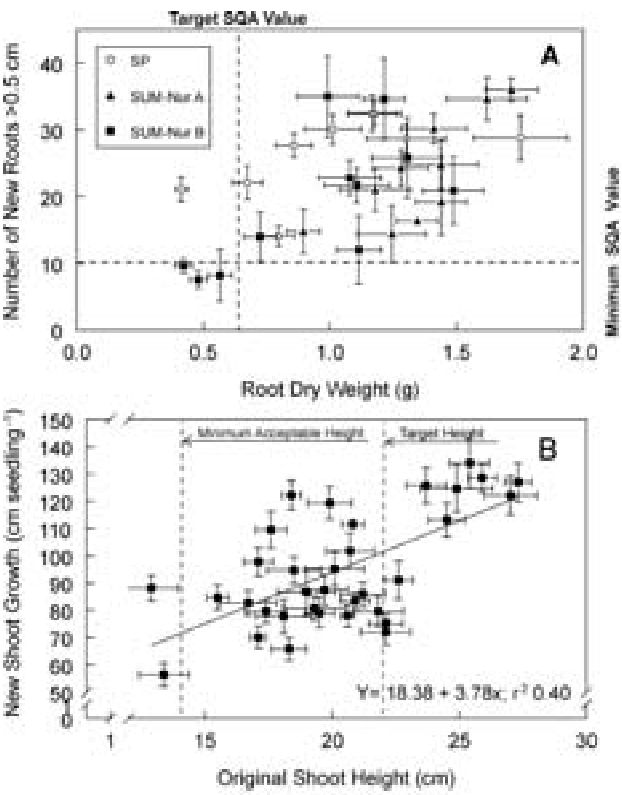

Figure 1. *Stock quality performance (mean ± SE) of interior spruce seedlings (1+0 stock from genetic sources within the same seedlot) produced in the 415B container Styroblock™ format (105 ml cavity volume) showing: A) root growth capacity in relation to the original root weight grown at three different nurseries for either spring (SP) or summer (SUM) planting programs, and B) shoot growth potential (i.e., a measure of total seedling shoot growth over a predetermined time, eight weeks, under optimum environmental conditions) in relation to the original shoot height for the spring planting program (Grossnickle, unpublished data). Dashed lines represent accepted BC MoF targets (Scagel et al. 1993).*

spruce seedlings have a greater number of branches and buds (Table 1). Thus, when all of these buds break and the shoot system elongates larger seedlings put on proportionally greater amounts of shoot biomass. This allows larger seedlings to occupy a greater area within the planting spot and capture more of the site resources (i.e., incoming solar radiation).

Field Performance Related to Initial Seedling Size

Trials have been conducted to determine whether there is a benefit to planting larger seedlings to ensure good plantation establishment on reforestation sites. These field trials have found that planting larger seedlings can be beneficial to seedling establishment and better growth up to 15 years after planting (Smith 1975, Chavasse 1977, Overton and Ching 1978, Balneaves 1989; Newton et al. 1993; South et al. 1993; South et al. 1995; Zwolinski et al. 1996, Mason 2001). This pattern was also evident in field trials with various spruce species; Sitka (South and Mason 1993), white (Mullin and Svaton 1972, Mullin and Christl 1981, McMinn 1982, Jobidon et al. 2003), interior (Dobbs 1976, Vyse 1982, Hines and Long 1986, Sutherland and Newsome 1988) and black (Jobidon et al. 1998, Jobidon et al. 2003).

So what is the major benefit of planting larger seedlings within many reforestation programs? Intuitively one would assume that seedlings with larger root and shoot systems have greater potential for rapid site occupation and access of site resources during the establishment phase. This section reviews published work on seedling size in relation to ecophysiological performance and seedling establishment.

Response to competition

Competition for light between planted seedlings and the site vegetation complex is one of the main limiting environmental factors that affect the performance of seedlings in the transitional phase of plantation development (Grossnickle 2000). Jobidon and co-workers (1997, 2003) found that shoot systems of larger stock had a greater exposure to the growing season available light, which resulted in greater shoot growth. The degree of this benefit of available light was directly related to the level of competition and silvicultural practices. So what is happening to these seedlings from an ecophysiological perspective? On sites with low levels of competition seedlings of all sizes received enough light to ensure a high level of photosynthetic capability (Fig. 2A). However, on sites with high levels of competition larger seedlings had access to greater levels of incoming light and thus greater photosynthetic capability (Fig. 2B). If seedlings on sites with high levels of competition were released from competitive vegetation, larger seedlings had much greater photosynthetic capability than smaller seedlings. In addition, the greater foliar mass of a larger seedling allows for greater seedling photosynthetic capacity. The combination of access to greater levels of incoming solar radiation and greater photosynthetic capacity could be critical in enhancing the ability of larger seedlings to grow quickly and occupy site resources during establishment. This is why large seedlings have been found to have a higher intrinsic growth potential than small seedlings on sites where competition is a silvicultural concern (Jobidon et al. 2003). The use of larger seedlings may be a good silvicultural strategy if vegetation competition is a major factor limiting plantation establishment (Thiffault 2004).

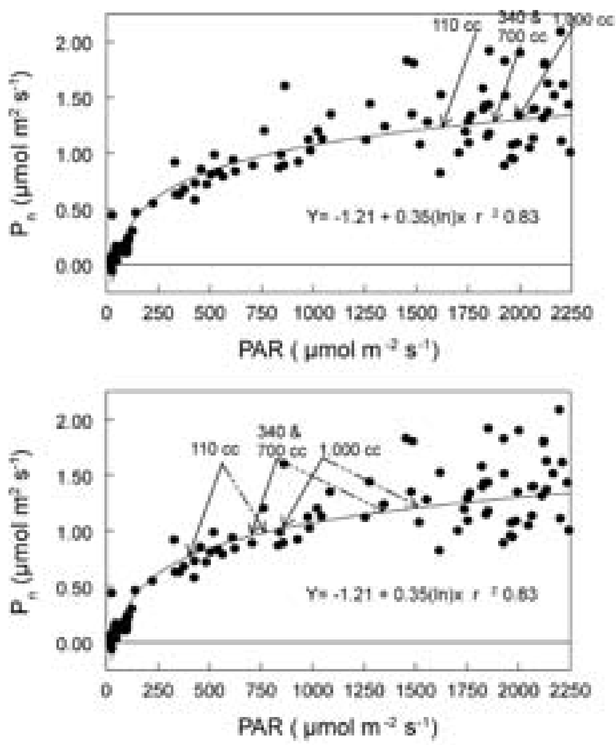

Figure 2. *Spruce seedlings hypothetical photosynthetic response pattern to a range of reforestation site light conditions. The photosynthetic pattern is for spruce seedlings measured on a field site under optimal soil water conditions (Grossnickle, unpublished data). The light levels are defined as the mean quantity of light reaching the mid-upper crown of four spruce seedling stock sizes (Stock height (cm) at planting: 110cc = 22.2 ± 3.3, 340cc = 35.7 ± 6.8, 700cc = 42.8 ± 9.3, 1,000cc = 47.3 ± 8.5) during the fifth growing season after being planted on reforestation sites (adapted from Jobidon et al. 2003). Figure A represents light levels in relation to their shoot system size on a reforestation site with a low level of competition. Figure B represents light levels in relation to their shoot system size on a reforestation site with a high level of competition with no vegetation release treatment (solid arrows) and two years after a vegetation release treatment (dashed arrows).*

Planting stress

Planting seedlings of larger size can also create risks in establishing a forest plantation. This may occur where limiting environmental conditions can put seedlings with a large shoot to root balance under physiological stress. The ability of a seedling to take up water is affected by its root system size and distribution, root-soil contact, and root hydraulic conductivity. The seedling shoot system, which is exposed to the atmospheric demand for water, has transpirational water loss from needles which is determined by the degree of stomatal opening and needle area. Typically, newly planted seedlings have restricted root placement, low root system permeability and/or poor root-soil contact, which can limit water uptake from the soil (Kozlowski and Davies 1975, Rietveld 1989, Burdett 1990). As a result, seedlings can be exposed to stress just after planting (i.e., planting stress) because they are not fully coupled into the hydrologic cycle whereby water flows from the soil to plant roots, through the plant and into the atmosphere. Stress occurs when a newly planted seedling's root system can not supply enough water to transpiring needles to maintain a proper water balance and ensure survival (Grossnickle 2005).

Under dry soil conditions, larger conifer seedlings are reported to have greater water stress (Rose et al. 1993; Stewart and Bernier 1995) or reduced growth (Baer et al. 1977; Hahn and Smith 1983) than smaller seedlings. Under dry conditions, black spruce seedlings with very large shoot systems (i.e., six times the foliar mass of small seedlings) had greater water stress and reduced photosynthesis compared to seedlings with smaller shoot systems (Lamhamedi et al. 1997). As the seedling shoot system reaches a certain size, the increased foliar mass can increase the seedling's susceptibility to water stress. This can be a problem in newly planted seedlings that have restricted root development. The susceptibility of larger seedlings to be exposed to water stress at planting is mitigated if seedlings have the capability to quickly develop new roots. Large container-grown Engelmann spruce seedlings had increased first-year survival compared to smaller seedlings (Hines and Long 1986) on sites that dry out as the growing season progresses. Hines and Long (1986) found that increased survival in larger seedlings was related to greater root growth over the initial four-week period after planting, which reduced seedling water stress. In most instances, spruce seedlings show a general trend of greater new root growth with a greater original root system size (Fig. 1B). This allows larger seedlings to generate enough roots, which supply enough water to transpiring needles, thereby maintaining a proper water balance and avoid planting stress conditions. However, increased root growth does not always occur in larger seedlings having bigger root systems, and this variability can be related to stock type, nursery cultural practices, and genetic source (Grossnickle 2000). In addition, restricted root development of newly planted seedlings can be limited by field site edaphic (i.e., low water and temperature) conditions (Grossnickle 2000). Caution should be used when considering whether to plant large stock on potentially dry sites that can limit initial root growth and subsequent seedling establishment.

Conclusions

What is the answer to the question "How big is big enough?" when it comes to seedling size and reforestation success? The answer is it depends. On sites where there is vegetative competition for light resources, larger seedlings that can put on proportionally greater amounts of shoot biomass can have a competitive advantage over smaller seedlings. On sites where limiting environmental conditions (i.e., drought, high evaporative demand or cold soils) can put seedlings with a large shoot to root balance under physiological stress and limit root development just after planting, seedlings with smaller shoot systems can have a competitive advantage over larger seedlings. Foresters need to recognize the strengths and weaknesses of all stocktypes. This is why stocktype selection in relation to site conditions should be part of an effective silvicultural strategy.

References

Baer, N., Ronco, F., Barney, C.W., and Baer, N.W. 1977. Effects of watering, shading and size of stock on survival of planted lodgepole pine. U.S. Dep. Agric. For. Ser. Res. Note RM-347.

Balneaves, J.M. 1989. Root collar diameter of 1/0 Radiata pine influences growth following planting. Forestry, 62: 125–130.

Burdett, A.N. 1987. Understanding root growth capacity: theoretical considerations in assessing planting stock quality by means of root growth tests. Can. J. For. Res.17: 768–775.

Burdett, A.N. 1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock. Can. J. For. Res. 20:415-427.

Burdett, A.N., Herring, L.J., and Thompson, C.F. 1984. Early growth of planted spruce. Can. J. For. Res. 14: 644–651.

Chavasse, C.G.R. 1977. The significance of planting height as an indicator of subsequent seedling growth. NZ J. For. 22:283-296.

Dobbs, R.C. 1976. Effect of initial mass of white spruce and lodgepole pine planting stock on field performance in the British Columbia Interior. Environ. Can., Can. For. Serv., Victoria, B.C. BC-X-149.

Folk, R.S., and Grossnickle, S.C. 2000. Stock-type patterns of phosphorus uptake, retranslocation, net photosynthesis and morphological development in interior spruce. New For. 19:27-49.

Grossnickle, S.C. 2005. Importance of root growth in overcoming planting stress. New Forests, In Press

Grossnickle, S.C. 2000. Ecophysiology of Northern Spruce Species: The Performance of Planted Seedlings. NRC Research Press, 409p.

Grossnickle, S.C. and Folk, R.S. 2005. Stock quality assessment of a somatic interior spruce seedlot. N. J. Appl. For. In Press

Grossnickle, S.C. and Major, J.E. 1994. Interior spruce seedlings compared to emblings produced from somatic embryogenesis. II) Stock quality assessment prior to field planting. Can. J. For. Res. 24:1385-1396.

Hahn, P.F., and Smith, A.J. 1983 Douglas-fir planting stock performance. Comparison after the third growing season. Tree Planters' Notes, 34: 33–39.

Hines, F.D., and Long, J.N. 1986. First-and second-year survival of containerized Engelmann spruce in relation to initial seedling size. Can. J. For. Res. 16: 668–670.

Jobidon, R., Charette, L., and Bernier, P.Y. 1997. Initial size and competing vegetation effects on water stress and growth of *Picea mariana* (Mill.) BSP seedlings planted in three different environments. For. Ecol. Manage. 103: 295–308.

Jobidon, R., Roy, V., and Cyr, G. 2003. Net effect of competing vegetation on selected environmental conditions and performance of four spruce seedling stock sizes after eight years in Quebec (Canada). Ann. For. Sci. 60:691-699.

Johnsen, K.H., Feret, P.P., and Seiler, J.R. 1988. Root growth potential and shoot activity of northern and southern provenances of 1–0 eastern white pine seedlings grown in a Virginia nursery. Can. J. For. Res. 18: 610–614.

Kozlowski, T.T., and Davies, W.J. 1975. Control of water balance in transplanted trees. Arboriculture 1:1-10.

Lamhamedi, M.S., Bernier, P.Y., and Hérbert, C. 1997. Effect of shoot size on the gas exchange and growth of containerized *Picea mariana* seedlings under different watering regimes. New For. 13: 209–223.

Lavender, D.P., Tinus, R., Sutton, R., and Poole, B. 1980. Evaluation of planting stock quality. New Zealand J. For. Sci. 10: 293-300.

Mason, E. 2001. A model of juvenile growth and survival of *Pinus radiata* D. Don. adding the effects of initial seedling diameter and plant handling. New For. 22:133-158.

McMinn, R.G. 1978. Root development of white spruce and lodgepole pine seedlings following outplanting. *In* Proc. Symp. On Root Form of Planted Trees. Edited by E. Van Eerden and J.M. Kinghorn. BC Min. For. and Can. For. Serv., Victoria, BC Joint Rep. 8. pp. 186-190.

McMinn, R.G. 1982. Size of container-grown seedlings should be matched to site conditions. *In* Proceedings, Canadian Containerized Tree Seedling Symposium, September 14–16, 1981, Toronto, Ontario. Edited by J.B. Scarratt, C. Glerum, and C.A. Plexman. COJFRC Symp. Proc. O-P-10. Canadian Forestry Service, Great Lakes Forestry Center, Sault Ste. Marie, ON. pp. 307–312.

Mullin, R.E. and Christl, C. 1981. Morphological grading of white spruce nursery stock. For. Chron. 57:126-130.

Mullin, R.E. and Svaton, J. 1972. A grading study with white spruce nursery stock. Commonw. For. Rev. 51:62-69.

Newton, M., Cole, E.C., and White, D.E. 1993. Tall planting stock for enhanced growth and domination of brush in the Douglas-fir region. New For. 7: 107–121.

Overton, W.S. and Ching, K.K. 1978. Analysis of differences in height growth among populations in a nursery selection study of Douglas-fir. For. Sci. 24: 497-509.

Paterson, J. 1997. Growing environment and container type influence field performance of black spruce container stock. New For. 13: 329–339.

Payandeh, B. and Wood, J.E. 1988. Identifying factors affecting plantation performance in boreal forests of Ontario. New For. 2:73-87.

Rietveld, W.J. 1989. Transplanting stress in bareroot conifer seedlings: its development and progression to establishment. North. J. Appl. For. 6:99-107.

Ritchie, G.A. 1984. Assessing seedling quality. *In* Forest Nursery Manual: Production of Bareroot Seedlings. Edited by M.L. Duryea and T.D. Landis. Martinus Nijhoff / Dr. W. Junk Publishers, The Hague. pp. 243–266.

Ritchie, G.A. 1985. Root growth potential: principles, procedures, and predictive ability. *In* Evaluating seedling quality: principles, procedures, and predictive ability of major tests. Edited by M.L. Duryea. Oregon State University, Forestry Research Laboratory, Corvallis, OR. pp. 93–106.

Rose, R., Gleason, J.F., and Atkinson, M. 1993. Morphological and water-stress characteristics of three Douglas-fir stocktypes in relation to seedling performance under different soil moisture conditions. New For. 7: 1–17.

Scagel, R., Bowden, R., Madill, M., and Kooistra, C. 1993. Provincial seedling stock type selection and ordering guidelines. British Columbia Ministry of Forests, Victoria, BC. 75 pp.

Simpson, D.G. 1990. Frost hardiness, root growth capacity, and field performance relationships in interior spruce, lodgepole pine, Douglas-fir, and western hemlock seedlings. Can. J. For. Res. 20: 566–572.

Simpson, D.G., and Ritchie, G.A. 1997. Does RGP predict field performance? A debate. New For. 13: 253–277.

Simpson, D.G., Vyse, A., and Thompson, C.F. 1988. Root growth capacity effects on field performance. *In* Proceedings, Combined Meeting of the Western Forest Nursery Associations, August 8–11, 1988, Vernon, British Columbia. Edited by T.D. Landis. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-167.

Smith, J.H. 1975. Big stock vs. small stock. In: Ann. Mtg. Western Forest Fire Comm., Vancouver BC, Canada, pp. 107-115.

Stewart, J.D., and Bernier, P.Y. 1995. Gas exchange and water relations of 3 sizes of containerized *Picea mariana* seedlings subjected to atmospheric and edaphic water stress under controlled conditions. Ann. For. Sci. 52: 1–9.

South, D.B., and Mason, W.L. 1993. Influence of differences in planting stock size on early height growth of Sitka spruce. Forestry, 66: 83–96.

South, D.B., Mitchell, R.J., Zutter, B.R., Balneaves, J.M., Barber, B.L., Nelson, D.G., and Zwolinski, J.B. 1993. Integration of nursery practices and vegetation management: economic and biological potential for improving regeneration. Can. J. For. Res. 23: 2083–2092.

South, D.B., Zwolinski, J.B., and Allen, H.L. 1995. Economic returns from enhancing loblolly pine establishment on two upland sites: effects of seedling grade, fertilization, hexazinone, and intensive soil cultivation. New For. 10: 239–256.

Sutherland, C. and Newsome, T. 1988. Field performance of five interior stocktypes with and without fertilization at the time of planting. USDA For. Serv. Gen. Tech. Rep. RM-167. pp. 195-198.

Sutton, R.F. 1990. Root growth capacity in coniferous forest trees. Hortic. Sci. 25: 259–266.

Thiffault, N. 2004. Stock type in intensive silviculture: A (short) discussion about roots and size. For. Chron. 80: 463-468.

Vyse, A. 1982. Field performance of small-volume container-grown seedlings in the central interior of British Columbia. *In* Proc. Can. Containerized Tree Seedling Symposium. Edited by J.B. Scarratt, C. Glerum and C.A. Plexman. Environ. Can., Can. For. Serv., Sault Ste. Marie, ON, COJFRC Symp. Proc. O-P-10, pp. 291-297.

Williams, H.M., South, D.B., and Glover, G.R. 1988. Effects of bud status and seedling biomass on root growth potential of loblolly pine. Can. J. For. Res. 18: 1635–1640.

Zwolinski, J.B., South, D.B., Cunningham, L., and Christie, S. 1996. Weed control and large bareroot stock improve early growth of *Pinus radiata* in South Africa. N.Z. J. For. Sci. 26: 163–172.

Cost – Quality Relationship of Norway Spruce Planting and Scots Pine Direct Seeding In Finland – Preliminary Results

V. Kankaanhuhta, T. Saksa, H. Smolander

Finnish Forest Research Institute, Suonenjoki Research Station, Juntintie 154,
FIN-77600 Suonenjoki , Finland

A new cost-effective method to make forest regeneration area inventories has been developed in Finland. The results reveal that there is significant variation both between the forest owners associations and many times also between the actors within one association. More information about this quality control system is available i.e. in the poster “Quality control system for regeneration activities in private forests in Finland” (Saksa et. al.). The aim of this study was to analyse the cost-quality relationship of the forest regeneration practices in forest owners’ associations (FOAs). Some preliminary results of Norway spruce (*Picea abies* L. Karst.) planting and Scots pine (*Pinus sylvestris* L.) direct seeding are presented.

Altogether 12 FOAs inventoried between the years 2000-2002 joined to the study. The participating FOAs were from five various forestry districts of Southern Finland (1-3 of each). The collected cost data of planted regeneration areas included soil preparation, seedlings, planting labor, supervision and other additional costs. The direct seeding chains included also costs of seeding and seeds. The recorded cost data without value added tax was imported to the database, which included the inventory data. The wholesale price index was applied to adjust the annual variation of the costs. For planting chains the criteria to pick the regeneration areas for further analysis were the availability of soil preparation, planting work and seedling cost data. For direct seeding chains the criteria were soil preparation and seed costs. Other costs of regeneration areas were also included, but they were not used as inclusion criteria because of naming practice variations in the invoices. Area weighted regeneration results and regeneration costs per hectare were calculated by municipalities.

The cost-quality relationship between FOAs’ consisting of one or more municipalities varied significantly for both regeneration chains studied. The investment on the forest regeneration may produce very different kind of results in different municipalities. As compared to the inventory results of the whole inventory data, these differences cannot be explained only by geographical or ecological differences, but mostly by differences in regeneration practices and organizational cultures. The comparison of smaller cost data set and the complete inventory data set revealed the difference in regeneration results mainly in favor for smaller cost data set. This is very logical considering the fact that the collected cost data is most complete for the areas fully carried out by the FOA and that the measures carried out by the FOA is supposed to be most consistent.

In general cost-quality relation seems to be very promising way to measure the forest regeneration processes’ performance. It opens a valuable view to the cost structure and importance of various stages in regeneration chains. Other ways to measure the regeneration processes’ performance are studied in other projects of the research group.

Soil Nutrient Supply Rates as an Indicator of Site Suitability and Seedling Growth Requirements

R.D. Hangs[1], K.J. Greer[1], K.C.J. Van Rees[2]

[1]Western Ag Innovations, 3 - 411 Downey Road, Saskatoon, SK S7N 4L8, Canada
[2]Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 5A2, Canada

Introduction

There is a stigma attached to conventional soil testing methodologies within the forest industry and for good reason; the nutrient availability data provided are poorly correlated with seedling nutrient uptake and growth during the early establishment phase (Pritchett and Fisher 1987). A single 'point-in-time' extraction only represents a *snapshot* of readily available soil nutrients and, therefore, may not adequately reflect the soil nutrient supply throughout the growing season (Stark and Hart 1997, Driscoll et al. 1999). Conversely, an index of soil *N supplying power* is biologically more meaningful, because it integrates all of the factors affecting nutrient availability over time (Pritchett and Fisher 1987). Unlike conventional soil extractions, *in situ* burials of ion-exchange membrane (IEM) integrate all of the principal edaphic factors affecting nutrient uptake by plants (i.e., soil moisture and temperature, mineralization and immobilization, buffer power, dissolution, ion diffusion from greater distances, free ion activities, etc.) regardless of soil type (Qian and Schoenau 2002). Consequently, IEM are an effective surrogate for *bio-mimicking* nutrient absorption by plant roots as they remove soil nutrients through ion-exchange; therefore, providing the most reliable index of nutrient bioavailability (Yang et al. 1991, Qian et al. 1992, van Raij 1998). The objective of this study then was to measure nutrient supply rates at several hybrid poplar plantations in northern Saskatchewan, using *in situ* burials of IEM, and then relate these data to plantation productivity during the early establishment phase.

Materials and Methods

Study sites

The data for this study were collected from four hybrid poplar plantations in northern Saskatchewan. Two sites are located approximately 25 km southwest of Meadow Lake, Saskatchewan (Cubbon: NW 22 58 19 W3; Culbert: SW 31 57 19 W3). The other two sites are located near Star City and Arborfield (NW 36 45 17 W2 and NE 4 46 12 W2, respectively). Although the topography of all sites is very gently undulating (i.e., slopes less than two percent), the soil and site characteristics are diverse (Table 1). This site diversity is advantageous in that it allows for a greater inference space in terms of providing accurate fertilizer recommendations based on the measured relationship between nutrient supply rates and early growth of hybrid poplar seedlings at each site. All sites underwent mechanical and chemical site preparation prior to planting and throughout each growing season (Table 1).

Experimental design

At the two Meadow Lake sites, the experimental design is a 3 x 2 x 2 factorial, randomized complete block and replicated three times. The treatments include: stock type (cuttings, rooted cuttings, and container seedlings), pruning (pruned lower branches and unpruned), and N fertilization split-plots (0 and 100 kg N/ha). For the fertilization treatment, half of the treatment plots within each block were control plots and the others designated fertilizer plots. Within the fertilizer plots, each plot was split in half (i.e., split-plot design) with one half receiving a broadcast application of NH_4NO_3 fertilizer (100 kg N/ha) on June 4, 2003 (year two of the plantation), while the remaining half will receive a similar application in June, 2005 (year four of the plantation). The remaining two sites had no imposed treatments, but instead were simply clonal studies set-up in a randomized complete block design (12 and 18 different hybrid poplar clones planted at the Star City and Arborfield sites, respectively) and replicated three times. The Meadow Lake and Star City sites were established in the spring of 2002, while the Arborfield site was planted in June 2003.

Soil nutrient analysis

Plant Root Simulator™-probes (Western Ag Innovations Inc., Saskatoon, SK) were used to measure soil nutrient availability at each site. Plant Root Simulator™-probes provide a basis for determining fertilizer recommendations for different cereal, oil seed, pulse, and forage crops in western Canada (Qian and Schoenau 2002) and have been used to study forest soil nutrient dynamics in both undisturbed and disturbed sites (Huang and Schoenau 1996,1997; Johnson et al. 2001; Duarte 2002; Hangs et al. 2004). The PRS™-probe consists of either cation- or anion-exchange resin membrane

Table 1. *Selected characteristics of four hybrid poplar study sites located in northern Saskatchewan.*

	Soil Characteristics				Site Characteristics				Vegetation Management Practices			
									Pre-planting		Post-planting	
Site	Association	Soil Type	Texture	PH	EC (mS/cm)	Prior Crop	ACC*	Rainfall† (mm)	Mechanical	Chemical	Mechanical	Chemical
Cubbon‡	Loon River	Orthic Gray Luvisol	sandy-loam to loam	6.5	0.8	alfalfa	3-4	190	- Deep till - Light cultivation	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Culbert‡	Bittern Lake	Brunisolic Gray Luvisol	sandy-loam to loam	5.4	0.7	pasture	4-5	190	Deep till (x2)	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)	Tandem disc	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Star City§	Melfort-Hoey	Orthic Black Chernozem	clay-loam to loam	5.1	0.8	canola	1-2	250	Tandem disc (x 2)	- Treflan (5 L/ha) - Sencor (395 g/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Arborfield¶	Eldersley	Orthic Gray Luvisol	clay-loam to loam	6.3	0.6	wheat	1-2	350	Tandem disc (x 2)	- Treflan (5 L/ha) - Sencor (395 g/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)

* Agriculture capability classification (Class 1: no significant limitations; Class 2: moderate limitations; Class 3: moderately severe limitations; Class 4: severe limitations; Class 5: very severe limitations).
† During the period of PRS™-probe burials.
‡ For a complete description (i.e., map unit, parent material, stoniness, drainage, etc.) see SCSR (1995).
§ For a complete description see SCSR (1989).
¶ For a complete description see Stonehouse and Ellis (1983).

encased in a plastic holding device and is inserted into soil to measure nutrient supply rates *in situ* with minimal disturbance (Fig. 1). At the Meadow Lake sites, four pairs of PRS™-probes (i.e., four cation- and four anion-exchange) were installed within each treatment plot, for a total of 288 PRS™-probes (12 treatment plots x 3 reps x 4 PRS™-probes x 2 types) per burial period at each site. At the other two sites, two pairs of PRS™-probes were installed within each clone plot, for a total of 144 (12 clone plots x 3 reps x 2 PRS™-probes x 2 types) and 216 (18 clone plots x 3 reps x 2 PRS™-probes x 2 types) PRS™-probes per burial period at the Star City and Arborfield sites, respectively. The PRS™-probes were inserted vertically into the Ap horizon (Fig. 2); thereby having the ion-exchange membrane effectively measure soil nutrient supply rates in the zone having the largest concentration of hybrid poplar roots (Block, 2004). The PRS™-probes were left in the soil for five weeks and then replaced with fresh PRS™-probes twice more during the growing season for a total of 15 weeks. Replacing fresh PRS™-probes in the same soil slot provides a true *in situ* measure of temporal nutrient availability and yields the most accurate index of nutrient availability to correlate with seedling growth. Consequently, continuously measuring soil solution nutrient availability should provide a basis for accurately predicting nutrient supply-limited uptake or growth, because it is an integral part of the mechanisms governing nutrient supply and uptake (Lajtha et al. 1999, Smethurst 2000).

The PRS™-probes within each treatment plot were combined for analysis, much like a composite soil sample, and this helped to account for any microscale variability. After removal, the PRS™-probes were washed free of soil and then thoroughly scrubbed and re-washed back in the lab prior to the analysis to ensure complete removal of any residual soil. Inorganic N as ammonium (NH_4^+-N) and nitrate (NO_3^--N) was determined colourimetrically and the remaining nutrients (P, K, S, Ca, Mg, Cu, Zn, Mn, Al, Fe, B, and Pb) measured using inductively-coupled plasma spectrometry. Unused PRS™-probe method blanks also were analysed to test for contamination during the regeneration and handling steps.

Seedling survival and growth

At the end of the growing season, seedling establishment and growth were assessed at each site by measuring seedling survival, ground-line diameter (GLD), and height. Determining the relationship between soil nutrient supply rate at both time of planting and throughout each growing season and subsequent seedling growth should help support effective management strategies, in terms of proper site selection and effectively managing fertilizer requirements.

Statistical analyses

The soil nutrient availability and seedling growth data were analysed independently by site using the GLM procedure in SAS (Version 8.0, SAS Institute Inc. Cary, NC). Mean comparisons were performed using least significant differences (LSD) at a significance level of 0.05. The LSD option was used to carry out pair-wise *t* tests (equivalent to Fisher's protected LSD) of the different means between treatments and clones. All data were tested for homogeneity of variances and normality. Simple linear regressions were performed using the

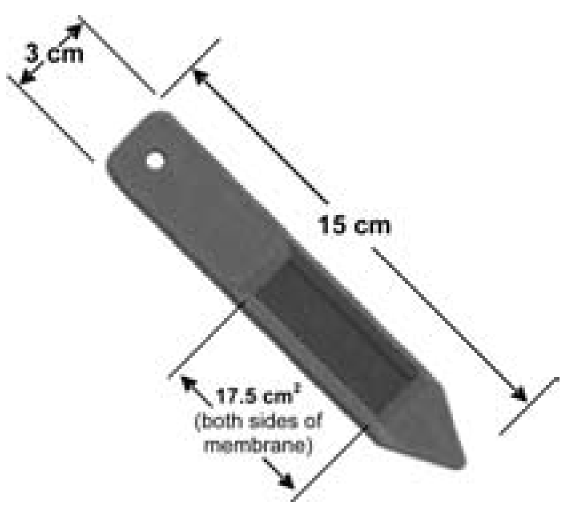

Figure 1. *Dimensions of a PRS™-probe.*

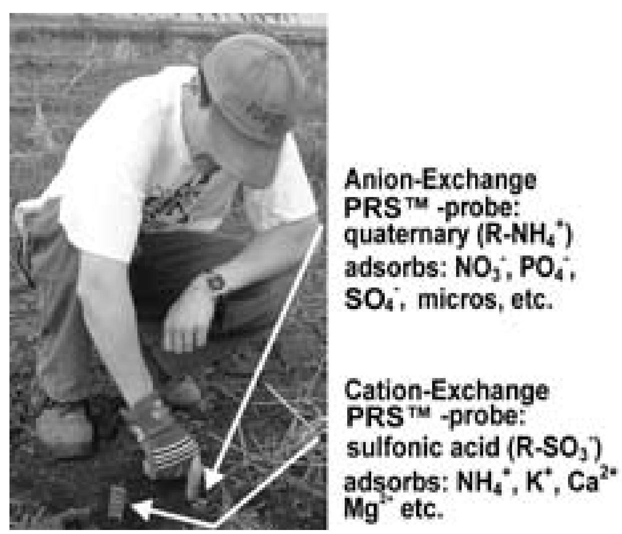

Figure 2. *PRS™-probes used to measure soil nutrient availability in situ.*

REG procedure in SAS (Version 8.0, SAS Institute Inc. Cary, NC) using pooled data (i.e., all sites) to quantify the relationship between the nutrient supply rate data during the growing season and growth of hybrid poplar seedlings over that same period. Residuals from the analyses were examined to the test the assumptions of equal variance and no data transformations were necessary.

Results and Discussion

Nutrient availability among sites

Within each site, there was relatively low variability in nutrient supply rate for most nutrients (i.e., CV < 20%; data not shown), which is not surprising considering that agricultural soils historically have less microscale variability compared with forest soils (Pritchett and Fisher, 1987). For all sites in this study, NO_3^--N was the predominant inorganic N source available for seedling uptake (Table 2), and is expected considering that NH_4^+-N often is rapidly nitrified in agricultural soils (Brady, 1990). The total N supply rates (i.e., NH_4^+-N + NO_3^--N) varied among the sites with Star City having the largest values. The Chernozemic soils at the Star City site clearly have greater N fertility compared with the Luvisols of the other sites, of which the Culbert soils had the smallest total N supply rate. The smallest supply rate at Culbert is probably attributable in part to increased N immobilization that is common to recently broken pasture having a wide C:N (Ellert and Gregorich, 1996; Kristensen et al., 2000; Parfitt et al., 2003). Of the Luvisols, the Cubbon site had the largest total N supply rates (Table 2) and this is due to the prolonged alfalfa production on this site, which resulted in significant N-fixation in these soils.

In terms of the remaining macro- and micronutrients, there was a wide range in supply rates among the four sites in this study (Table 2) and this can be attributed to a number of factors, including differences in past management practices (i.e., crop, fertilization, site preparation technique, etc.), soil type, and growing season conditions. Such variability in nutrient variability among these different sites is essential, for subsequently relating them to seedling growth, if accurate recommendations are to be made across a large inference space. Of particular interest though, is the extremely large manganese supply rate measured at the Cubbon site compared with the other sites (Table 2). One possible mechanism for this could have been the mixing of the acidic subsoil with the calcareous topsoil, during the deep tillage of this site prior to planting, which would have lowered the soil pH and increased manganese availability. Typically, with decreased soil pH and increased manganese availability, there is a concomitant decrease in magnesium availability (Havlin et al., 1999), and was measured using PRS™-probes (Table 2). In addition, while in sustained forage production this field had a balanced fertility package applied annually with both macro and micronutrients, including Mn (Dave Cubbon, personal communication), which also helps to explain the larger Mn supply rates at the Cubbon site.

Nutrient availability following fertilizer N treatment

At both Meadow Lake sites, the addition of fertilizer N resulted in increased NH_4^+-N, NO_3^--N, and total N supply rates, relative to plots having no fertilizer N added, with no marked effect on the supply rates of other nutrients (Table 3). Specifically, following fertilizer N addition, there was increased NH_4^+-N availability from June to July at both the Cubbon and Culbert sites relative to the plots without

***Table 2.** Mean cumulative nutrient supply rates, measured using in situ burials of PRS™-probes, at four hybrid poplar sites from early June to late August 2003*.*

Site	n	NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Cu	Zn	Mn	Al	Fe	B	Pb
		μg/10cm²/12 weeks														
Cubbon	18	6b†	813b	819b	9.7a	281a	129b	3735a	367d	<mdl‡	3.0a	109.9a	52.5a	23.6b	1.0b	0.2a
Culbert	18	10a	568d	578d	3.4b	260a	81c	3393b	611c	0.5a	1.9c	10.7b	43.3b	44.4a	2.9a	0.5a
Star City	54	6b	1153a	1159a	1.7c	125b	140ab	2956b	1275a	0.5a	2.6b	11.4b	31.3c	43.5a	1.1b	0.5a
Arborfield	54	4c	651c	656c	1.8c	52c	174a	3847a	798b	0.5a	1.7c	6.5b	27.3c	35.8a	0.7c	0.7a

* Arborfield site planted early June, so for comparison purposes only June to August data is shown.
† Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.
‡ Method detection limit (0.1 μg/10cm2/12 weeks).

fertilizer N applied (Fig. 3). Subsequent nitrification of this NH_4^+-N resulted in a corresponding pulse of soil NO_3^--N from July to August. This measured increase in soil N supply rate following a single fertilizer application, together with the ability to quantify the nitrification of added fertilizer NH_4^+-N to NO_3^--N, demonstrates the sensitivity of the PRS™-probes to measure treatment effects and their efficacy in determining soil nutrient availability. Unlike the Cubbon site, the plots without fertilizer N at the Culbert site had a marked increase in NH_4^+-N supply rate as the season progressed, and can be attributed to the effect of tillage on increased N mineralization in this former pasture soil.

The added fertilizer N had minimal effects on the supply rates of most other nutrients, with the exception of potassium, calcium, manganese, and aluminium at Cubbon and sulphur at Culbert (Table 3). Specifically, the increased NH_4^+-N levels at Cubbon acted to displace the interlayer potassium within the clay minerals, thereby increasing the potassium in soil solution and availability for plant uptake. Furthermore, the increased availability of calcium, manganese and aluminium can be attributed to the net decrease in soil pH following the nitrification of the NH_4^+-N in soil. At Culbert, the decreased sulphur supply rate in fertilized plots at Culbert probably is due to microbial immobilization, in order to maintain an N:S required for their metabolic processes, as N immobilization increased at that site throughout the year. This immobilization-induced decrease in NO_3^--N supply rate as the season progressed is apparent when comparing the Culbert NO_3^--N data with Cubbon, where sustained alfalfa production prior to plantation establishment resulted in larger NO_3^--N pools that remained relatively consistent throughout the growing season (Fig. 3). The measured residual soil N supply rate following a single fertilizer application and its effect on the availability of other nutrients, together with the ability to quantify the nitrification of added fertilizer NH_4^+-N to NO_3^--N, demonstrates the sensitivity of the PRS™-probes to measure treatment effects and efficacy in measuring soil nutrient availability.

Relationship between soil nutrient availability and hybrid poplar seedling growth

Across all sites, the total N supply rate often was better correlated with seedling height, GLD, and stem volume growth than other nutrients (data not shown). In addition, the total N supply rate had a stronger correlation (R^2 0.54 to 0.98, P <0.01) with seedling growth when calculated on an individual treatment combination basis instead of using pooled data including more than one stock type, pruning method, fertilizer rate, and clone. This is not surprising considering that each treatment has a varied influence on seedling growth rate and form, cold hardiness, mortality, etc. and adds considerable variability to the seedling growth data and, therefore, weakens the resultant correlation with the PRS™-probe nutrient supply rate data. Indeed, such variability is not representative of typical operational practices. Consequently, Fig. 4 illustrates the strong relationship between total N supply rate measured over the 2003 growing season and the stem volume growth increment (believed to be the most accurate indicator of overall seedling vigour and growth) of outplanted seedlings each year from a single hybrid poplar clone (var. Walker), planted as rooted cuttings with no fertilizer N applied and ranging in age from 1 to 2 years depending on the site.

Table 3. *Mean (n=18) cumulative nutrient supply rates, measured using in situ burials of PRS™-probes, at two Meadow Lake hybrid poplar sites from early May to late August 2003 in plots with and without fertilizer N application.*

		NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Cu	Zn	Mn	Al	Fe	B	Pb
Site	Treatment	µg/10cm²/15 weeks														
Cubbon	Fertilizer*	58a†	1396a	1455a	26.9a	957a	158a	3966a	420a	0.5a	5.0a	386.7a	80.2a	78.7a	2.6a	0.4a
	No Fertilizer	33b	972b	1004b	25.4a	638b	189a	3651b	416a	0.5a	4.0a	192.5b	68.8b	77.6a	3.2a	0.4a
Culbert	Fertilizer	26a	717a	742a	11.9a	746a	50b	3704a	611a	0.6a	4.0a	32.8a	40.2a	46.1a	3.6a	0.5a
	No Fertilizer	30a	489b	519b	10.0a	656a	68a	3740a	666a	0.6a	3.9a	25.7a	38.5a	47.0a	4.0a	0.5a

* 100 kg/ha NH4NO3 fertilizer broadcast applied on June 4, 2003.
† For each site, means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

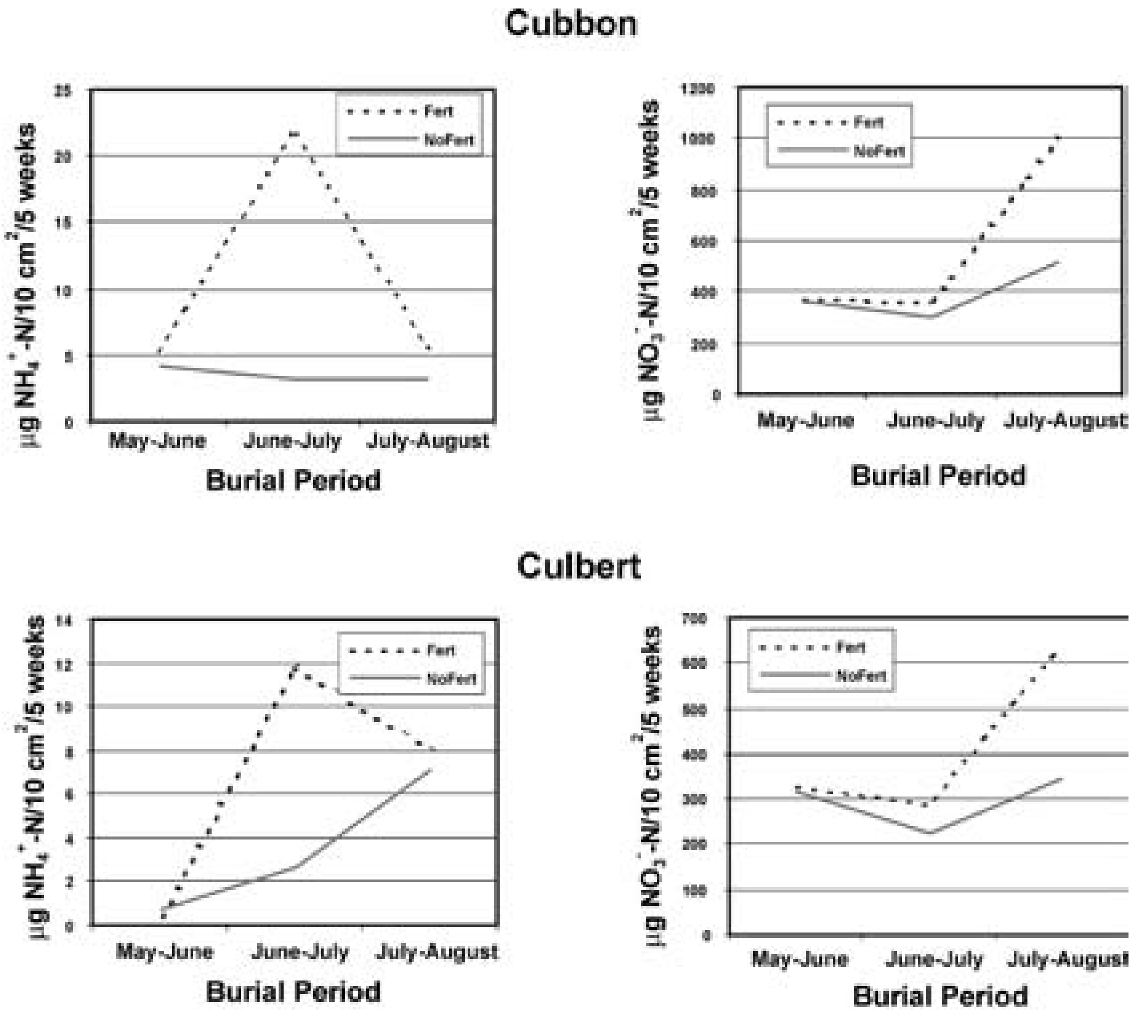

Figure 3. *Mean (n=18) NH_4^+-N and NO_3^--N supply rates, measured using in situ burials of PRS™-probes, in 2003 at two Meadow Lake hybrid poplar sites in plots with (Fert) and without (NoFert) broadcasted NH_4NO_3 fertilizer (100 kg/ha) on June 4, 2003. For each burial period, means having the same letter are not significantly different (P >0.05) using LSD.*

Mechanistic models that predict the early growth of outplanted seedlings not only require accurate estimates of soil N supply throughout the growing season (Kelly and Mays 1999), but more importantly, a biologically meaningful index of N availability that is correlated with outplanted seedling N uptake and growth. Notwithstanding the relatively good correlation between soil N availability measured using the PRS™-probes and the early growth of hybrid poplar seedlings, frankly speaking the R^2-values were smaller than expected, considering the strong correlations with plant uptake and growth often reported (Qian and Schoenau 2002, Hangs et al. 2004). The relatively dry conditions at each site certainly would have contributed to the weaker than expected relationship, because presumably soil moisture would have been a factor limiting seedling growth. Also, it is plausible that other nutrient limitations, such as phosphorus at the Meadow lake sites, may have limited seedling growth to a certain degree (Van Rees, unpublished data). Considering Western Ag Labs' historic *critical nutrient supply rate* levels for growing annual crops in Saskatchewan (data not shown), phosphorus would be considered insufficient for growing an annual crop. Although the differences in nutrient requirements of hybrid poplar compared with an annual crop are undefined at this time, this illustrates the importance of a balanced approach to soil fertility assessments (i.e., complete crop nutrition plan and, therefore, not simply N) and

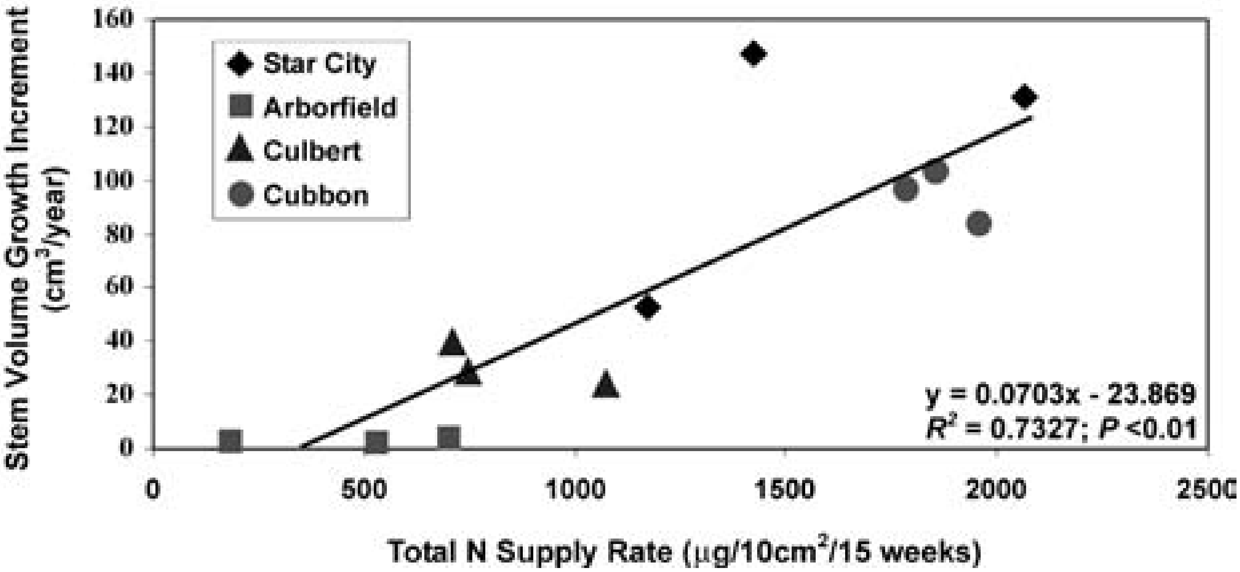

Figure 4. *Relationship between total N supply rate, measured using in situ burials of PRS™-probes, and hybrid poplar (var. Walker) seedling stem volume growth increment. Each data point is a mean of either 9 (Arborfield) or 25 (Star City, Cubbon, and Culbert) seedli*
the site.

amendments prior to planting hybrid poplar seedlings and throughout the early establishment phase.

Conclusion

The results of this study support the assertion that *in situ* burials of IEM provide biologically meaningful data and, therefore, are a very useful tool for measuring nutrient availability in hybrid poplar plantations during the early establishment phase. Specifically, the PRS™-probes were sensitive enough to measure differences in soil nutrient supply rates among sites differing in past management practices, soil types, and climatic conditions. In addition, they were capable of quantifying differences in N supply rate following fertilizer N addition and the temporal changes in NH_4^+-N and NO_3^--N supply rates throughout the growing. And finally, but most importantly, their data is strongly correlated with seedling growth. Further research is needed to determine the threshold soil nutrient supply rates for different hybrid poplar clones during the early establishment phase. Determining the relationship between soil nutrient supply rates and seedling growth should help to support effective management strategies, in terms of proper site selection and the elucidation of possible fertilizer requirements.

Acknowledgements

We thank the Saskatchewan Forest Centre for helping to fund this research and Bill Schroeder, of Agriculture and Agri-Food Canada, and Roger Nesdoly, of Mistik Management Ltd., for allowing us access to their hybrid poplar plantations. This work was enriched by the input of many colleagues. People such as Garth Inouye, Rick Block, Neil Booth, Amanda Kalyn, Ashley Anholt, and Leroy Bader supplied valuable field support and help with compiling site information.

References

Block, R.M. 2004. Fine Root Dynamics and Carbon Sequestration in Juvenile Hybrid Poplar Plantations in Saskatchewan, Canada. M. Sc. Thesis. Department of Soil Science, University of Saskatchewan, Saskatoon, SK.

Brady, N.C. 1990. The Nature and Properties of Soils-10th Edition. Macmillan Publishing Company, New York, NY. 621 pp.

Driscoll, K.G., Arocena, J.M., and Massicotte, H.B. 1999. Post-fire soil nitrogen content and vegetation composition in Sub-Boreal spruce forests of British Columbia’s central interior, Canada. For. Ecol. Manage. 121: 227-237.

Duarte, N. 2002. Nitrogen form and availability measured with ion exchange resin in a loblolly pine stand on the coastal plain of North Carolina. M.Sc. Thesis. Dept. Soil Science, North Carolina State University, Raleigh, NC.

Ellert, B.H. and Gregorich, E.G. 1996. Storage of carbon, nitrogen and phosphorus in cultivated and adjacent forested soils of Ontario. Soil Science 161: 587-603.

Hangs, R.D., Greer, K.J., and Sulewski, C.A. 2004. The effect of interspecific competition on conifer seedling growth and nitrogen availability measured using ion-exchange membranes. Can. J. For. Res. 34: 754-761.

Havlin, J.L., Beaton, J.D., Tisdale, S.L., and Nelson, W.L. 1999. Soil Fertility and Fertilizers: An Introduction to Nutrient Managament-6th Edition. Prentice Hall. New Jersey. 499 pp.

Huang, W.Z. and Schoenau, J.J. 1996. Microsite assessment of forest soil nitrogen, phosphorus, and potassium supply rates in-field using ion exchange membranes. Commun. Soil Sci. Plant Anal. 27: 2895-2908.

Huang, W.Z., and Schoenau, J.J. 1997. Seasonal and spatial variations in soil nitrogen and phosphorus supply rates in a boreal aspen forest. Can. J. Soil Sci. 77: 597-612.

Johnson, D.W., Hungate, B.A., Dijkstra, P., Hymus, G., and Drake, B. 2001. Effects of elevated carbon dioxide on soils in a Florida scrub oak ecosystem. J. Environ. Qual. 30: 501-507.

Kelly, J.M., and Mays, P.A. 1999. Nutrient supply changes within a growing season in two deciduous forest soils. Soil Sci. Soc. Am. J. 63: 226-232.

Kristensen, H.L., McCarty, G.W., and Meisinger, J.J. 2000. Effects of soil structure disturbance on mineralization of organic soil nitrogen. Soil Sci. Soc. Am. J. 64:371-378.

Lajtha, K., Jarrell, W., Johnson, D.W., and Sollins, P. 1999. Collection of soil solution. Pp. 166-182 *in* Robertson, G.P., C.S. Bledsoe, D.C. Coleman, and P. Sollins, eds. Standard Soil Methods for Long Term Ecological Research. Oxford University Press, New York.

Parfitt R.L., Scott N.A., Ross, D.J.; Salt G.J., Tate, K.R. 2003. Land-use change effects on soil C and N transformations in soils of high N status: comparisons under indigenous forest, pasture and pine plantation. Biogeochemistry 66: 203-221.

Pritchett, W.L., and Fisher, R.H. 1987. Properties and Management of Forest Soils. J. Wiley and Sons, New York. 494 pp.

Qian, P., and Schoenau, J.J. 2002. Practical applications of ion exchange resins in agriculture and environmental soil research. Can. J. Soil Sci. 82: 9-21.

Qian, P., Schoenau, J.J., and Huang, W.Z. 1992. Use of ion exchange membranes in routine soil testing. Commun. Soil Sci. Plant Anal. 23: 1791-1804.

Saskatchewan Centre for Soil Research (SCSR). 1989. The Soils of Stat City Rural Municipality No. 428. SCSR-Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

SCSR. 1995. The Soils of Loon Lake Rural Municipality No. 561. SCSR-Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Smethurst, P.J. 2000. Soil solution and other soil analyses as indicators of nutrient supply: a review. For. Ecol. Manage. 138: 397-411.

Stark, J.M., and Hart, S.C. 1997. High rates of nitrification and nitrate turnover in undisturbed coniferous forests. Nature 385: 61-64.

Stonehouse, H.B. and J.G. Ellis. 1983. The Soils of the Hudson Bay-Swan Lake Map Areas 63D and 63C. SCSR-Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

van Raij, B. 1998. Bioavailable tests: alternatives to standard soil extractions. Commun. Soil Sci. Plant Anal. 29: 1553-1570.

Yang, J.E., Skogley, E.O., Georgitis, S.J., and Schaff, B.E. 1991. Phytoavailability soil test: development and verification of theory. Soil Sci. Soc. Am. J. 55: 1358-1365.

Deciduous Competition: Impact on Growth of Plantation Spruce

C. Hawkins, J. Lange, K. Menounos

Mixedwood Ecology Group, University of Northern British Columbia, Prince George, BC, V2N 4Z9, Canada

In British Columbia (BC), forest companies are required to meet administratively set free-to-grow standards within a specified timeframe before responsibility for the plantation can be transferred back to the Crown. In recent years, it has become apparent to industry and government forest professionals that a disconnect exists between administrative and biological free-to-grow. Stands that are obviously biologically free-to-grow (harvest in 50 to 70 years without further intervention) are not administratively free-to-grow because of a deciduous component. Considerable sums have been spent on chemical and mechanical brushing treatments to meet administrative free-to-grow requirements. The total free-to-grow liability in central and northern BC exceeds 100 million dollars. Financial and ecological benefits would accrue if administrative brushing was reduced.

We have studied the relationship between birch (*Betula papyrifera* Marsh.) or trembling aspen (*Populus tremuloides* Michx.) competition and interior spruce (naturally occurring hybrids of *Picea glauca* (Moench) Voss and *P. engelmanii* Parry ex Engelm.) growth since 2001 in sub boreal and boreal forests of BC. In the sub boreal east of Prince George, BC, significant levels of paper birch appear to have little or no impact on spruce growth (Table 1) in a 16-year-old plantation. In addition, percent white pine weevil (*Pissodes strobi* Peck) attack of spruce is significantly reduced when growing with birch. Surveys of understory vegetation demonstrated no significant variation in species diversity (richness, α, or β measures) between brushed and non-brushed treatments. Species composition varied between treatments with a greater occurrence and abundance of 'weedy' and pioneer species in brushed areas.

West of Mackenzie, BC in the sub boreal, we observed that aspen densities up to 4000 stems per hectare (sph) had no impact on radial growth of spruce: diameter at breast height (dbh) was 1.7 cm with no aspen and 1.6 cm with 4000 sph of aspen in plantations up to 13 years of age. We sampled 8 stands, ranging in age from 10 to 19 years, in the boreal forest near Fort Nelson, BC and observed similar spruce responses to birch competition (Table 2). The results from this wide range of sites suggest that spruce can thrive with considerably more deciduous competition than is outlined in the administrative free-to-grow regulations. As a result for these stand types, less brushing is required and stands with more structural and species diversity will develop.

Table 2. *Mean spruce growth response by birch density class in Fort Nelson.*

Variable	Stems per hectare					
	0	1000	2000	3000	4000	5000
DBH, cm	8.0	7.1	7.2	6.8	7.1	6.7
DBH inc, mm	6.5	8.2	5.2	5.1	7.6	5.9
HDR	71	77	79	81	79	84

Table 1. *Sixteen-year measurements for a spruce–birch complex in the sub-boreal BC forest.*

Treatment	Stems per hectare		DBH, cm		Height, m		Volume, m3		
	Birch	Spruce	Birch	Spruce	Birch	Spruce	Birch	Spruce	WPW attack[1]
Herbicide	368	1055	6.9	10.9	7.1	5.8	.018	.036	13.5
Low	991	1268	7.4	10.7	7.6	6.3	.022	.040	8.6
Medium	2305	1067	7.1	10.4	8.1	6.6	.021	.037	5.7
High	3768	1105	6.6	9.9	7.8	6.4	.018	.033	4.7

[1]WPW, white pine weevil

Twenty Years Later – Revisiting A Jack Pine Mycorrhizae Study Near Raith, Ontario

N.J. Luckai

Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, ON P7B 5E1

Introduction

Potential for ectomycorrhizae to enhance the survival and growth of boreal tree seedlings, especially container grown stock, has been the subject of much research over the past 25 years. This presentation focuses on the work done as part of my Master of Science in Forestry research program in the late 1970s. Partners in the project were the Institute for Mycorrhizal Research and Development (IMRD), a division of the USDA, and the Ontario Ministry of Natural Resources, specifically the Thunder Bay Forest Tree Nursery. The project involved a field trial of two sources of inoculum of *Pisolithus tinctorius* (Pers.) Coker and Couch (*Pt*) and two fertilization regimes. In the late 1970s, when this project was initiated, there was a great deal of interest in this particular fungal symbiont and trials were being established across the United States and, in this case, in northern Ontario. *Pt* has a documented history of enhancing tree survival and growth particularly on very disturbed sites such as mine tailings (Marx *et al*. 2002).

Methods and Results

Original study – Jack pine seedlings were inoculated with *Pt* from two sources (IMRD and Abbott Laboratories) at three different ratios of inoculum to growing media (1:30, 1:15 and 1:7.5). Over a four-month growing period, seedlings received either a full "F" fertilization schedule (32 mg nitrogen (N), 10.5 mg phosphorous (P), 19 mg potassium (K)) or a nominally half "1/2 F" fertilization schedule (20 mg N, 6 mg P, 12 mg K). Seedlings were assessed for physical (height, weight, root collar diameter) and chemical (total N, P, K) characteristics as well as for ectomycorrhizal development. The latter was confirmed by IMRD (see Marx *et al*. 1982). Detailed results of the assessment are found in Phillips (1981). In summary, inoculated seedlings on the lower fertilizer regime were smaller but formed more ectomycorrhizae, nutrient (N, P, K) concentrations were lower and contents were higher for mycorrhizal seedlings; combined with generally higher dry weights, this suggested greater growth efficiencies for the mycorrhizal seedlings (Marx *et al*. 1982).

A field trial, approximately 100 km north of Raith, ON, was established in July 1978 (Fig. 1). Four replications of 49 seedlings each (approximately 1 m by 1 m spacing) were established using an RCB design. The site, classified as Site Class 2 jack pine (Plonski 1981) had been harvested in the mid-1970s, used as a landing as late as 1977 and scarified in 1978. Soil was a well-drained, deep sandy loam. Measurements were made in the late summer of 1979 after one full growing season. At that time *Pt* ectomycorrhizal seedlings exhibited better growth (total height, height increment, total dry weight, RCD) than the un-inoculated counterparts; fully fertilized seedlings generally did better than ½ F seedlings; consistently, the smallest seedlings were C, ½ F (un-inoculated, reduced fertilizer) (see Fig. 2). There was no difference in seedling survival (mean at 90%). Although *Pt* was isolated from the roots, it was not an aggressive competitor; colonization of all outplanted seedlings by native fungi was apparent within one year. The conclusion at the time was that *Pt's* main effect had been to promote rooting in the first growing season (Navratil *et al*. 1981).

Figure 1: *Location of the jack pine* Pisolithus tinctorius *field trial, established in 1978 in northwestern Ontario.*

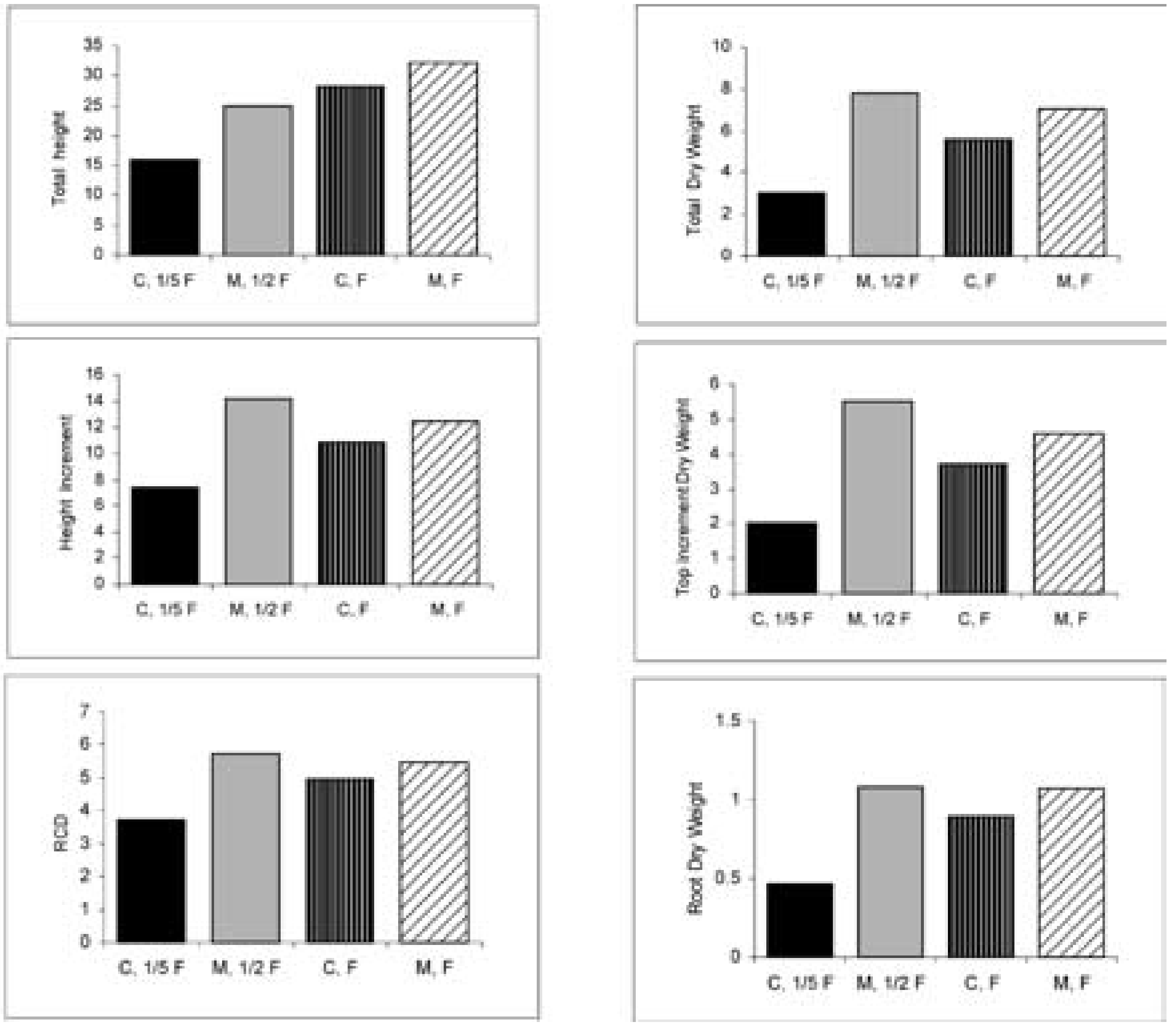

***Figure 2:** Physical parameters of outplanted jack pine seedlings measured in the late summer of 1979. Height (cm), RCD (mm), Dry Weights (g). C – Control, M – Mycorrhizal, F – full fertilization, ½ F – Reduced fertilization*

In the summer of 1999, we located the original study and re-measured all the plots. We decided to concentrate on the four treatment groups that had been selected by Navratil *et al.* (1981). These were the un-inoculated controls ("C") and the USDA 1:15 ("M") seedlings raised at Full ("F") and half Full ("1/2 F") fertilization. There was no difference in survival (mean of 75%), total height (from 9.8 to 10.8 m) or DBH (8.4 to 10.6 cm). Tree size was highly variable. We decided to use a stem analysis approach to determine if the original differences had persisted after outplanting; we also designed a study to determine if *Pt* had survived in the plots. These studies were undertaken by undergraduate students as their thesis projects. Bennett (2000) selected trees randomly to represent average growth and Stickel (2001) selected from the largest trees to represent potential of the treatments. Both used a series of selection rules to reduce the effect of uneven competition. Nutrient analysis of the soil and foliage (total carbon, N, sulphur plus a range of cations) from a random selection of trees was completed in the fall of 2003.

Stem analysis utilizes a detailed dissection of whole tree stems in order to map out the height and diameter growth over time. Volumes of stem sections were then calculated using Smalian's formula (Husch *et al.* 1982); the tree tip was treated as a cone.

Present and historical volumes (dm^3) for the average and largest trees are shown in Fig. 3 and 4, respectively. Based on average tree size, the fully fertilized, mycorrhizal (M, F) trees were consistently and significantly the smallest. There were no differences between the mean volumes of the largest trees.

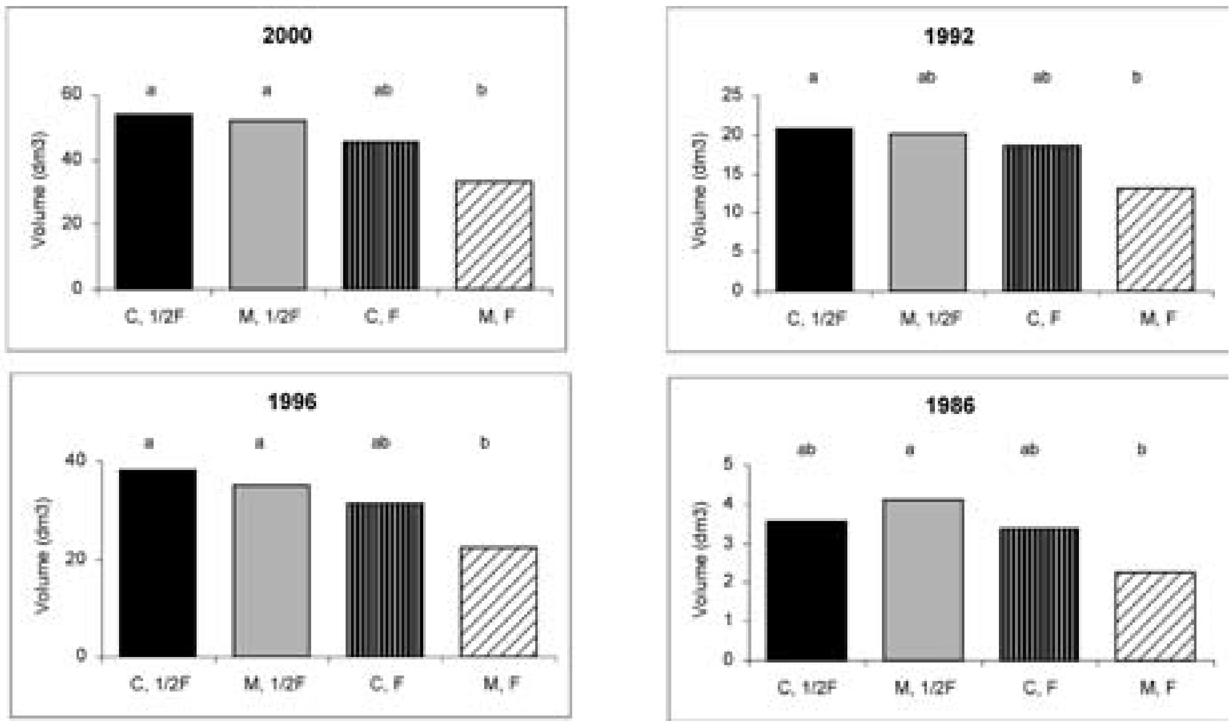

Figure 3: *Present and historical mean volumes (dm³) of average jack pine trees established in 1978. C – Control, M – Mycorrhizal, F – Full fertilization, ½ F – Reduced fertilization. Bars with different letters are significantly different at p = 0.05.*

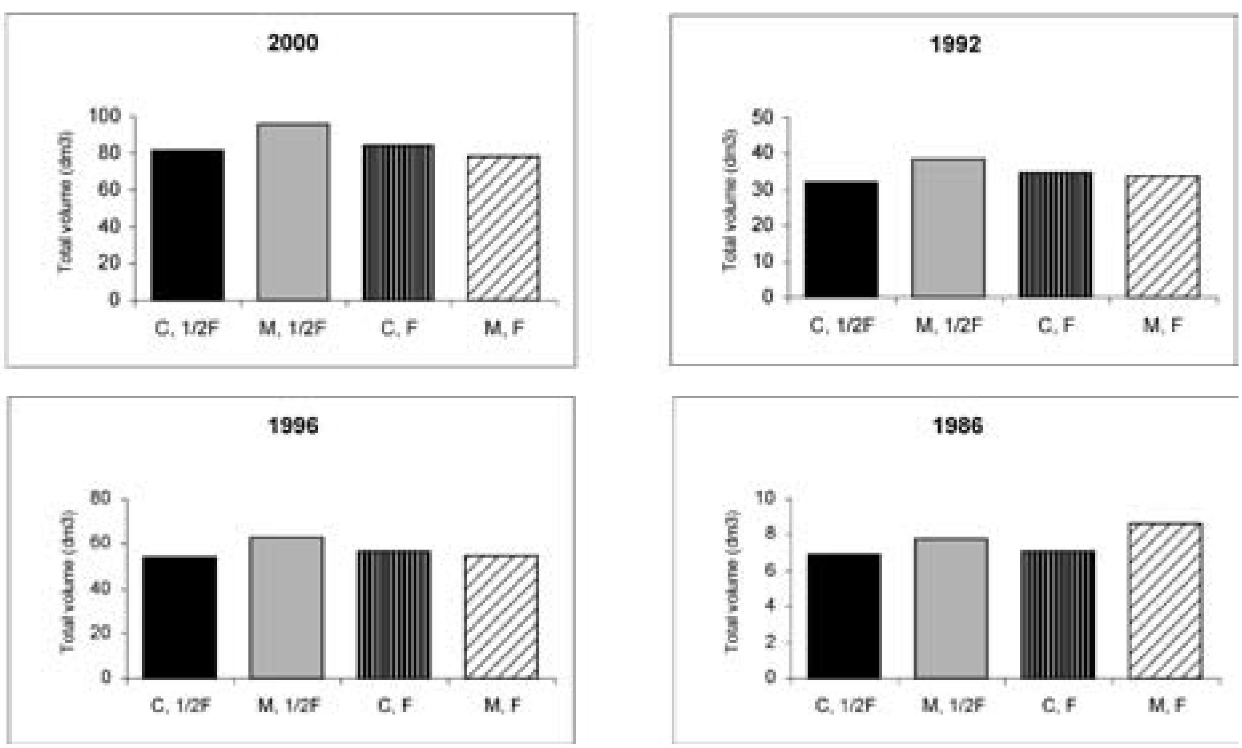

Figure 4: *Present and historical mean volumes (dm³) of the largest jack pine trees established in 1978. C – Control, M – Mycorrhizal, F – Full fertilization, ½ F – Reduced fertilization. No significant differences among treatments.*

van Straaten (2000) used a variety of techniques but was unable to isolate *Pt* from the ectomycorrhizal short roots of selected jack pine trees. Nutrient analyses of both soil and foliage showed no difference between treatments.

Conclusions

- Initial differences didn't translate into long term differences
- Control seedlings did just as well, if not better, than inoculated seedlings
- All trees exhibited some form of ectomycorrhizae; *Pt* wasn't isolated from any of the selected trees therefore not a strong competitor
- *Pt* may still be appropriate for severely disturbed sites
- Reinforces importance of matching site with tree and (native?) mycorrhizal species

Acknowledgements

- Undergraduate thesis students – Sam Bennett, Peter Stickel, and Oliver van Straaten
- Technical assistance (Mensuration field and lab) – Frank Luckai
- Technical assistance (Pathology lab) – Dr. E. Setliff and Lynne Sevean
- Technical assistance (Nutrient analyses) – Dale Goodfellow

Literature Cited

Bennett, S. M. 2000. A stem analysis approach to investigating the growth effects of *Pt* – inoculum on jack pine past the seedling stage. H.B.Sc. Forestry Thesis. Faculty of Forestry, Lakehead University. Thunder Bay, ON. 143 pp.

Husch, B., C.I. Miller and T.W. Beers. 1982. Forest Mensuration. John Wiley and Sons. Toronto, CA. 402 pp.

Marx, D.H., J.L. Ruehle, D.S. Kenny, C.E. Cordell, J.W. Riffle, R.J. Molina, W.H. Pawluk, S. Navratil, R.W. Tinus and O.C. Goodwin. 1982. Commercial vegetative inoculum of *Pisolithus tinctorius* and inoculation techniques for development of ectomycorrhizae on container-grown tree seedlings. For. Sci. 28: 373-400.

Marx, D.H., L.F. Marrs and C.E. Cordell. 2002. Practical use of the mycorrhizal fungal technology in forestry, reclamation, arboriculture, agriculture and horticulture. Dendrobiology 47: 27-40.

Navratil, S., N.J. Phillips and A. Wynia. 1981. Jack pine seedling performance improved by *Pisolithus tinctorius*. For. Chron. 57(5): 212-217.

Phillips, N.J. 1981. Response of jack pine (*Pinus banksiana* Lamb.) seedling to inoculation with *Pisolithus tinctorius* (Pers.) Coker and Couch. M. Sc. Forestry Thesis. School of Forestry, Lakehead University. Thunder Bay, ON. 158 pp.

Stickel, J. P. 2001. Effects of fertilization and ectomycorrhizal inoculation on the growth of jack pine (*Pinus banksiana* Lamb.) past the seedling stage. H.B.Sc. Forestry Thesis. Faculty of Forestry, Lakehead University. Thunder Bay, ON. 143 pp.

Van Straaten, O. 2000. A comprehensive study on the long-term viability of *Pisolithus tinctorius* (Pers.) Coker and Couch. in juvenile jack pine ecosystems and the influence of tree size or presence on soil respiration rates. H.B.Sc. Forestry Thesis. Faculty of Forestry and the Forest Environment, Lakehead University. Thunder Bay, ON. 105 pp.

Nine Different Nursery Fertilizer Regimes Still Affecting Jack Pine Plantation Growth After 12 Years

W. Smith[1], D. Willis[2], S.J. Colombo[3]

[1] WayDa Gro Forestry Services, P.O. Box 598, Washago, ON L0K 2B0
[2] Jiffy Products (N.B.) Limited, 850 Widdifield Road, R.R.#1, North Bay, ON P1B 8G2
[3] Ontario Forest Research Institute, c/o Centre for Northern Forest Ecosystem Research, 955 Oliver Road, Thunder Bay, ON P7B 5E1

Introduction

The efficient use of N-fertilizer is an important objective in container tree nutrient regimes as it is typically the element most utilized by plants and frequently limits growth of seedlings (Landis 1989).

A wide array of N-fertilizer regimes, however, can produce healthy, plantable, greenhouse-cultured container tree seedlings. Scarratt (1986), for example, found that any of the 10 fertilizer treatments applied at 100 ppm nitrogen (N) to jack pine yielded similar seedling morphology, with no apparent advantage conferred by special forestry mixes or starter and finishing preparations, despite large differences in supplied nutrients. Colombo and Smith (1988) measured greatest shoot, diameter and root dry weight in containerized jack pine which corresponded to 9.19 mg N per seedling and 1.91–2.33% foliar N. Timmer and Armstrong (1987) found that 10 mg N per seedling applied to red pine in an exponential fashion resulted in superior seedling height, dry matter production and root development. Others (Burgess 1990, Troeng and Aczell 1988) have also found advantages in applying fertilizer to seedlings in an exponential fashion during the rapid growth phase, particularly as a means of increasing root development and lowering shoot to root ratios.

However, few container seedling fertilizer programmes are assessed in terms of resultant field performance. Timmer et al. (1991) found that containerized black spruce seedlings raised on an exponential fertilizer regime had significantly greater growth than those on a conventional regime, one year after planting seedlings in pots filled with forest soils. Black spruce seedlings ‘loaded’ in the greenhouse attained foliar N% of 2.68 and resulted in significantly greater height and dry matter production one season after outplanting (Timmer and Munson 1991). In a review, Landis (1985) found that while nursery fertilization does not necessarily affect seedling survival after outplanting, seedling growth was strongly positively related to pre-plant fertilizer regimes for a variety of coniferous species. In particular, pre-plant foliar N levels were the best indictors of out-plant seedling height development, with R-squared values reaching 0.84.

The present investigation follows the field survival and growth of jack pine container seedlings that developed under a variety of nitrogen fertilization treatments.

Materials and Methods

Nursery

Jack pine (*Pinus banksiana* Lamb.) seedlings grew in a plastic covered greenhouse at Northern Greenhouse Farms, Iroquois Falls, Ontario, and Latitude 48^{o} 46’N, Longitude 80^{o} 41’W. The seedlings were sown on June 26, 1989 into Jiffy Forestry Pellets type 2865-165 (Jiffy Products (NB) Ltd., Shippagan, New Brunswick) at a density of 990 pellets per m^2. Each pellet was approximately 6.5 cm in height and 3 cm in diameter (after expansion) and contained 50 cc of sphagnum peat moss amended to a pH of 4.5 and electrical conductivity of 1.0 millimhos. Jiffy pellets are covered by a mesh net that compartmentalizes individual cavities/pellets.

Seedlings developed under natural daylight. Greenhouse conditions ranged from night minimum to day maximum temperatures of 15 to 20^{o}C.

Twenty-seven trays (1 tray = 33 pellets) were arranged on benches in a randomized block design (8,910 total seedlings) such that each of the nine fertilizer treatments was replicated three times, with one tray representing one treatment per replication.

Seedlings were fertilized using the following treatments of differing concentrations of N:

1. 0x, water only (0 ppm N); 2. ½x, (50 ppm N); 3. 1x, (100 ppm N); 4. 1.2x, (120 ppm N); 5. 1.4x, (140 ppm N); 6. 2x, (200 ppm N); 7. 6x, (600 ppm N); 8. 1/2Ex (half exponential rate); and 9. Ex (full exponential rate). The “x” refers to a rate of 100 ppm N, frequently applied to jack pine seedlings on an operational basis in Northern Ontario. Exponential rates were established using the function of Ingestaad and Lund (1979):

$Nt = Ns (e^{rt} – 1)$
Where,

Nt = amount of N to be added weekly (ppm N)
Ns = start N (5 ppm N)
r = relative addition rate (Daily addition rates of N are 6% for Ex and 3% for ½ Ex)
t = frequency of relative addition rate (7 days).

The value for Ns was established from Timmer and Armstrong (1987). Nitrogen was supplied as 12% NO_3^-, 8% NH_4^+, from a water soluble 20-8-20 Plant Products Forestry growing – phase mix, applied by a hand-held watering can to each tray, starting three weeks after germination and continuing for twelve weeks. A starter fertilizer of 11-41-8 (100 ppm) was applied once every two weeks after germination to all treatments except 0x. Fertilizer was applied weekly, with supplemental irrigation as required to prevent seedlings from reaching their wilting point. Seedling germination was considered complete on June 26, based on tested seed viability and vigour.

Fifteen weeks after germination, seedlings were measured and samples collected. Ten seedlings were randomly extracted from each tray and measured for height (from root collar to bud tip), root collar diameter, and then oven dried for total dry weight. The first two rows and columns of trays were not sampled to provide a buffer against edge effects. Thirty seedlings per treatment were recorded. Differences between treatments were compared using ANOVA and the Least Significance Difference Test (Snedecor and Cochran 1980).

Percentage N in foliage was determined from a composite sample of three randomly selected, then over dried, seedlings per treatment by the Kjeldahl method (Bremner and Mulvaney 1982) at the Hugh John Flemming Forestry Complex in Fredericton, New Brunswick.

After measurements, seedlings were moved in trays to an outside holding area in the same design pattern as in the greenhouse to harden and over winter under snow. No further fertilization was applied prior to shipping seedlings for planting the following spring.

Field

Seedlings were planted on June 14, 1990 by E.B. Eddy Forest Products Ltd. of Espanola, Ontario in the Upper Spanish Forest, Latitude 47° 28’ N, and Longitude 81° 50’ W.

The site is a level, glaciofluvial outwash plain, characterized by deep, rapidly drained course sands capped with 20 cm of well-drained sandy loam. Organic horizons average only 2.5 cm in thickness. Due to a weakly developed Ae horizon, this soil is classified as Mini Humo-Ferric Podzols (Anon. 1974).

Lesser vegetation includes low-bush blueberry (*Vaccinium angustifolium* Ait.), trailing arbutus (*Epigaea repens* L.), wintergreen (*Gaultheria procumbens* L.), bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) and club lichens (*Cladina* spp.). These species are all indicative of dry, relatively infertile site conditions (Sims et al. 1989).

Seedlings were carefully planted at 2.0-metre spacing within furrows prepared by a TTS Delta hydraulic disc trencher. The experimental design consisted of a randomized complete block having 10 replications of 5-tree row plots for each of the 9 fertilizer treatments. Thus, a total of 50 seedlings from each treatment were planted, for a total of 450 seedlings.

Seedlings were measured in 1993 and again in 2002 for total height and diameter at one-third of stem height. Stem volumes were estimated using the formula for a cone as follows (Vol (cc) = (πR^2 X HT)/3). Data was examined by one-way ANOVA and Least Significant Difference tests to determine treatment effects.

Results

Nursery

The amount of nitrogen supplied to seedlings by the nine fertilizer treatments ranged from 0 to approximately 49 mg per seedling over the twelve-week fertilizer period (Table 1). Approximately 32% of the fertilizer passed between pellets and did not enter into calculations of applied N. The ‘x’ or operational N level of 100 ppm N delivered 8.1 mg N/seedling.

There was no significant increase in seedling nursery height, diameter, shoot dry weight or total dry weight beyond the 1/2x fertilizer treatment, corresponding to a rate of 4.1 mg N/seedling (Table 1). Only the 0x and the 1/2Ex treatments, delivering 0 and 1.6 mg N/ seedling, respectively, were associated with significantly decreased morphology and pronounced deficiency symptoms of stunted growth and needle chlorosis. Seedlings in all other treatments met accepted Ontario Ministry of Natural Resources standards for height and root collar diameter.

Foliar N concentrations in seedling needles increased linearly from 1% in the water only treatment up to a maximum of nearly 3% for the 2x and 6x treatments (Fig. 1). The exception to this trend was the Ex treated seedlings, which showed a slight but non-significant increase in % N over seedlings in the higher N-applied x treatment. This

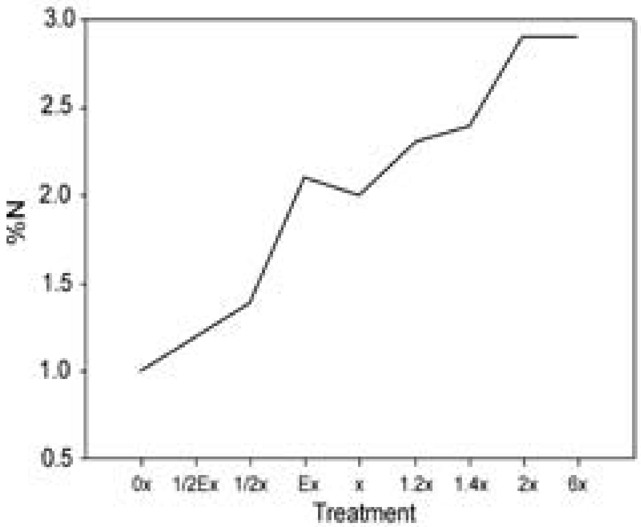

Figure 1. *Foliar N concentrations in needles according to fertilization treatment.*

verifies the high fertilizer levels at crop rotation end in the exponential regime and accounts for greener needles heading into the over wintering stage (Table 1).

On the basis of expression of seedling morphology and defined in terms of nutrient uptake patterns (Landis 1985), deficiency growth symptoms were evident at an N applied amount of less than 4 mg per seedling. Optimum-luxury consumption was in the wide range of 4–48 mg applied N per seedling, as plants were able to uptake additional fertilizer without any reduction in morphology and total biomass. Above applied rates of 16 mg N per seedling, percentage N in needles remained stable at 2.9, despite increased availability (Fig. 2). Toxic growth response to high N was not observed and is therefore above 48 mg N per seedling.

Table 1. *Amount of N applied by treatment and response of jack pine seedlings at greenhouse rotation end. Values within a row followed by the same letter are not statistically different at p = 0.05.*

Fertilizer level	0x	1/2Ex	1/2x	Ex	x	1.2x	1.4x	2x	6x
N applied (mg/seedling)	0	1.6	4.1	5.9	8.1	9.7	11.4	16.2	48.7
Foliar N (%)	1	1.2	1.4	2.1	2	2.3	2.4	2.9	2.9
N content (mg)	1.7	2.4	3.7	6.0	6.4	7.5	6.5	7.8	8.4
Height (mm)	53.9 (b)	75.3 (b)	106.3 (a)	108.8 (a)	115.9 (a)	124.1 (a)	111.9 (a)	118.5 (a)	118.4 (a)
Diameter (mm)	1.0 (c)	1.1 (bc)	1.3 (ab)	1.4 (ab)	1.4 (ab)	1.5 (a)	1.4 (ab)	1.4 (ab)	1.5 (ab)
Ht:diameter ratio	52.5	66.0	78.8	78.1	79.7	82.9	79.9	82.3	80.1
Root weight (mg)	54.0 (ab)	57.0 (a)	53.6 (ab)	55.1 (a)	53.8 (ab)	50.0 (ab)	43.8 (abc)	40.2 (bc)	35.6 (c)
Shoot weight (mg)	112.3 (c)	141.2 (b)	212.9 (a)	231.2 (a)	268.0 (a)	274.8 (a)	227.1 (a)	228.7 (a)	256.0 (a)
Shoot:root ratio	2.1 (e)	2.4 (d)	4.0 (cd)	4.2 (bc)	4.9 (bc)	5.3 (bc)	6.1 (bc)	6.7 (ab)	7.2 (a)
Total weight (mg)	166.3 (c)	198.2 (bc)	266.5 (ab)	286.3 (a)	321.7 (a)	324.8 (a)	270.8 (ab)	269.0 (ab)	291.6 (a)

Field

Seedlings in all treatments had 90% or greater survival three seasons after planting (Table 2), except seedlings grown without fertilizer that showed a low survival of 70%. Even the small amount of fertilizer of 1.6 mg N per seedling at the 1/2Ex treatment increased survival substantially. After 12 years the survival trend is similar with very little loss between the 3rd and 12th year.

Seedling height three years after planting ranged from 11.3 cm at 0x to 40.8 cm at 6x (Table 2). Height was significantly greater with all fertilizer treatments than seedlings grown with water only, but high levels of fertilizer did not significantly improve height over the conventional treatment (x).

Seedling stem volume three years after planting increased with amount of fertilizer applied, resulting in significant increases at the higher treatments of 11 mg N/seedling or greater (Fig. 2). Lowest response was for water-only seedlings at 4.1 cm^3 which was more than a 200% reduction in growth below the conventional x fertilization level of 8.1 mg N per seedling. By contrast, the 2x and 6x treatments increased stem volume by 43 and 58%, respectively, over the conventional x treatment, to a maximum of 11.7 cm3 at the 6x treatment level. In 2002, stem volumes are over 500 times larger than in 1993, but the trend is similar. Although seedlings that were not fertilized in the greenhouse are smaller, the differences between these and seedlings that received up to 11.4 mg per seedling are not significant. The 2x and 6x treated seedlings are now 45% and 64% larger, respectively, than the conventional x treatment.

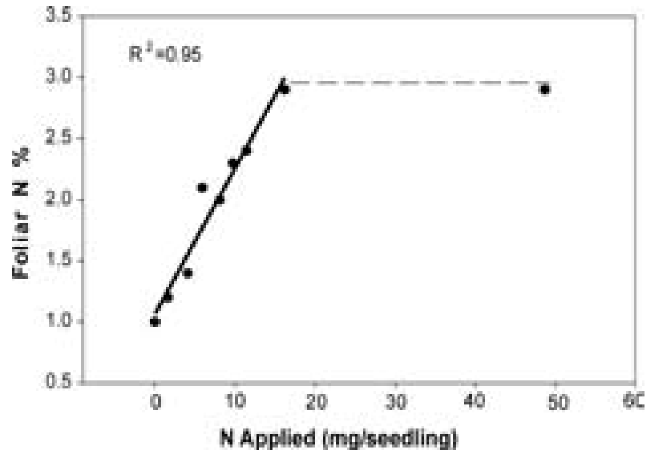

Figure 2. *Relationship between the amount of N applied to a crop and the resulting foliar N level.*

Three years after planting, fertilized seedlings in all treatments were reduced to a relatively low level of nitrogen concentration of between 1.58 and 1.73% (Fig. 1). This is a considerable reduction from pre-plant levels that reached as high as 2.9%.

Stepwise linear regression between pre-plant seedling characteristics and stem volume three years after planting (Table 3) shows a strong positive relationship with %N (R^2 = 0.84), N content (R^2 = 0.72) and shoot to root ratios (R^2 = 0.85). Root weight also showed a high R^2, at 0.75, but this is clearly inter-correlated with shoot to root ratios. Much weaker R^2 values were obtained for pre-plant seedling height, diameter, and total dry weight (Table 3). Again, the trend is similar after 12 years (Figs. 3 and 4).

Table 2.
Values within a row followed by the same letter are not statistically different at p = 0.05.

Fertilizer level		0x	1/2Ex	1/2x	Ex	x	1.2x	1.4x	2x	6x
Stem volume (cm^3)	1993	4.1 (a)	6.4 (b)	7.1 (b)	7.7 (c)	7.4 (c)	7.7 (c)	8.7 (d)	10.6 (d)	11.7 (d)
	2002	2938 (a)	3470 (ab)	3095 (a)	3517 (ab)	3605 (ab)	3309 (a)	3807 (ab)	5234 (bc)	5927 (c)
Height (cm)	1993	18.6 (a)	32.9 (b)	32.2 (b)	33.5 (b)	36.9 (bc)	32.9 (b)	37.5 (bc)	40.2 (c)	40.8 (c)
	2002	356 (a)	350 (a)	338 (a)	361 (a)	341 (a)	333 (a)	363 (a)	388 (a)	396 (a)
Survival (%)	1993	70	98	94	90	96	90	94	94	90
	2002	70	96	90	88	96	86	94	88	88

Table 3. *Coefficient of determination (R^2) of pre-plant seedling characteristics with third year (1993) and twelfth year (2002) post plant jack pine stem volumes.*

Year	%N	N Content	Shoot: Root	Height	Diameter	Height: Diameter	Root Weight	Shoot Weight	Total Weight
1993	0.84	0.72	0.85	0.58	0.61	0.56	0.75	0.44	0.33
2002	0.89	0.72	0.81	0.24	0.30	0.18	0.93	0.18	0.23

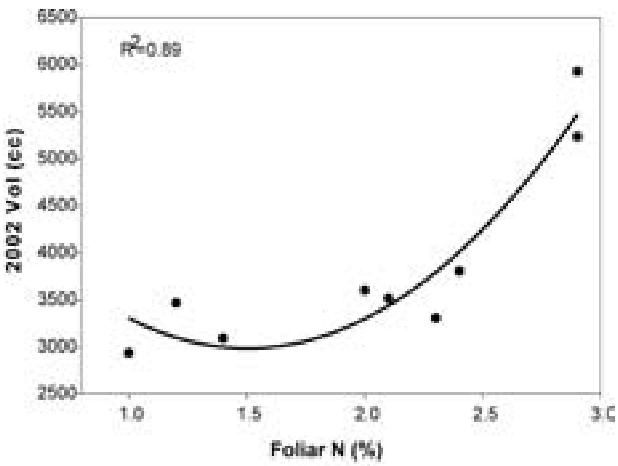

Figure 3. *Relationship between foliar N level at the greenhouse and stem volume after 12 years in the plantation.*

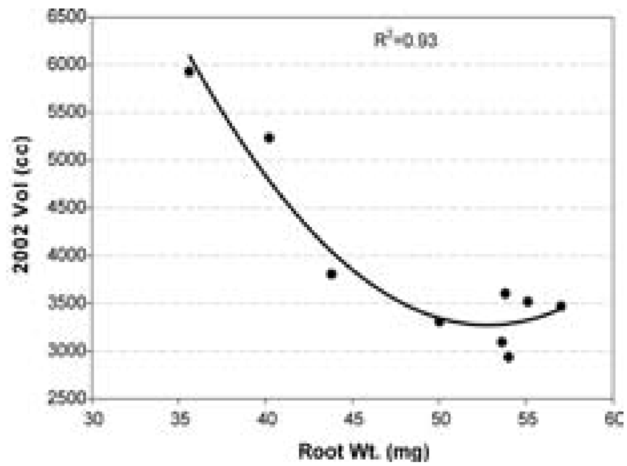

Figure 4. *Relationship between root weight after the nursery phase and stem volume after 12 years in the plantation.*

The negative correlation between root weight at time of planting and tree size after 12 years (Fig. 3) is unusual, since it means that, in this case, jack pine seedlings with smaller root systems grew faster in the plantation. As is implied in Figs. 3 and 4, the seedlings with the smaller root systems also had the highest foliar N concentration (2.9%)

Discussion

High shoot/root ratios (or low root weights) are not generally considered to be positive traits in terms of planting stock quality. However, smaller root systems in seedlings that have been heavily fertilized throughout the nursery phase are expected. At high soil fertility levels, seedlings will develop shoots preferentially over roots. This trend was also reported by Timmer and Munson (1991). In addition, Salonius and Beaton (1994) discovered that three years after planting, seedling shoot to root ratios converged to a common value on the same site. Therefore, shoot to root ratios are probably expressions of cultural practices at the nursery and are not reliable indicators of field performance. The fact that the seedlings with the higher foliar N levels performed the best in the field probably outweighed any possible negative effect of initial small root systems.

It is also possible that the smaller root systems were less damaged due to container separation at planting time. There may have been fewer interconnecting roots in trays grown at higher nitrogen rates, meaning there would be fewer roots severed when seedlings were separated for planting. Even with smaller root systems, the fabric encasing the Jiffy plug held the soil and root together to allow planting. The ability to plant container seedlings having less developed root systems is an advantage only Jiffy containers have. The timing of pruning interconnecting roots in Jiffy's is an important cultural practice that needs further study.

This study relates high pre-plant nitrogen to improved field performance. The greatest enhanced growth occurred in seedlings that received 16 mg and 49 mg at the greenhouse. Conventional fertilizer schedules at that time (1990) tended to apply a total of about 10 mg per seedling. Seedlings that received 49 mg did not perform better than seedlings that received 16 mg. This suggests that conventional fertilizer schedules should target about 16 mg per seedling to avoid wasting fertilizer while maintaining healthy foliar nutrient levels. However, there are likely other application methods to ensure optimum foliar nutrient levels at time of planting.

Timmer et al. (1991) suggest that exponential feed programs at the greenhouse may be optimum for developing a more physiologically acclimatized seedling and also effectively 'load' the seedling with nitrogen prior to planting. Our two exponential treatments may have accomplished this if trees were grown for several weeks more or if the schedule started with a higher nitrogen level.

Nutrient 'spiking' is a practice of providing high levels of fertilizer to the container soil just prior to planting. Timmer and Teng (2004) found that by soaking the soil plug with fertilizer prior to planting to increase soil fertility and plant nutrient status, plant biomass and nitrogen levels were increased by 81% and 156%, respectively, one year after outplanting.

It is clear that high pre-plant nitrogen improved seedling outplant performance. Timmer and Munson (1991) suggest that N is a stored nutrient reserve which can be tapped by seedlings soon after planting. Munson and Bernier (1993) recorded a rapid decline in N of black spruce in the first year after planting. van den Driessche (1985) found that Douglas-fir seedlings lost all pre-plant nitrogen in the first two months after planting. The advantage of high nitrogen reserves, therefore, is conferred to seedlings as a short term burst of accelerated growth. This initial advantage given to treated seedlings then carries forward through the formative years of plantation establishment. This study indicates that this advantage is evident 12 years after planting.

Another feature of high nitrogen reserves is that it benefits only the seedling, and not the surrounding competing vegetation. When considering the high cost of plantation tending programs, greenhouse based techniques such as targeting high nitrogen content should become increasingly attractive, and seedlings that perform better in the field should be worth more.

Finally, industry standards in North America presently rely on seedling morphology after the nursery phase as a measure of acceptable planting stock. It is notable that within the range of size in this study, greenhouse seedling height and diameter did not relate to outplant performance. Perhaps foliar nutrient status could prove to be a useful tool for assessing planting stock quality.

References

Anon. 1974. The system of soil classification for Canada. Can. Dept. of Agric., Publ. 1455.

Bremner, J.M and C.S. Mulvaney. 1982. Total nitrogen. Pp. 595-624 *in* R.H. Miller, D.R. Keeney and A.L. Page, eds. Methods of Soil Analysis. Part 2., Chemical and Microbial Properties, Am. Soc. Agron. Inc. Madison, WI.

Burgess, D. 1990. White and Black spruce seedling development using the concept of relative addition rate. Scand. J. For. Res.5: 471-480.

Colombo, S.J. and W.A. Smith. 1988. Response of containerized black spruce and jack pine seedlings to fertilization rate and growing medium. Ont. Min. Nat. Resour., For. Res. Rep. No. 116.15 p.

Ingestaad, T. and A.B. Lund. 1979. Nitrogen stress in birch seedlings. I. Growth technique and growth. Physiol. Plant. 45:137-148.

Landis, T.D. 1985. Mineral nutrition as an index of seedling quality. In, Duryea, M.L. (ed). Proceedings: Evaluating Seedling Quality: Principles, Procedures and Predictive Abilities of Major Tests. Oct. 16-18, 1984. Oregon State University, Corvalis, OR.

Landis, T.D., R. Tinus, S.E. MacDonald and J. P. Barnett. 1989. Seedling Nutrition and Irrigation, Vol. 4, The Container Tree Nursery Manual. USDA For. Serv., Washington, D.C. Agric. Handbk. 674 119 pp.

Munson, A.D. and P.Y. Bernier. 1993. Comparing natural and planted black spruce seedlings. II. Nutrient uptake and efficiency of use. Can. J. For. Res. 23:2435-2442.

Salonius, P. and K. Beaton. 1994. Effect of root packing on field performance of container seedlings. Paper at: Making the Grade, Sept. 11-15, 1994. IUFRO Symposium, Sault Ste. Marie, ON.

Scarratt, J. B. 1986. An evaluation of some commercial soluble fertilizers for culture of jack pine stock. For. Can. Great Lakes For. Centre. Info.Rep. 0-X-377.

Sims, R.A ., W.D. Towill, K.A. Baldwin and G.M. Wickware. 1989. Field guide to the Forest Ecosystem Classification for Northwestern Ontario. For. Can. Great Lakes For. Cent. Sault Ste. Marie, ON.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods. The Iowa State University Press. Ames, IA. USA.

Timmer, V.R. and A.D. Armstrong. 1987. Diagnosing nutritional status of containerized tree seedlings: comparative plant analyses. Soil Sci. Am. J. 51:1082-1086.

Timmer, V.R. and A.D. Munson. 1991. Site-specific growth and nutrition of planted response. Can. J. For. Res. 21: 1058-1065.

Timmer, V.R., G. Armstrong and B.E. Miller. 1991. Steady-state nutrient pre-conditioning and early outplanting performance of containerized black spruce seedlings. Can. J. For. Res. 21: 585-594.

Timmer, V.R., and Y. Teng. 2004. Pretransplant fertilization of containerized Picea mariana seedlings: Calibration and bioassay growth response. Can. J. For. Res. 34: 2089-2098.

Troeng., E. and L. Aczell. 1988. Growth regulation of Scots pine seedlings with different fertilizer composition and regimes. New For. 2:119-130.

van den Driessche, R. 1985. Late season fertilization, minerals nutrients reserves, and retranslocation in planted Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings. For. Sci. 31(2):485-496.

RCDlob: An Individual Tree Growth and Yield Model for Loblolly Pine That Incorporates Root-Collar Diameter at Time-Of-Planting

C.L. VanderSchaaf[1] and D.B. South[2]

[1]Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
[2]School of Forestry and Wildlife Sciences and Alabama Agricultural Experiment Station, Auburn University, AL 36849-5418

Introduction

There are many growth and yield models for loblolly pine (*Pinus taeda* L.) plantations in the US (Smalley and Bailey 1974, Baldwin and Feduccia 1987, Lenhart 1996, Baldwin and Cao 1999, Burkhart et al. 2004). However, none relate root-collar diameter (RCD) at the time-of-planting to future tree growth. In fact, throughout the world, very few models have related seedling size at establishment to future growth and yield. Ground-line diameter (GLD) at time-of-planting was used in New Zealand as a predictor variable to estimate tree growth and survival of *Pinus radiata* D. Don (Mason 2001). In South Africa, survival up to two years after planting was modeled for *P. radiata* (Zwolinski et al. 1994). Although GLD at time-of-planting has a strong relationship with RCD (VanderSchaaf and South 2003), a nursery manager might be mislead into producing a smaller than intended target RCD when given an output from a model that is based on initial GLD. Factors such as planting depth, top pruning effects on stem taper, and perhaps genetic differences in taper between families of loblolly pine seedlings can produce variability in the relationship between RCD and GLD at time-of-planting.

Nurseries in the Southeastern US usually produce seedlings with an average root-collar diameter (MRCD) at planting of less than 4 mm (South et al. 2001). Such small seedlings can be produced inexpensively since when grown close together, the costs associated with herbicides, fertilization, lifting, etc. are minimized. Since planters are paid based on the number of seedlings planted and not on the number of seedlings surviving after a certain amount of time, crews prefer to plant seedlings with small root systems (South et al. 2001). Growing larger seedlings at lower seedbed densities will increase the cost of production (by perhaps $4-7 per thousand seedlings). Larger seedlings will also reduce hand-planter revenue per hour because of greater seedling root mass that requires more time to plant properly (Caulfield et al. 1987, South et al. 2001). However, seedling root mass does not impact the speed of machine-planting. Wider spaced, morphologically-improved seedlings (MI) generally cost more to produce and purchase than standard seedlings (South et al. 2005) but they have exhibited greater growth and survival compared to standard seedlings (Shoulders 1961, Shipman 1964, Sluder 1979, South et al.1985, Dierauf et al. 1993, South 1993, South et al. 1995, South et al. 2001, South and Rakestraw 2002). Planting loblolly pine seedlings that were grown at low nursery densities may provide economic advantages (Caulfield et al. 1987, South 1993, South and Rakestraw 2002, South et al. 2005), especially when outplanted at wider spacings (South 1993, South and Rakestraw 2002, South et al. 2005).

Resource managers in the US need tools to assist in determining the economic trade-offs between (1) increased seedling and outplanting costs, and (2) greater survival and growth from planting MI seedlings (plus lower per unit area establishment costs due to a reduction in the number of seedlings outplanted). Currently, to make such calculations, a manager must make assumptions about the performance of MI seedlings. Although published papers provide information to support such assumptions, a predictive model would allow resource managers to conduct growth and economic analyses using costs and revenues that are more specific to their particular area. Additionally, a modern establishment model would allow users to vary the distribution of seedling sizes at time-of-planting (e.g. Mason 2001). The objective of this research was to develop individual tree mortality, diameter at breast height (DBH), and height models to relate RCD at time-of-planting to future growth and economic returns.

Methods

We used a distance-independent model procedure to relate growth to RCD at time-of-planting. A logistic model was used to estimate the probability of individual tree survival (Hamilton 1986, Flewelling and Monserud 2002, Moore et al. 2004).

Data

Data were obtained from four sites located on the Atlantic Lower Coastal Plain in Georgia and South Carolina (South et al. 2001, VanderSchaaf and South 2003). Two seedling ideotypes (average across all sites of 5.0 mm for the standard seedlings and 8.5 mm for the morphologically-improved seedlings) were planted. Two plantation regeneration management scenarios (1 – standard, 2

– intensive) were used. Both scenarios involved raking, piling, and burning all residual debris followed by a bedding treatment in the summer. In addition to these site preparation treatments, the standard management scenario included a broadcast herbicide treatment of hexazinone and sulfometuron in March plus fertilization with diammonium phosphate (DAP). In addition to the standard management scenario treatment applications, the intensively managed plots received a broadcast herbicide application of imazapyr and metsulfuron in mid-summer of the planting year and again one-year later. A treatment of DAP plus potassium chloride was applied 2 years after planting. More detailed descriptions of treatments were provided by South and others (2001). Sampling age was up to 12 years old (Table 1). Planting density varied by site from 1495 to 1794/ha.

Modeling procedures

Height and diameter equations

Both linear and nonlinear regression equations were examined for height and DBH. Equations for a particular dependent variable were selected using both statistical and biological properties but biological properties were the overriding concern. Parameters were checked to make sure that they were consistent with biological theory (e.g. greater numbers of trees per ha surviving at a particular age should not increase the estimate of DBH). Additionally, predicted values of stand development were examined to determine whether a particular equation or sets of equations produced reasonable values across a range of ages and values of the regressors. After accounting for biologically meaningful variables, we selected the function with the lowest untransformed average absolute value residual. Residual errors were examined for trends.

Since we wanted to extrapolate predictions of individual tree height and DBH beyond the range of ages in the data for economic rotation purposes, the Chapman-Richards equation was selected to model both individual tree height, [1], and DBH [2]:

Proc Model (SAS 1989) using the Gauss-Newton algorithm was used to estimate parameters in the individual tree height and DBH model functions. All variables were significant at alpha levels less than 0.0001. These models were developed using longitudinal data and thus errors are most likely correlated which can result in biased confidence intervals and hypothesis tests. However, parameter estimates are still asymptotically unbiased (Schabenberger and Pierce 2002). Since all variables were significant at alpha levels less than 0.0001 (and we were more concerned with biological meaning than statistical significance of coefficients), we ignored the correlation value when estimating parameters.

A sigmoid growth curve ensures reasonable estimates of the response variables at ages of 15, 20, 25 yr. Zeide (1989) reported the Chapman-Richards equation was superior to other sigmoid growth equations for predicting DBH. We tested other growth equations such as the Gompertz, Logistic, Monomolecular, and the Weibull but found they overestimated DBH. Zeide (1989) found the Power Decline I, or the Korf (Zeide 1993), sigmoid growth equation was superior to the Chapman-Richards equation for predicting DBH. We found the Korf equation resulted in reasonable estimates of DBH at older ages, but the combination of this equation with the mortality model, [5], resulted in an over-prediction of mortality at older ages. Thus, we used the Chapman-Richards equation to predict DBH.

The allometric relationship between individual tree height and DBH is widely known – often referred to as the constant-stress theory (Zeide and VanderSchaaf 2002). Although most use DBH to predict height, we chose to model DBH as a function of height. Our reasoning for this is because we are predicting growth at young ages (i.e. 1 and 2 years) as well as for older ages. We feel that resource managers want to know when basal area growth begins on trees in relation to RCD. One approach is to first predict height, and once predicted height values have reached DBH (4.5 feet), predict DBH. Thus, natural resource managers can use our model for not only long-

[1] $$\mathbf{Ht = 31.89971\ (1-e^{-0.06266Age})^{1.637244\ -\ 0.01852RCD\ -\ 0.17411Treat}}$$

Where: Ht – total individual tree height (in meters), Treat – 1 – Standard regeneration scenario, 2 – intensive regeneration scenario, n = 16344, Adj. R^2 = 0.9454, RMSE = 1.1259, Durbin-Watson test statistic (DW) = 1.0973

[2] $$\mathbf{DBH = [41.90266+9.146058LnHt-6.72958LnTPH](1-e^{-0.799929Age})^{19.46781\ -\ 1.98092Treat}}$$

Where: Ln – natural logarithm, DBH – individual tree DBH in cm, TPH – trees per ha, n = 12669, Adj. R^2 = 0.9125, RMSE = 1.8090, DW = 1.4876 term growth and yield and economic analyses in relation to RCD, but also to get a reasonable idea of when basal area production begins on individual trees in relation to RCD.

Quite often cross-equation correlation exists between model errors in a biological system of equations (Amateis et al. 1984, Borders 1989, Hasenauer et al. 1998). This is particularly true if a predicted dependent variable is an independent variable in another equation (thus the variable is an endogenous variable). Cross-equation correlation is thought to produce inefficient and possibly inconsistent parameter estimates (Borders 1989, Hasenauer et al. 1998). Hasenauer et al. (1998) state the gain in parameter efficiency is higher when equation error structures have greater correlations. If cross-equation correlation exists, then when total tree height is overpredicted we would expect DBH to be overpredicted (Borders 1989). If there is a high degree of correlation between equation error structures, a Two Stage Least-Squares or Three Stage Least-Squares analysis could be used to estimate parameters. However, both Two and Three Stage Least-Squares use predetermined variables (those regressors that are not dependent variables in the equation system – thus they are exogenous or considered to be fixed) in the first stage of parameter estimation (Amateis et al. 1984, Borders 1989, Hasenauer et al. 1998) and the modeler must declare what predetermined variables are used. Amateis et al. (1984), Borders (1989), and Hasenauer et al. (1998) state the first stage uses predetermined variables to predict the endogenous variable and that these estimated endogenous variable values are used as replacements (instruments) for the observed endogenous variable values – thus Two and Three Stage Least-Squares ignore the biological model form of the endogenous variable in the first stage. Therefore, the proper selection of predetermined variables is essential – choosing non-meaningful predetermined variables could introduce more problems than if the simultaneous nature of the model system was ignored altogether. We do not want to ignore the biological model form of [1] and thus we choose not to use Two or Three Stage Least-Squares. Parameters were estimated using an alternative parameter estimation methodology for simultaneous systems presented in Borders (1989); however, the estimated parameters produced biologically incorrect estimates of DBH (it should be noted that for this particular analysis, the Ln transformation of height was not used in [2] rather untransformed height). Thus, we estimated parameters for both [1] and [2] in a recursive manner, obtained predicted values, calculated errors, and then determined the correlation between the error structures of the two models ([1] and [2]). The cross-equation correlation was near 0.15. Due to the low cross-equation correlation, thus producing little gains if a simultaneous equation system was used (Hasenauer et al. 1998), biologically poor parameter estimation using the system presented by Borders (1989), and potential problems with using Two and Three Stage Least-Squares, we decided to treat the system as recursive.

When using [2] to predict DBH at ages of 2, 3, and 4, some illogical predictions occurred. For example, the quadratic mean diameter would decrease from age 2 to 3. Thus, we developed equations to predict diameter growth at young ages using data up to age 4. Since we recommend users not to use our model system for planting densities greater than 2400/ha, it is a reasonable assumption that DBH is independent of planting density until age 4. Once again, we assumed a recursive nature between the DBH and total tree height [1] equations:

$$DBH = 0.486749Ht^{1.065413} \left[\frac{RCD}{MRCD}\right]^{0.102213} Treat^{0.114943} \qquad [3]$$

Model [3] can be used to estimate DBH until age 4.

Mortality equations

Parameters in the mortality equations were obtained using Proc Logistic (SAS 1989). The dependent variable for [4] and [5] is the probability that a tree will survive into the next growing season. To estimate whether a tree that has not reached breast height will survive to the next growing season, [4] should be used:

$$\ln\left[\frac{P_i}{1-P_i}\right] = 4.9499+0.7307\left[\frac{RCD}{MRCD}\right]Treat \qquad [4]$$

Where: n = 1938

Once a tree reaches breast height, [5] can then be used to estimate the probability of a tree surviving into the next year:

$$\ln\left[\frac{P_i}{1-P_i}\right] = 6.8866+0.4621\ DBH-0.5845Age-0.0631BA \qquad [5]$$

Where: BA – basal area in square meters per ha, n = 12437

Maximum-Size Density Relationships

Since we are extrapolating growth beyond age 12 yr, the model uses Maximum-Size Density Relationships (MSDRs) to constrain growth (Maguire et al. 1990, Mack and Burk 2002, Monserud et al. 2004). We recommend a Maximum Stand Density Index (MSDI) value of 1112 along with an exponent of 1.6 for equation [6]. Reineke (1933) originally estimated the MSDR boundary slope to be -1.6 and determined a MSDI of 1112 (450 x 2.47) for naturally-regenerated stands in the Western Gulf region of the US. Equation [6] was used to calculate a SDI value for a given stand age and structure.

$$\mathrm{SDI} = \mathrm{TPH}\left[\frac{\mathrm{QMD}}{25.4}\right]^{1.6} \qquad [6]$$

Previous studies have determined that a MSDI of 1112 is applicable for loblolly pine plantations in the southern US (Dean and Baldwin 1993, Hasenauer et al. 1994). A brief explanation of how MSDI constrains stand development follows. Quadratic mean diameter (QMD) and tree per ha (TPH) are predicted using a combination of equations [1], [2], [3], [4], and [5]. Only when the predicted SDI exceeds 1112 will the MSDI tool be initiated. If a stand's SDI is predicted to exceed 1112 then the estimate of QMD will be maintained but the estimate of TPH will be reduced such that a MSDI of 1112 is achieved. In order to obtain the required TPH to satisfy [6], we recommend users select those trees with the smallest DBH to die. In general, the MSDI tool is activated only for planting densities near 2470/ha.

Results and Discussion

All models have biologically meaningful parameter estimates ([1], [2], [3], [4], and [5]). Biologically correct parameter estimates aid in predicting response variables beyond the range of the regressor values used to estimate parameters. As with any model, we want to verify predicted stand development across a range of regressor values.

Verification Results

Due to the time and costs associated with measuring RCD prior to planting, it is difficult to verify our model using datasets independent of those used in parameter estimation since few independent datasets exist. Thus, we decided to verify our model by comparing our estimates of stand development to other growth and yield models. It is not the intention of the verification analysis to quantify differences. Quantifying differences between our model and other models would be difficult due to the stochastic nature of our model. Rather, we merely want to see whether our predictions are reasonable; especially for the planting densities near 740 and 2470/ha.

One main component of any empirical growth and yield model is an estimate of site productivity. In general, regardless of RCD, planting density, and regeneration scenario, estimated average height of dominants and co-dominants using our model is around 22.5 to 25 meters at age 25 yr. To be conservative, we used 24.4 meters as the site index value (base age 25 yr) for all models during the verification. The growth and yield models for cutover sites were; Ptaeda 3.1 (Burkhart et al. 2004), and a model developed by Baldwin and Feduccia (1987) specifically for Western Gulf loblolly pine plantations. Thus, predictions from the model by Balwin and Feduccia might not be comparable since RCDlob was fitted using data from genetically improved seedlings in the Lower Atlantic Coastal Plain. Ptaeda 3.1 is a distance-dependent individual tree model while the other model is a stand-level diameter distribution model. Model structure differences between our model and the verification models should have minimal impact on growth and yield predictions.

For verification, we compared our predicted values for planting densities of 740, 1729, and 2470/ha using an RCD of 4.5 mm for all seedlings and a standard regeneration scenario up to age 25 (Fig. 1). Due to the stochastic nature of the mortality models in RCDlob, we compare predictions of 3 different runs from our model

Table 1. *Summary of the data used in model fitting. Where:* MI = *morphologically improved seedlings,* S = *standard seedlings,* BAH = *square meters of basal area per ha,* SDI = *stand density index (from equation 6),* Ht = *arithmetic mean height,* QMD = *quadratic mean diameter.*

Size	Age yr	BAH m^2/ha	SDI	Ht m	QMD cm
MI	1	.	.	0.8	.
MI	2	.	.	2.3	.
MI	3	0.7	33.9	3.9	2.3
MI	4	1.2	53.7	5.4	3.0
MI	8	24.9	619.0	10.8	14.1
MI	10	28.9	698.7	12.1	15.2
MI	12	35.2	817.8	14.7	16.8
S	1	.	.	0.6	.
S	2	.	.	2.0	.
S	3	0.5	26.8	3.5	2.0
S	4	1.0	45.0	4.9	2.8
S	8	23.2	579.3	10.2	13.9
S	10	27.6	666.7	11.7	15.2
S	12	33.3	775.6	14.0	16.8

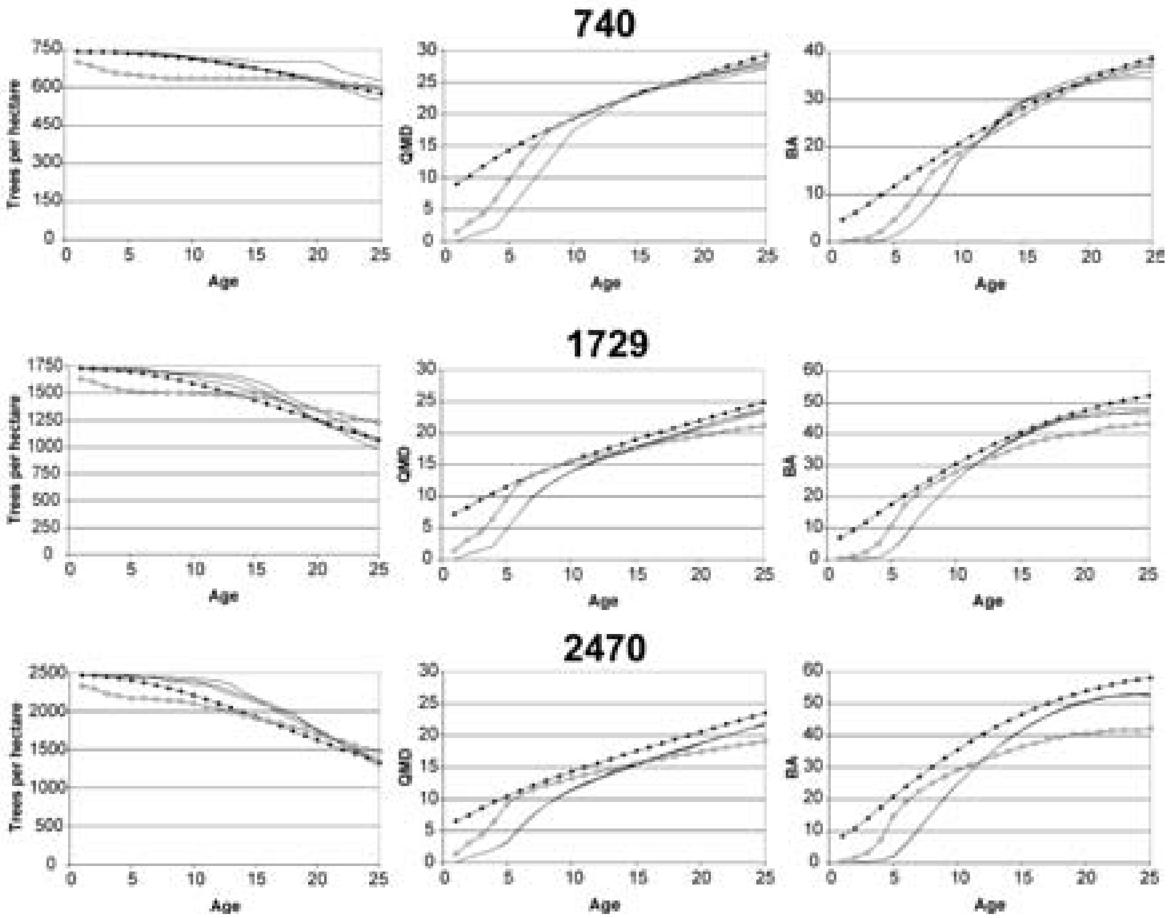

Figure 1. *Comparison of growth projections from three RCDlob simulations (lines with no points) to two other cutover loblolly pine plantation growth and yield models (Baldwin and Feduccia 1987 – filled black diamonds, Burkhart et al. 2004 – nonfilled circles) for three different planting densities of 740 seedlings per ha (SPH), 1729 SPH, and 2470 SPH. In RCDlob, a standard regeneration scenario was selected using 4.5 mm diameter seedlings.*

to the verification growth and yield model programs. Generally, data used to fit both verification models are from stands operationally planted prior to 1985. Thus, it is a reasonable assumption that the plots were planted using seedlings that had an average RCD near 4.5 mm and, at the maximum, a Standard regeneration scenario. In addition to the limits imposed by equation [6], estimates from RCDlob are based on a maximum annual diameter growth of 2.54 cm (up to age 10 yr) and a maximum annual diameter growth of 1.27 cm for older stands.

As seen in Fig. 1, and based on the verification growth and yield model program projections (Baldwin and Feduccia 1987, Burkhart et al. 2004), our model gives reliable estimates of stand development across the range of planting densities from 740 to 2470/ha. In general, our model has greater predicted survival than the two other models for young stand ages. This may be reflective of the relatively high regeneration intensities in our dataset; even for the standard regeneration scenario. In addition, our model has lower early basal area and DBH development which is consistent with our data. The model by Baldwin and Feduccia (1987) does not have an inflection point. Although the model was fit using data from plantations younger than age 10 yr, the majority of their data are from plantations older than age 10 yr and thus their model may not be highly applicable for ages younger than 5 to 10 yr.

Conclusions

Our growth and yield model is the first that allows the user to vary initial RCD for loblolly pine. In addition, we allow the user to input cost data and price data for pulpwood, chip-n-saw and sawtimber sized products. Since the model outputs volumes and net-present value economics, plantation managers can easily calculate the cost/benefit ratio for planting morphologically improved seedlings.

In the past, many land managers have deferred to the hand-planter when defining the desired seedling size for outplanting. Now managers in the lower-coastal plain can determine for themselves how much revenue they are giving up by planting small-diameter loblolly pine seedlings.

Literature Cited

Amateis, R.L., Burkhart, H.E., Greber, B.J., and Watson, E.E. 1984. A comparison of approaches for predicting multiple-product yields from weight-scaling data. For. Sci. 30: 991-998.

Baldwin, V.C., Jr., and Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed West Gulf plantations. USDA For. Serv. Res. Pap. SO-236. 27 p.

Borders, B.E. 1989. Systems of equations in forest stand modeling. For. Sci. 35: 548-556.

Burkhart, H.E., Amateis, R.L., Westfall, J.A., and Daniels, R.F. 2004. PTAEDA 3.1: Simulation of individual tree growth, stand development and economic evaluation in loblolly pine plantations. Sch. of For. and Wildl. Res., Va. Polytech Inst. and State Univ. 23 p.

Caulfield, J.P., South, D.B., and Boyer, J.N. 1987. Nursery seedbed density is determined by short-term or long-term objectives. South. J. Appl. For. 11: 9-14.

Dean, T.J., and Baldwin, V.C. 1993. Using a stand density-management diagram to develop thinning schedules for loblolly pine plantations. USDA For. Serv. Res. Pap. SO-275. 7 p.

Dierauf, T.A., Scrivani, J.A., and Chandler, L.A. 1993. Loblolly pine seedling grade – effect on survival and growth through 20 years. Virginia Department of Forestry Occasional Report 107. 38 p.

Flewelling, J.W., and Monserud, R.A. 2002. Comparing methods for modeling tree mortality. In Second Forest Vegetation Simulator Conference. Edited by N.L. Crookston and R.N. Havis. Proc. RMRS-P-25, USDA Forest Service, Rocky Mountain Res. Sta., Ogden, UT, pp. 168-175.

Hamilton, D.A., Jr. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. For. Sci. 32: 989-1000.

Hasenauer, H., Burkhart, H.E., and Sterba, H. 1994. Variation in potential volume yield of loblolly pine plantations. For. Sci. 40: 162-176.

Hasenauer, H., Monserud, R.A., and Gregoire, T.G. 1998. Using simultaneous regression techniques with individual-tree growth models. For. Sci. 40: 162-176.

Lenhart, J.D. 1996. Total and partial stand-level yield prediction for loblolly and slash pine plantations in East Texas. South. J. Appl. For. 20: 36-41.

Mack, T.J., and Burk, T.E. 2002. User's Manual for Resinosa – An interactive density management diagram for red pine in the Lake States. Univ. Minnesota, College of Natural Resources and Minnesota Agricultural Experiment Station, Department of Forest Resources Staff Paper Series No. 158. 25 p.

Maguire, D.A., Schreuder, G.F., and Shaikh, M. 1990. A biomass/yield model for high-density *Acacia nilotica* plantations in Sind, Pakistan. For. Ecol. Manage. 37: 285-302.

Mason, E.G. 2001. A model of the juvenile growth and survival of *Pinus radiata* D. Don.; Adding the effects of initial seedling diameter and plant handling. New Forests 22: 133-158.

Monserud, R.A., Ledermann, T., and Sterba, H. 2004. Are self-thinning constraints needed in a tree-specific mortality model? For. Sci. 50: 848-858.

Moore, J.A., Hamilton, D.A., Jr., Xiao, Y., and Byrne, J. 2004. Bedrock type significantly affects individual tree mortality for various conifers in the inland Northwest, U.S.A. Can. J. For. Res. 34: 31-42.

Reineke, L.H. 1933. Perfecting a stand-density index for even-age forests. Journal of Agricultural Research. 46: 627-638.

Rencher, A.C. 2000. Linear models in statistics. John Wiley and Sons, Inc. New York, NY. 578 p.

SAS Institute, Inc. 1989. SAS/ETS user's guide. Version 6. 4th ed., Cary, N.C.: SAS Institute, Inc.

Schabenberger, O., and Pierce, F.J. 2002. Contemporary statistical models for the Plant and Soil Sciences. CRC Press, Boca Raton, FL., USA. 738 p.

Sluder, E.R. 1979. The effects of seed and seedling size on survival and growth of loblolly pine. Tree Planters' Notes 30: 25-28.

Smalley, G.W., and Bailey, R.L. 1974. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia highlands. USDA For. Serv. Res. Pap. SO-97. 57 p.

South, D.B. 1993. Rationale for growing southern pine seedlings at low seedbed densities. New Forests 7: 63-92.

South, D.B., Boyer, J.N., and Bosch, L. 1985. Survival and growth of loblolly pine as influenced by seedling grade: 13-year results. South. J. Appl. For. 9: 76-81.

South, D.B., and Rakestraw, J.L. 2002. A loblolly pine seedling-grade genotype study. South. J. Appl. For. 26: 1-6.

South, D.B., Rakestraw, J.L., and Lowerts, G.A. 2001. Early gains from planting large-diameter seedlings and intensive management are additive for loblolly pine. New Forests 22: 97-110.

South, D.B., VanderSchaaf, C.L., and Britt, J. R. 2005. Reforestation costs can be decreased by lowering initial stocking and outplanting morphologically improved seedlings. Native Plants 6(Spring): 76-82.

South, D.B., Zwolinski, J.B., and Allen, H.L. 1995. Economic returns from enhancing loblolly pine establishment on two upland sites: Effects of seedling grade, fertilization, hexazinone, and intensive soil cultivation. New Forests 10:239-256.

VanderSchaaf, C.L., and South, D.B. 2003. Effect of planting depth on growth of open-rooted *Pinus elliottii* and *Pinus taeda* seedlings in the United States. Southern African Forestry Journal 198: 63-73.

Zeide, B. 1989. Accuracy of equations describing diameter growth. Can. J. For. Res. 19: 1283-1286.

Zeide, B. 1993. Analysis of growth equations. For. Sci. 39: 594-616.

Zeide, B, and VanderSchaaf, C.L. 2002. The effect of density on the height-diameter relationship. In Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference. Edited by K.W. Outcalt. Gen. Tech. Rep. SRS-48, USDA Forest Service, Southern Res. Sta., Asheville, NC, pp. 463-466.

Zwolinski, J.B., Donald, D.G.M., van Laar, A., and Groenewald, W.H. 1994. Regeneration procedures of *Pinus radiata* in the Southern Cape Province Part V: Post planting mortality and growth of trees in response to the experimental treatments and planting site environment. Southern African Forestry Journal 168: 7-21.

51987
(0.3k P.R. 05 12 31)
ISBN 0-7794-9196-3
ISSN 0319-9118