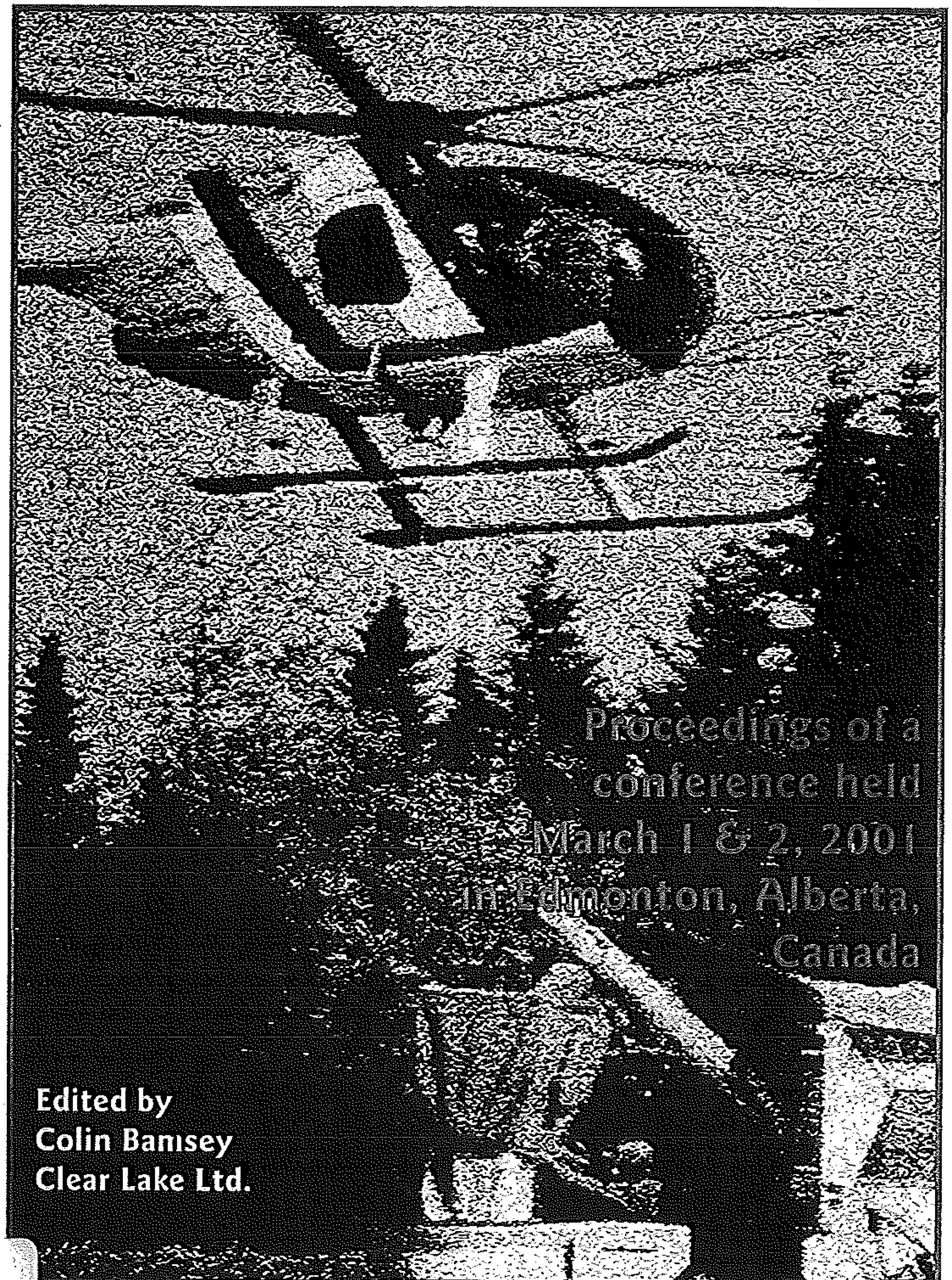
Enhanced Forest Management:
Fertilization & Economics



Proceedings:

Enhanced Forest Management: Fertilization & Economics

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edited by Colin R. Bamsey, R.P.F.

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Session Moderators helped focus each of the presentations, and added their individual knowledge to the conference. They were:

- Pat Wearmouth, Weyerhaeuser Company Limited, Grande Prairie, Alberta
- Richard Krygier, Tall Timber Forestry Services Co. Ltd., Whitecourt, Alberta
- John Huey, Sundance Forest Industries Ltd., Edson, Alberta
- Bob Udell, Weldwood of Canada, Hinton Division, Hinton, Alberta

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Setting up the stage for the third time

S. Navratil[1]

Welcome, it is rewarding to see you all here. I will start with an historical perspective and lead up to Alberta's current perspective on Enhanced Forest Management.

My career has made a full circle, starting in forestry practice, advancing through the science of tree diseases, university teaching, research in silviculture, and now back to practical forestry. It has taken me 40 years to complete this circle, and 20 of these years were spent in Alberta.

I mention this because over the last five years I have been working on the interface where science meets practice, and is used in practice. I am referring specifically to Enhanced Forest Management (EFM) activities where new techniques and advanced knowledge for increasing yield and value are vigorously sought and applied.

Over these last few years, I have witnessed enormous changes in forest management in Alberta. While there were some isolated thinning and fertilization research trials in the 1970s and 1980s in Alberta, they were largely established by the federal government, namely by Dr. Yang and Dr. Bella, and no, or very minimal, operational thinning or fertilization was done during that period.

In the late 1990s and now in 2000, thinning, fertilization and other intensive silviculture and EFM applications have already become or are fast becoming operational realities and components of standard forest management plans.

The definition of Enhanced Forest Management is simple:

> *EFM increases the productivity of a site beyond that of sites managed to meet basic management standards.*

However, the definition also implies that some things need to be done differently or improved. That also sounds simple but changes do not initiate themselves—they need to be created, sponsored and advanced. Changes require visionary people and affirmative action to create opportunities. I will refer to what has been happening in Alberta recently as the four Alberta EFM prerequisites.

The number one Alberta EFM prerequisite has been the establishment of the Forest Resource Improvement Association of Alberta or FRIAA. The establishment of the FRIAA program in Alberta has been a key step in advancing EFM initiatives in the province. For the benefit of our guests from other regions, FRIAA is a non-profit association whose membership consists of forest industry firms who each pay membership dues based on stumpage. More information can be obtained from FRIAA's website (www.friaa.ab.ca).

What I have witnessed is FRIAA's funding power, and its profound influence on creating opportunities for establishing research trials, increasing knowledge in general, and for assisting in the application of new and advanced techniques. In addition to facilitating project funding, applications to FRIAA must be well structured and include detailed methodology. This ensures that their investments in research and trials are based upon sound principles and will be secure.

A cooperation between the Alberta forest industry and the provincial government under the auspices of the Enhanced Forest Management task force produced the *number two Alberta EFM prerequisite—"Policy requirements for implementation of EFM," a report released in 1997.*

This task force, consisting of the Alberta Forest Products Association and the Alberta government developed a comprehensive policy framework that facilitates EFM implementation. The policy framework addresses seven key areas from resource planning, stand productivity, monitoring and AAC guidelines to tenure and stumpage assessment.

The number three prerequisite is perhaps less well known. The 2000 Alberta regeneration standards support the implementation of EFM initiatives by providing an

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opportunity for management by objective, flexible regeneration standards. The document—Attachment B, "An implementation framework for enhanced forest management in Alberta"—sets up the goals, requirements and technical details for EFM implementation, including yield forecasting, validation, performance standards and compliance monitoring.

With these three steps, the administrative framework has been set. Concurrently with the administrative steps, an additional task was to support implementation through the build-up of knowledge, expertise transfer and extensive learning at all levels. This can be encapsulated into the *number four prerequisite, creating conditions and actions for improved knowledge applicable in Enhanced Forest Management initiatives.*

The Alberta Land and Forest Service, namely Dave Patterson and Dennis Quintilio initiated the organization of the Alberta EFM conferences, and our small team, Colin Bamsey and myself, started in 1996 planning conferences. Our goal was to increase accessibility to the knowledge essential for EFM.

Our theme was not only "knowledge must precede implementation" but also "knowledge must be made available and documented in proceedings." The topic of the first Alberta EFM conference was "Stand density management: Planning and implementation," and was held in November 1997 in Edmonton.

The topic of the second EFM conference in Alberta was "Stand density management: Using the planning tools," held in November 1998 in Edmonton, and the proceedings from both of these conferences have been published.

Funding was provided primarily by the provincial government for the first two conferences. Forest industry firms and the Alberta government, specifically the Alberta Environment, Land and Forest Service, are jointly sponsoring today's conference, the third EFM conference in Alberta. Millar-Western Forest Products Ltd, Sundance Forest Industries Ltd, Weldwood of Canada Ltd, Hinton Division and Weyerhaeuser Canada Ltd, Alberta Division have all sponsored this conference.

The sponsors have selected the topics for today's conference.

Forest fertilization & economics of EFM

The topic of forest fertilization is very fitting indeed. The last two conferences on fertilization of forest stands in this part of North America were held about ten years ago. The "Improving forest fertilization and decision-making in British Columbia" conference was held in March 1988, in Vancouver and the "Forest fertilization: sustaining and improving nutrition and growth of western forests" conference was held in February 1991, in Seattle, USA.

The topic of fertilization is also fitting for other reasons. One interesting reason is that in the most recent silviculture textbook (Nyland 1996), fertilization is mentioned in only one paragraph with respect to nursery production, and in three sentences with respect to plantations. Therefore, an opportunity to bring forward the most up to date knowledge on the fertilization of forest stands from temperate forest regions of North America and Europe was very appropriate and in a way, fascinating.

As in our two previous conferences, we sought to assemble the best experts from North America and Europe. Names like Weetman, Pettersson, Brockley, Morisson, Allen, Soikkeli, and Klinka commonly occur, and are highly regarded in the fertilization literature. We have them all here today, ladies and gentlemen.

At the same time, we wanted to maintain some relevancy with conditions in Alberta and the practical applications of the research, and wanted you to learn about some operational experiences, and observations from the ground up. That is the impetus for this afternoon's session devoted to operational fertilization.

Be it in Europe or North America, forestry has historically always struggled with the dilemma between biological efficiency and silvicultural investment versus economic efficiency and business investment. We silviculturists argue and genuinely believe in the biological investment, and believe that over concern about economic efficiency in silviculture may short-change future generations.

However, we all recognize that expenditures in EFM must be guided by efficiency criteria, and that successful implementation of EFM must be based on an adequate and predictable return on investment among many other criteria. What may be an effective silvicultural intervention in setting the stand on an increased yield trajectory may not be a viable proposition for large scale application in the Boreal forest.

I must admit that the selection of the most competent speakers on the economics of EFM—please note we did not limit ourselves to economics of fertilization only—was a challenge. Primarily because the topic is very broad, it ranges from the yield forecasting of EFM interventions, to stand level versus forest level decision-making, cost-benefit analysis, profitability, and tenure and land ownership.

We wanted to cover the entire spectrum and have selected speakers to examine some crucial issues, world market influences, forest level impacts and financial analyses from both government and industry perspectives. Again, the names Baskerville, Promenitz, Rotherham, Holtman and Winter guarantee expertise and enlightenment. We also have representatives from a new generation of economists who will add diversified views.

As with any conference, we wish we had more time to include additional topics, such as seedling nutrition and fertilization at the time of plantation establishment. There has been excellent work in these areas produced in Canada by V. Timmer in Ontario, K. van Reese in Saskatchewan, R.van den Driessche in British Columbia to name a few. We are also aware of some shortcomings on other topics such as the integration of non-fiber values and environmental concerns. Perhaps these could be topics for the future conferences.

It is gratifying to see attendance like this from Alberta and other provinces and also the USA. It demonstrates that you found the program meaningful. And I would like to thank all of our speakers for accepting our invitations; it was a pleasure to make contacts with you. I hope that all of you will agree that we have assembled the best speakers on the selected topics from North America and Europe.

Enjoy learning and take with you encouragement and new knowledge for improved forestry practice.

Reference

Nyland, R.D. 1996. Silviculture, concepts and application. The McGraw-Hill Companies, Inc. New York, 633 p.

Canadian Forest Fertilization: Some history and basic understandings

Gordon F. Weetman[1]

Abstract

Aerial forest fertilization with nitrogen has been operational in coastal Douglas-fir stands since the 1960s; nitrogen plus sulfur and boron have been applied operationally to interior Lodgepole pine since the 1980s; nitrogen and phosphorus are applied to cutover western red cedar and hemlock forests on Northern Vancouver Island. Forest fertilization has been tested across Canada since the 1960s. Implementation on predominantly Crown forests of Canada has been limited to British Columbia due to lack of incentives and financing for silviculture investments. Biological responses to fertilization have closely paralleled those found in Scandinavian boreal forests and northern U.S. forests. Optimum nutrition trials show promise of large and sustained increases in stand growth rates. Nitrogen fertilization has been found to be a cost-effective way to temporarily increase the growth rate of young plantations, and thinned stands with adequate live crowns and room for crown expansion. Unthinned stands and low value stands are not recommended for fertilization. Fertilizer applied in the planting hole has not given consistent responses.

The mineralogically rich, glacial origin forests soils in the natural forests of Canada are rarely deficient in macro-elements except nitrogen. The paradox of N shortages in soils with high organic-N content is related to low rates of N mineralization. Unfortunately neither N mineralization rate, nor any other mineral soil or humus analysis has proven to be a good predictor of stand response on natural forests.

Reliance has to be placed on foliar analyses of stands, foliar vector analyses of single tree screening trials or response in empirical trials using conventional plots. Nutrition and fertilization cooperatives for large scale testing are difficult to establish on Canadian Crown lands. Case histories are presented of attractive and unattractive opportunities for fertilization by licensees under present forest policies on Alberta Crown lands.

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Introduction

There have been seven forest fertilization symposia or workshops for northern and temperate North America dating from 1973 to 1992. I counted 1,500 pages of every aspect of fertilization in them (see reference list). There is a huge body of literature and experience with forest fertilization. The Scandinavian experience with boreal forests goes back over 80 years. The fact that this session is in Alberta indicates that forestry is coming of age in Alberta. Fertilization is like icing on a good cake—only used when somebody has "baked" a really valuable stand condition. One does not aerially fertilize large areas of untended forests. Crown land forest fertilization is quite different from private forest land. Licensees do not have equity in timber, only in allowable cuts. This makes a huge difference. Forest policy rather than biology controls silviculture on Crown lands.

In 40 years of experimenting with, reading and attending symposia about, and travelling to look at forest fertilization, one cannot help but develop a set of impressions and knowledge about four areas of fertilization:

1. What is the place for aerial forest fertilization in the intensive management of large areas of natural crown forests licenses in Canada on undisturbed glaciated soils? This is quite different from private land forests in the US and Scandinavia.
2. What fertilizer will do, and not do, to tree growth and stand development and the associated environmental impacts? This is widely portable knowledge.
3. How to go about diagnosing and screening responsive forest site and stand type combinations? This is also widely portable.
4. How to measure and express response and link the data to yield production. This tends to be very provincial.

This paper attempts to summarize these four areas in a simple way to reflect many decades of research and development and operational experience.

While little fertilization research has been done in Alberta, Alberta's boreal forests and soils are so similar to British Columbia and Scandinavian forests that there are some reliable answers to questions about the place of fertilization here.

A caution:
An appreciation of the potential for fertilizer use is based on a clear understanding of:

1. How N fertilizer influences growth of individual trees; forest soils and tree physiology knowledge is needed. Many old notions about the influence of tree species on forest soils have not been supported by experiments (Binkley 1994).
2. How stands develop over time; a grasp of self thinning theory and stand simulation is helpful.
3. The guiding principles of forest fertilization.
4. How rational economic decisions are made to invest money in temporarily increasing stand growth rates to improve wood supply on Crown land leases; knowledge is required of wood supply modeling and allowable cut effect protocols.
5. The circumstances and information needs which allow the public forest owners to agree to operational aerial fertilization in natural forests.

Forest fertilization can be a fast and effective way to waste silviculture budgets with little job creation and get the public concerned and upset. However, no other silviculture treatment can increase stand CAI so quickly and effectively and increase yields and accelerate stand operability and value at such little human effort over large areas of forest. Its use should be professionally prescribed by competent RPFs solidly linked to forest level wood supply problems. They should be accountable, knowledgeable and duly diligent. Its use is not for the empirical amateur or dilettante or faint of heart.

Some history

(see Table 1, following Conclusion)

Some of the early studies of nutrition of trees and fertilization date from the 1800s. The early emphasis was on plantation establishment on old fields, moorlands and disturbed sites. Interest in large-scale aerial fertilization of natural forests and industrial plantations developed in the 1950s in North America and Scandinavia. Following the establishment of networks of empirical fertilization trials, with parallel monitoring and studies of tree and forest soils nutrition, major industrial programs were in place in the US in the 1960s; notably with nitrogen in the Douglas-fir region and phosphorus in the southern pine region. In Canada interprovincial testing started in the 1960s. Large-scale aerial applications have only been used in British Columbia. Interest in forest fertilization waned in the 1980s and 1990s in eastern Canada. There is a large body of literature and scientific study of fertilization of forests, including all the symposia. It is customary to review some elementary background about fertilization, nutrition of trees and soil fertility at each symposia. This paper follows that custom.

Which fertilizer to use?

Nitrogen (N)

Nitrogen deficiencies tend to be widespread in temperate and boreal forest ecosystems on mineral soils in Canada. N availability is usually dependent on the rate of conversion of large reserves of organic-N to mineral-N (mineralization), especially in soils with humus horizons; this is a microbially mediated process.

$$\text{Organic-N} \Rightarrow NH_4N^+ \Rightarrow NO_3N^-$$

Soil or humus analysis for total N, organic N, NH_4^-N, NO_3^-N, extractable "available" N and even the amount of conversion of organic to NH_4N in a sample can over time (mineralization rate) tend not to be realistic indications of the actual amount of N available to tree roots in undisturbed podzolic or luvisolic forest soils. While trees recycle nutrients through litterfall after crown closure, the rate of N mineralization is usually not enough to provide for maximum tree growth. Thus, many forest stands are stressed for N; there is strong biological competition for N. Fully stocked stands are "tight" for N with little leakage in leachates. N is the lowest hole in the barrel in the barrel analogy and is often the first limiting factor for growth.

On rich sites, with high cation capacity in fine textured forest soils and those with lateral movement of nutrients in water and perhaps of N fixation by alder, N supplies may be much greater. Such sites support the best growth of "demanding species" like white spruce.

Foresters have long recognized that richer sites with greater N availability support more herbaceous plants. When intact mature forests are clearcut or burned and the demand for N is removed and the humus organic N reserves are warmed there is a period of rapid N mineralization (assart flush). Foresters, and early pioneers using slash and burn agriculture, rapidly learned to capture this temporary flush of N with prompt planting or seeding—before other N-loving vegetation captured the site.

Nitrogen fertilizers come from ammonia plants using cheap energy and the Haber process to fix atmospheric N. They produce urea (NH2CO, 45% N and ammonium nitrate NH_4NO_3, 36% N). When added to the forest floor surface it is taken up immediately by trees and other plants in the first growing season, either as NH4-N or NO3-N, shortcutting the inadequate endogenous N mineralization rate.

Phosphorus (P) and Potassium (K)

In the natural forests of Canada with undisturbed forest soils developed in glacial deposits over the last 10,000 years since glaciation, there tends to be enough available P and K for tree growth even when N is added, provided the tree roots are in a mineral soil. If trees are only rooted in organic matter, P and K are often deficient. Old fields on sandy soils, with low cation exchange capacity, may have had the K resources reduced by agriculture. Ericaceous plants (Salal, Kalmia, Ledum, Vaccinium, Calluna) have proven to be effective competitors for N and P for trees rooted in organic and mineral soils (heathland degeneration). In these situations N and P may be required, as in the case on northern Vancouver Island on salal invaded cutovers planted to cedar and hemlock.

Magnesium (Mg), Calcium (Ca) and Manganese (Mu) and Iron (Fe)

None of these elements are usually in short supply in natural, intact forest soils. Lime additions have not been found to increase N availability, but have improved growth in sugar maple stands with dieback.

Boron (B) and Sulfur (S)

Some soils in the interior of British Columbia and in Alberta have been found to be so low in B and S that when N is added low B induced aborted buds are produced or N response is constrained by lack of S and available SO_4. These elements are normally added to urea fertilizer (see Brockley – this symposium).

Sludge and municipal waste water

Since forest ecosystems are "tight" for nutrients and very effective filters, sludge and municipal waste water can be disposed of on these forests. There is a lot of R & D and operational use.

What happens to the fertilizer and the stand?

Urea is converted by the urease enzyme to NH_4-N which is immediately taken up in the spring by the tree roots and the N goes into all needle age classes. The current year needles get larger and contain more N. The next year the trees produce more needles. N uptake of added N is low, often about 25%. Response is proportional to the N uptake up to a certain point. NO_3-N leakage is usually negligible. N not taken up is immobilized by soil microbial population. Thus we fertilize the trees, not the site. The growth response is temporary and is considered to be equivalent to an increase in site index. Stand growth is accelerated through a stand density management diagram.

Most response is due to more needle biomass, but some is due to high photosynthetic rates. Repeated N fertilization is the usual practice. Repeated applications designed to sustain elevated foliar nutrient concentrations (optimum nutrition trials) have shown very large growth responses even in boreal climates (Tamm, Aronsson and Flower-Ellis 1999).

Diagnosis and testing

Stand fertilizer prescriptions are usually based on foliar analysis. These can be static, i.e., check untreated plots against well established foliar standards (Ballard and Carter 1986). The standards have been calibrated against field testing. We do not have tested standards for hardwoods or true firs.

Testing can be based on conventional plots, usually with factorial designs O, N_1, N_2 versus other elements—often as a balanced mix. It is very tough to find uniform sites and sites big enough to permit enough replications of factorial designs with 30 trees in the net measurement plots. Conventional plot experiments are costly, take several years and have been used world-wide in cooperative large-scale programs. Adding thinning levels O, T, and T_2 further complicates a program. The BC Forest Productivity coastal installations (about 80 of them) used N x T factorials in the 1960s. The data sets may become intractable with huge variation and field problems. Conventional plot use in dense stands with mortality confounds response determination. Crowns may lack room to respond.

The other alternative testing uses single trees—usually five to 10 per replication. Fertilizer is added around each tree. Complex factorials can be tested. Reliance is placed on foliar vector analysis—i.e., sampling needles after one growing season and using the shift from controls in the nutrient concentration + unit needle weight. First year unit needle weight increase is usually predictive of subsequent tree volume response. Foliar vector analysis was used to screen many lodgepole pine stands in British Columbia twenty years ago (Weetman, Fournier and Schnorbus 1988). They were used to diagnose the checked plantation problems on northern Vancouver Island. Single tree trials are fast and cheap, but do not give per hectare volume responses. They are used world wide today.

Testing can be by site association, i.e., try to calibrate edatopic grids for response to check for limiting factors. Testing can also just cover a broad range of sites, this is usual in a generally responsive species like coastal Douglas-fir. Cooperative networking of conventional plot installations over a wide area has yielded the N dosage/length and size of response/predictability of response relationships. If a species is responsive over a range of low to medium site indexes – annual applications can be broad scale with confidence in response. This is the case for coastal Douglas-fir. Western hemlock response is very variable, so variable in fact, that it is not commercially fertilized. Jack pine tends to be generally responsive. Lodgepole pine is variable to N applications, even with boron and sulfur added. Prescription using foliar analysis is essential for lodgepole pine.

There are seven opportunities for better nutrition in Crown lands:

1. Container nursery stock nutrition … use of exponential nutrient loaded seedlings (see Timmer's work: www.forestry.utoronto.ca/ac_staff/current/timmer_detail.htm
2. Reach free growing faster … avoid liability of "industry outstanding" cutblocks.
3. Avoid "green-up" and adjacency problems in spatial wood supply scenarios … reach 3m height sooner.
4. Accelerate second growth operability by crop plans using PCT and create CT opportunity with fertilization to get temporary increase in site index … ask for faster harvest of mature growing stock.
5. Add volume to thinned or low density valuable stands five to 10 years before harvest.
6. Break lodgepole repression by PCT plus N fertilizer.
7. Fertilize fully-stocked stands to fix more carbon to get carbon credits from guilty extractors of fossil fuels.

Case situations of possible fertilizer use

(see Figure 1)

Case 1: Old natural forest by past rotation age: Fertilization may increase tree growth but the extra growth may be offset by tree mortality. It is not recommended.

Case 2: Pole sized natural forest, not thinned, fully stocked, dense, with competition induced mortality, crowns packed together, little room for crown expansion:

Do not fertilize because crowns cannot expand and mortality offsets volume increase—result: low net increase. Fertilization just accelerates stand development like a temporary increase in site index.

Example: Interprovincial Fertilization Program showed:

1. Fertilization efficiency (kgN/extra M^3) is not economic for low value pulpwood.
2. No significant acceleration of stand operability. Fertilization of large areas of untended natural forest could fix more carbon and thus be eligible for carbon credits; scenarios have been developed.

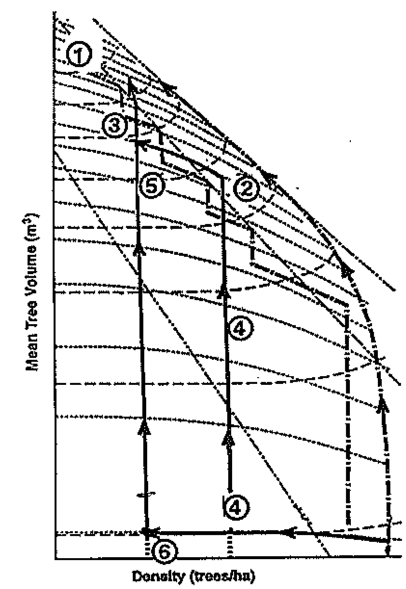

Figure 1. Location on stand density management diagram of cases 1 to 6 of fer ilization opportunities.

Case 3: Mature, tended/thinned stands close to rotation age with room for crown expansion, all trees merchantable, no mortality, little risk of loss, trees of high value, responsive species:

Examples: Sweden, Weyerhaeuser, Douglas-fir on private lands. Results show fertilization is economic at the stand level, i.e., extra wood in late rotation fertilization really pays and is a very good investment. Fertilizer increases volume over 5–8 year period in high value trees. Such stands are very rare in Canada, e.g., Douglas-fir on the east side of Vancouver Island (TimberWest).

Case 4: Pre-commercially thinned stands of responsive species, no mortality foreseen:

Fertilize to accelerate stand operability to fill age class gap in wood supply scenarios, i.e., rationale for fertilization is at the forest, not stand level, in terms of wood supply and ACE. This is the major reason for forest fertilization in Canada and elsewhere with natural forests with unbalanced age class distributions, e.g., BC aerial N + B + S applications to spaced lodgepole pine. It really works. The scale of fertilization is linked to the PCT program. Traditional tests involve N x T factorial experiments; often with 3 replications:

	T0	T1	T2
N0	3	3	3
N1	3	3	3
N2	3	3	3

Some are famous, e.g., Shawnigan Lake, B.C. Coastal Productivity installations (Darling and Omule 1989). Their results are used to calibrate stand growth simulators such as TASS/TYPSY.

Case 5: Commercially thinned pole sized stands with no mortality expected, room for crown expansion:

Fertilize, e.g., lodgepole pine beetle proofing, coastal Douglas-fir. Such stands are rare in western Canada. Fertilization can pay for itself at stand level if fairly close to rotation. Used in Douglas-fir with repeated CTs, 3 to 4 times/rotation.

Case 6: Fresh (1–2 years) cutover in natural forest with plantation proposed:

Fertilization in planting hole might help planted trees get roots established. Record is spotty, but it is popular with "teabags" of fertilizer to accelerate "green-up." Most sites are undergoing assart flush—i.e., high levels of N mineralization which is reflected in brush and fireweed growth. Fertilization with vegetation management (to stop grass/brush from taking up the fertilizer) has given spectacular results: "Nutrient loaded" container stock is an advantage.

Case 7: Old fields and backlog cutovers with assart flush completed, and site occupied by vegetation:

Planting with vegetation management plus fertilization can be very helpful. This is particularly true for ericaceous vegetation invaded cutovers, e.g., Vaccinium, Ledum, Kalmia, Salal (Gaultheria) and Calluna (Taylor 1991).

In summary, operational fertilization is restricted to responding and valuable stands that have been thinned or spaced so that tree mortality is not anticipated. Usually the benefits of fertilization lie at the forest level in accelerating the operability and development of thinned stands. Strategic use of fertilizer in selected stands and locations is part of an enhanced timber supply analysis (McWilliams and Carter 1994).

Situation in Alberta

FMA holders want increases in annual allowable cut (AAC) or Allowable Cut Effect (ACE) obtainable through "Enhanced Forest Management" (EFM). Any increases in AAC on Crown forests are presently governed by some rigorous protocols prepared by R. Dempster (Alberta Environment 2000). The requirements are in Table 2. As in BC, approved increases in AAC require on-the-ground proof of performance and reliable forecasting of stand yield; by necessity reliance has to be placed on stand computer simulation backed by calibration against responsive stands. Little has been done in Alberta. So much fertilizer research and development has already been done elsewhere that the improved yield curves and accelerated operability and determination of which stands are responsive are fairly predictable for jack pine, lodgepole pine and white spruce. Aspen is largely unknown.

Fertilizer research and development is a logical part of an Alberta growth and yield strategy. Cooperative testing is required. It is unlikely AAC increases due to fertilization will occur soon. It would be logical for Alberta to cooperate with northern BC, Saskatchewan and Manitoba in testing of fertilizers. Unfortunately PAPRICAN and the Canadian Forestry Service are no longer in a position to provide leadership.

Operational fertilization on Canadian crown lands outside of BC has not developed, in spite of all the research and development. The hindrances are the lack of a policy framework for ACE, the low value of boreal conifers, lack of corporate equity in growing stock and lack of incentives for licensees.

Summary

There is a large body of experience with forest fertilization relevant to Alberta boreal forests. The following is a list of requirements:

Table 1. Brief Review of Canadian interior and boreal forest fertilization

1950s
- Recognition by Hesselman and Rommel 1937+ trials in Northern Sweden old boreal spruce stand that humus N mineral supplies were not adequate and repeated ammonium nitrate additions produce big responses in 250 year old stand.

1960 – 80s
- Fortune magazine has centerfold showing aerial forest fertilization. Canadian forest industry interest aroused as Douglas-fir fertilization starts in PNW and BC and Sweden start to fertilize.
- PAPRICAN initiates Interprovincial Fertilization Trials 1968-83 in cooperation with Alberta, Saskatchewan, Ontario, Quebec, New Brunswick and Nova Scotia testing N1, N2, N2+P, N2+K, N2+PK in closed, unthinned natural stands.
- Northern Ontario Pulpwood Fertilization Program set up (963 PSPs.)
- Quebec sets up forest fertilization program.
- Canadian Forestry Service is interested.
- C.O. Tamm in Sweden starts long-term optimum nutrition trials and T. Ingested starts fundamental work on tree nutrition which changes nursery nutrition.

1980 – 2000
- Eastern provinces lose interest in forest fertilization, except sugar maple decline in Quebec in late 80s suggest need for large scale cation additions. Maples recover, program dies.
- 1980 start of screening trials and conventional plot trials, interior lodgepole pine.
- Operational aerial fertilization started for PCT treated lodgepole pine.
- Maximum productivity trials started in spaced lodgepole and spruce stands in BC.
- Struggle in BC over mandatory spacing in dense stands and linkage to unbalanced age classes and need to accelerate second growth operability.
- Continued debate on treatment of repressed lodgepole pine. N fertilization tried.
- Irving fertilizes New Brunswick spruce plantations.
- Canadian Forestry Service drops most fertilization, silviculture and growth and yield work.
- Need for fast "green up" arouses interest in fertilization at time of planting.

2000+
- Need for more carbon fixation in Canada's forest arouses interest in large N fertilization of established stands in fixed forest area.
- Industry proposals for enhanced forest management awaken Alberta interest.

Table 2. Requirements of forest companies in Alberta for an allowable cut effect in an enhanced forest management component of a detailed forest management plan for Forest Management Agreement (FMA) tenure. (Alberta Environment 2000)

- Spatially referenced timber supply analysis, with forecasting of landscape effects and biodiversity objectives, and meaningful performance tracking;
- Forecasting of allowable cuts, and the attainment of other resource values, with and without EFM;
- Risk assessment evaluating the impacts of incorrect projections (specifically an evaluation of what will happen to future harvest levels if after 20 years it is found that the anticipated yield increases are not achieved);
- Assessment of alternative utilization standards;
- Forecasting allowable cuts from public timber tenures, with and without integration of private land or external Crown lands (if applicable).

1. All fertilization of stands is done after other growth rate improving steps have been taken in each stand, i.e.,
   - correct species
   - adequate stocking
   - density control to avoid competition
   - reduced mortality and also salvage mortality
2. Fertilization of stands with ongoing mortality accelerates stand development temporarily but does not substitute for thinning.
3. Tree crowns need room to expand; trees need 30% + live crown ratio to start and then need extra room to respond. Fertilization of dense, unthinned stands makes no sense.
4. Stumpage values must be greater than the cost of extra fertilizer produced wood, i.e., greater than \$10–30/m^3.
5. The extra wood must be needed at the time and place it is produced in terms of forest level wood flows and AACs. Simulated stand development of fertilized stands need linkage to forest level wood supply models.
6. The more valuable the end product use of the log, the more reason to fertilize it, i.e., saw timber vs. pulp.
7. The extra wood grown should preferably be of high quality, i.e., in small branch knots or knot-free, and the grade must be recognized in scaling/stumpage system and log price and market.
8. The environmental effects and impacts must be known, acceptable, and understood by foresters who prepare fertilization prescriptions.
9. The money must be available to pay for the fertilization.
10. The scale and access of the stands for treatment must lend themselves to operational fertilization.
11. The magnitude and variation in response should be known and able to be simulated.

Conclusion

The forest industry in Alberta wants to "cut a deal" with the Province over the use of fertilization to obtain more allowable cut today. Thus the immediate task is to document what we know today about its use. Then the industry will want to go with our knowledge base, fertilize and monitor the results to see if risks are acceptable.

We do know a lot about how to diagnose stands, prepare prescriptions and monitor performance. The technology of implementation is proven and available with willing and able contractors. We also have good research and development strategies for cooperative testing. The challenge to the industry is to commit themselves to corporate learning and organize themselves to get the information. We know there is a huge potential to increase stand growth rates by fertilization.

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Fertilization of conifers in Finland

Paavo Soikkeli[1]

Fertilization in the past century and its goals

Fertilization was not carried out on any large scale in Finland until the 1960s, although some studies were made on peatland in the 1920s, using ash as the fertilizer. In 1960 forestry specialists realized the possibility of improving the nutrients in soil, and in the 60s and 70s the goal was to grow as much forest as possible. The 1980s saw the spread of large-scale disease in the forests, and fertilization was believed to be either the cause of the problem or the solution to it. In the early 90s fertilization was discontinued almost completely, but later in the decade it came to be seen as very profitable for forest owners.

Why fertilize?

The total volume of forest cut in Finland in the 1960s was 57 million m^3/year, compared to a total growth of 53 million m^3/year. This was a very serious situation, as Finland's chief exports were based on the forest industry. Measures were taken to increase forest growth, mainly through fertilization and drainage of peatland. Most of the drainage land was fertilized immediately after ditching. Since 1965 about 3 million hectares of forest have been fertilized, and more than 5 million hectares of peatland have been ditched. Finland was in fact granted a loan by the IMF for these purposes.

Grounds and results

Forestry is an economical way of utilizing the forest ecosystem. The Finnish soil lacks nitrogen, and extensive research has proved that 150 kg nitrogen/ha will give an increased yield of 15-20 m^3 in 8-10 years. On peatland the fertilizer is PK (P 40 kg/ha, K 70 kg/ha) and the response time is longer— about 15 years.

Silviculture and fertilization

After regeneration, our goal is to grow as many as 4000-5000 Scots pine/ha. Cleaning is done if necessary. Saplings are thinned at a height of 5–8 m, after which 2000 of the best trees are left. The first commercial thinning is done at a tree height of 13–14 m and at this stage the best stands are selected for fertilization. After the first thinning there are about 1000 of the best trees left. The second and third thinnings are done at a tree height of 17–22 m, after which there are about 500 trees left for harvesting. If the quality of stand is good it is fertilized again about 10 years before final felling. The goal is to maximize the value increment and the volume of good saw logs.

If the target stand is 70 years old, it is possible to earn 4000 FIM/ha, with the costs at less than 1000 FIM/ha. This has given rise to the slogan: "one markka for the forest and three markka for the forest owner." The internal rate of return is 20%. If you fertilize 40–60 year old stands three times in 18 years it is possible to earn 9000 FIM/ha, giving an internal rate of return of 10% or more, depending on the time of thinning.

Value increment of Scots pine

In Finland the price of Scots pine saw logs depends on their quality. First class bottom log is priced at 350 FIM/m^3 and second class bottom log at 230 FIM/m^3. Second log cheaper at 180 FIM/m^3, as there are dry knots inside the log. The price of top log is higher at 230 FIM/m^3, because the knots are sound. Pulpwood sells at 130 FIM/m^3.

With successful fertilization, it is possible to obtain 20 m3/ha more timber than without. The amount of pulpwood decreases and the volume of saw logs may increase for example by 30 m^3/ha. The following table illustrates the benefits gained by fertilization. The conclusion is that fertilization increases the value of the stand rather than the volume. Fertilization improves the shape and size of the logs, especially of the top logs.

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It is important that an individual tree does not grow too wide a growth ring and that there are no dry knots in the wood.

It is advantageous if every stem in the stand is a saw-timber stem.

Table 1. Benefits of Fertilization

Value without fertilization			
total volume m³/ha	250 m³/ha		
	m³	Fmk/m³	
Saw log Bottom I	50	350	17500
Saw log Bottom II	70	230	16100
Saw log Second log	40	180	7200
Saw log Top log	40	230	9200
Pulpwood	50	130	6500
Total		250	56500
Value with fertilization			
total volume m³/ha	270 m³/ha		
	m³	Fmk/m³	
Saw log Bottom I	60	350	21000
Saw log Bottom II	75	230	17250
Saw log Second log	50	180	9000
Saw log Top log	45	230	10350
Pulpwood	40	130	5200
Total		270	62800
Gain	6300		
Cost	1000		
Profit	5300		

Fertilizers

Nitrogen is the main component of fertilizer. In Finland it is useful to add small amounts of micro-nutrient, especially boron. The Finnish company Kemira Agro has extensive experience in producing fertilizers. They are able to produce suitable fertilizer just on time if they are provided with timely information on the volume and area to be fertilized. This is important for logistics. We do not normally analyze needles or soil.

We spread fertilizer in the following amounts: urea 350 kg/ha (N 46.3%), saltpeter 600 kg/ha (N 26%) and slowly soluble nitrogen Kemifix (N 35%) 450 kg/ha. On peatland we generally use PK 450 kg/ha (P 9% and K 16%).

Methods of fertilization

Spreading by airplane

It is possible to use special airplanes to spread fertilizer, which is a fairly convenient method. The airplanes fly as near to the tops of the trees as possible. The results of spreading is uniform if there is a good stand control system. It is essential for the controller and the pilot to co-operate and to have good radio connection.

A wide logging road can be used as a landing strip. The length of runway should be 500 m, although it is advantageous if it is much longer. The distance to the target area should not be more than 8 km, and the mean distance not more than 3–4 km. It is possible to fly in the early mornings and in the evenings and during summer nights. The cost of spreading is 200 FIM/ha and other costs can be high if there are problems with the weather. One load is 600 kg.

Flights and loading are done by contractors.

Spreading by helicopter

The use of helicopters for fertilization is still rather uncommon, but the method is being developed and pilots are undergoing training for this purpose. It is easier to find helicopter landing areas by the side of logging roads, and the maximum flight to be targeted is only 2 km. Spreading by helicopter is somewhat more expensive, however, and the quality of work is not as high as we would like. One load is normally 800 kg. It is possible to develop the efficiency of the method by using modern technology, such as GPS. Some companies are currently spreading ash on peatland. Ash is obtained in large quantities from the burning of bark in pulp and sawmills.

Spreading by forwarder

If the stand is thinned and there are logging roads, it is very easy to fertilize by forwarder. The cost is only 150 FIM/ha and the quality of work is very good. The spreader is installed in the timber transportation space. One load is 2400 kg, divided into four bags, which are delivered to the roadside or as near to the stand as possible. The fertilizer is spread by a contractor. In our case the spreader is owned by Metsahallitus, and it has been developed continuously

over the last 12 years. In my opinion this is the cheapest and best method if the stand has been thinned and there are logging roads in the vicinity.

Environment

Care must be taken around lake and river systems. No fertilization should be carried out at distances of less than 50 m from a lake, river or stream. Airplanes and helicopters are noisy and their use in the early mornings and summer nights will be a problem near villages and summer homes.

Fertilization is beneficial for the growth of berries, but citizens must be warned not to pick berries during the year of fertilization or the following year. This is a requirement for organic production. Fertilization on frozen ground is prohibited.

Experiences

It is hard to believe that forest fertilization is so profitable. Much research has been conducted in Finland and it always leads to the same conclusions: that the internal rate of return is 20% and the increase in timber yield is 15-20 m³/ha.

At present the timber drain in Finland is 65 million m³/year compared with an increment of 76 million m³/year. This explains why fertilization is not a topic of interest in Finland at the moment. Today we fertilize only 20, 000 ha/year.

Forests should not be fertilized too young, and the trees must be higher than 14 m. Select the best Scots pine stands on moderately fertile soil. It is of the utmost importance to increase the felling yield of saw logs, as pulpwood is too cheap and there is enough of it already.

It is possible to shorten the rotation and improve the structure of the development class.

Only fertilizers especially designed for forests should be used.

It is best to use forwarders and spreaders, as there are always people who claim that aerial application pollutes the waters and the environment. It is essential always to control and document the work. If aerial fertilization is used, carry out the work before mid-September.

Stands where there is a risk of break from heavy snow should not be fertilized, which in our conditions means no fertilization of stands at altitudes of more than 220 m above sea level.

Experience of fertilization on mineral soils in coniferous stands in Sweden

Folke Pettersson[1]

Summary

1. The industrial forest enterprises see nitrogenous (N) fertilization as a cost-effective method of boosting the yield of timber in their coniferous stands. It peaked in the late 1970s, when almost 200,000 ha of land was fertilized every year. That represents one per cent of the total area of productive forest land in Sweden. However, the scale of fertilization has declined sharply over the past ten years and, today, the area of land fertilized annually is only 20,000 ha. What will happen to N fertilization in the future will largely depend on the revised Swedish FSC standard to be published in 2003.

2. All operational fertilization has been concentrated on nitrogen enrichment of the soil. In experiments with other nutrients, including phosphorus, potassium and magnesium, no additional effect on the growth response as compared with pure ammonium nitrate (AN) has been detected. In addition, at a standard dosage of 150 kg/ha, the response to AN is 30–40% higher than when urea is used. At the end of the 1980s, the enterprises extended the interval between treatments from 5–7 years to 10 years or more. This was in response to findings that the financial return was greater if refertilization was delayed until the response to the previous treatment had ceased (usually after 9 or 10 years).

3. Suitable stands for N fertilization are coniferous stands in the intermediate age class or above, containing only a small proportion of hardwoods and on sites of average class. The total response in growth is between 13 and 20 m^3/ha at a standard AN dosage of 150 kg/ha. The growth response in stands today is just as high as it was in the 1960s. This is also true in southern Sweden, despite the heavy anthropogenic deposition of nitrogen occurring in parts of that region (amounting to between 15 and 20 kg of N/ha per year).

4. The careful selection of suitable stands, sound planning and good fertilization technique are of utmost importance to good growth response. It is also important to coordinate nitrogenous fertilization treatment and final felling—felling should not be done until the response to fertilization has ceased in the stand. In the past, the forest enterprises used to rely on information from the stands database; nowadays, however, they conduct field surveys of all potentially suitable stands. Fertilizer contractors are given details of reserve stands in which any surplus fertilizer can be spread. This produces a much greater growth response than the old procedure, whereby any surplus fertilizer was spread in stands that had already been treated.

5. In practice, fertilizer is seldom spread evenly over a stand, which means that the growth response will be reduced by 5–15%, especially on more fertile sites. The key factors to even distribution of fertilizer are the availability of accurate maps, even stand borders, good spreading equipment and high-quality fertilizers. The use of helicopters for spreading has resulted in more uniform distribution, although the improvement was not as high as expected. Tractors should always be used to spread fertilizer on small sites or on awkwardly shaped stands with uneven borders.

6. The environmental impact of nitrogenous fertilization has been studied widely over the past decade. No adverse long-term effects after normal dosages of nitrogen have been recorded, although some short-term changes in the soil chemistry and surfacewater runoff have been observed. Fertilization also increases the amount of carbon in the humus layer.

7. The industrial forest enterprises are able to avoid incurring interest charges on the cost of fertilization. That's because the estimated volume increment from fertilization is included in the timber budget for the year and is extracted from other stands during the same year. The production cost of the added volume of timber resulting from fertilization is approximately US\$10/m^3. This figure can be compared with the cost of buying stumpage on the open market—which is about \$30/m^3.

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Introduction

We have known for a long time that the growth of forest trees on mineral soils in Sweden is usually limited by a nitrogen deficiency in the available nutrient supply (e.g., Tamm, 1999). In the mid-1950s, the industrial forest enterprises started to show an interest in fertilization, which led to the establishment of a host of field trials. At the same time, development work directed at finding suitable methods for spreading the fertilizer was started. The enterprises saw fertilization as a cost-effective means of boosting the production of timber in their forests (the industrial forest enterprises in Sweden are not self-sufficient but need to purchase large quantities of timber from family forest enterprises).

The initial growth response from nitrogenous fertilization on mineral soils was so promising that, at the beginning of the 1960s, it signaled the start of fertilization on an operational scale. Since then, operational fertilization has focused almost exclusively on nitrogen enrichment of mineral soils in coniferous stands—there has been some fertilization on peat soils but only to a very limited extent. Another distinctive feature is that nearly all operational fertilization has been done by the industrial forest enterprises; despite the high profitability of fertilizing older stands before final felling, this has only been done on a very limited scale in family-enterprise forestry.

It soon became clear that the basic questions concerning the criteria for selecting suitable stands for fertilization, together with the expected growth response from the use of different mixes and different dosages, were more complicated than was first thought. The industrial forest enterprises therefore decided to coordinate the applied research. This started in 1967, with the setting-up of the Institute for Forest Improvement, which today is part of SkogForsk—the Forestry Research Institute of Sweden. Over the years, substantial funding has gone into the applied research. In the 1960s and 1970s, the main focus was on timber production but, in the 1980s, increasing attention was directed at the environmental effects of fertilization.

The procedures used by the forest enterprises for selecting stands, fertilization planning, etc., have been developed gradually, in pace with acquisition of new knowledge and practical experience. Because operational fertilization and fertilization research proceeded in parallel from the very beginning, it was inevitable that mistakes would be made in practice because of gaps in our knowledge, such as in the selection of suitable stands.

The purpose of this paper is to present the knowledge and experience of fertilization that we have accumulated over the years. The paper deals with fundamental issues, such as how to choose suitable stands and the effects of fertilization on tree increment and the environment, and also with the practical aspects of planning and fertilizer spreading. It is solely concerned with fertilization on mineral soils in coniferous stands.

The scale of operational fertilization over the years and the situation today

Operational fertilization has been practiced for more than 40 years in Sweden. During this period, between 1.6 and 1.7 million hectares of productive forest land has been treated with nitrogenous fertilizer at least once. This corresponds to 7 or 8% of the total forest land in Sweden, which amounts to some 22 million ha. The major forest holdings of the industrial forest enterprises are situated in central and northern Sweden, and it is here that most fertilization has been carried out. Over the years, some 40–45 million cubic meters of additional timber have been produced as a result of fertilization. Fertilization on peat soils has been done on a very limited scale, the total treated area amounting to 10,000 ha over the 40-year period.

In the family-enterprise forestry sector, there is considerable scope for fertilization. About half of Sweden's forest land is owned by 300,000 private individuals, whose average forest holding is 50 ha.

Because these family-owned forest enterprises are a disparate group, with different objectives for their enterprises, there are probably a wide variety of reasons explaining the lack of fertilization in this sector. One problem is that those families with the smaller holdings need to collaborate through forestry cooperatives or with other woodlot owners in their area, if hiring a fertilization contractor is to be viable.

Operational fertilization peaked in the late 1970s, when almost 190,000 ha of forest land was treated annually (Figure 1). Yet this represented less than one per cent of the total forest land in Sweden. Since the end of the 1980s, the scale of fertilization declined steadily until the mid-1990s, when it leveled out at about 20,000 ha per year. At the end of the 1980s, the enterprises extended the interval between treatments in a given stand. At the beginning of the 1990s, the National Board of Forestry, with a view to reducing adverse effects on the environment, introduced guidelines that limited the total quantity of nitrogen that could be added to a stand during a rotation. The recommendations limit fertilization to two treatments in a single rotation for central Sweden and to four treatments in the north, corresponding to dosages of 300 and 600 kg of nitrogen per hectare, respectively. As regards the south of the country, treatment with nitrogenous fertilizer was discouraged altogether because of the high annual levels of nitrogen being deposited by air pollution (15–20 kg/ha). Consequently, very little fertilization has been carried out in the south and such treatment ceased entirely at the end of the 1980s.

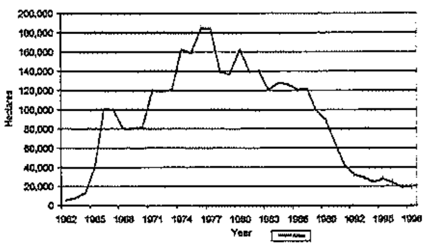

Figure 1. Fertilization on forest land, 1962–1999.

Owing to the lengthening of intervals between treatments and the limits imposed by the National Board of Forestry, the number of suitable sites available for fertilization has declined and, with it, the scale of operational fertilization. However, the singularly most important reason for the sharpness of the decline has been the opposition to fertilization brought to bear by the environmentalists.

For some years now, all industrial forest enterprises performing fertilization have had their forestry certified in accordance with the Forest Stewardship Council (FSC). The Swedish FSC standard states that all landowners using nitrogenous fertilizer must demonstrate that it neither presents a threat to the long-term productive capacity of the soil nor is detrimental to other ecosystems or to biodiversity. The submissions, together with supporting documentation, must be produced by 2003 at the latest. Research to fill the gaps in our knowledge and to provide the basic information needed for meeting the FSC requirement has been under way for a number of years in a project known as *Nitrogenous fertilization 2002*. What the future holds in store for fertilization on an operational scale will largely be determined by the review of the Swedish FSC standard in 2003.

Nutrients

The early emphasis on adding nitrogen to mineral soils was largely because of the findings on the oldest experimental sites, which showed that the addition of other elements, such as phosphorus (P), potassium (K) and magnesium (Mg), to the fertilizer mix exhibited no additional effects to those achieved using purely nitrogenous mixes (Nohrstedt, 1990; Pettersson, 1994a). Similar studies of experiments set up in the 1980s again failed to identify any clear indications of increased response from such mixes (Nohrstedt et al, 1993; Pettersson, 1994a).

Experiments have shown that nitrogen deficiency is still the principal growth-limiting factor on mineral soils, with the exception of gray-brown podzolic soils and soils with a humus layer consisting of a well-humified peat layer. This is also true in the south of the country, where annual nitrogen deposition is high (15–20 kg/ha). The growth response after a first application of fertilizer is as strong today as it was 35 years ago (Pettersson, 1994a)—even in the south.

In one trial, the application of compensatory fertilizer mixes exhibited a significantly stronger growth response than did purely nitrogenous mixes. The trial involved nutrient optimization in Norway spruce plots, with annual treatments at relatively high dosages (Tamm, 1985). However, similar trials in plots of Scots pine exhibited no significant growth response from elements other than nitrogen (Tamm, 1985 & 1999).

As the results from an increasing number of experiments were published, a pattern emerged that showed that, in the majority of cases, the response to repeated treatment in the plots was lower than that from the first application of fertilizer (Pettersson, 1987 & 1990a; Jacobson & Nohrstedt, 1993). This phenomenon was most pronounced when intensive fertilization regimes involving high dosage levels and short treatment intervals were used (Figure 2). Yet analysis of the needles failed to identify any nutrient imbalance in the needles in response to fertilization. Similarly, no explanation of the lower response levels from repeated applications could be found from analysis of the soil (Jacobson & Nohrstedt, 1993).

The main hypothesis for the weaker effects of fertilization was that an inadequate uptake of minerals other than nitrogen limited the ability of the trees to utilize fully the additional nitrogen applied in subsequent fertilization treatments. The reduced uptake could be attributable to reduced availability of other minerals and/or a decline in root absorption.

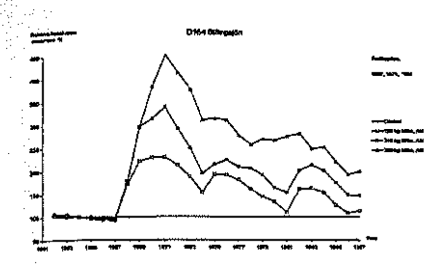

Figure 2. Relative basal area increment after fertilization at seven-year intervals in a Scots pine trial D 164, Billingsjön. AN fertilizer mix.

The results of a large number of trials in which repeated treatment with nitrogen and other minerals was carried out showed that the growth response to nitrogen alone was significant and normal (Jacobson & Pettersson, 2001), (Figure 3). The application of PKMg in addition to N produced a slightly higher (6%) but insignificant response as compared with those plots treated with a purely nitrogenous mix. The findings suggest that the reason for the reduced response in repeated applications could be attributed to the decline in root absorption of the nutrients available from refertilization. We know, for instance, that the development of root hairs is impaired by high dosages of nitrogen (e.g. Ahlström et al, 1988) and that the root system can become shallower (Persson, 1992). It is therefore probable that the adverse effects on the root systems and mycorrhizae, and the consequent reduced growth response, become stronger with increased nitrogen dosage and shorter treatment intervals.

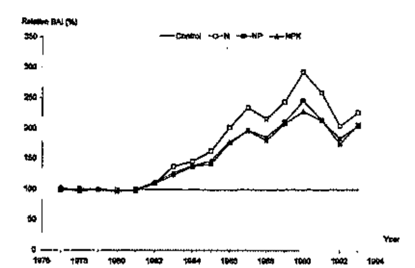

Figure 3. Relative basal area increment in the 170 Ramsele experimental site (Norway spruce). A nitrogen dosage of 150 kg/ha was applied every two years during the period 1982–92. P and K were applied in 1990 and 1992. Mean value of three replications.

In the 1970s, growth disorders were observed in some Scots pine stands in the north of the country in which repeated applications of nitrogen fertilizer had been made. The disorders were manifest in the form of dead buds on leaders, and needle losses in the tops of the crowns (Figure 4). Analysis of the needles identified the cause of the problem to be a deficiency of a micronutrient, boron, brought about by fertilization (Albrektson et al, 1977). Subsequent studies of boron found that the application of nitrogen fertilizer reduces the concentration of boron in the needles by 3–6 ppm, and the risk of boron deficiency arises when the natural concentration of boron in the needles is 10 ppm or less (Möller, 1983). The natural concentration of boron in the needles varies between 5 and 20 ppm, the lowest levels being recorded in the north. The studies also found that a boron dosage of 1 kg/ha was sufficient to maintain or even boost the boron concentration after nitrogen fertilization. These findings resulted in boron being added to nitrogenous fertilizer mixes for application on forest land.

Figure 4. Boron-deficiency symptoms after repeated nitrogen fertilization on mineral soils.

Fertilizer mixes

During the infant years of operational fertilization in the 1960s, urea was almost the only fertilizer used—because it was the cheapest. However, field studies soon revealed that an ammonium-nitrate (AN) mix produced a stronger growth response (Möller, 1972). Foresters were quick to adopt the new knowledge and, since the mid-1970s, AN mixes have been used almost exclusively for nitrogen enrichment of the soil.

At normal dosages, the growth response to AN mixes is 30–40% higher than to urea mixes (Pettersson, 1994a). The contrast is greatest on weak soils and at lower dosages. Dosage tests have shown that both types of fertilizer mix can produce the same maximum response (Figure 5), but that a substantially higher dosage is needed for urea. The explanation for the lower response to urea is that a larger proportion of the nitrogen becomes fixed when in the form of urea, thus reducing the amount of nitrogen available for uptake by the trees. In addition, some of the urea applied can be lost through evaporation of the ammonium on application (e.g. Melin, 1986).

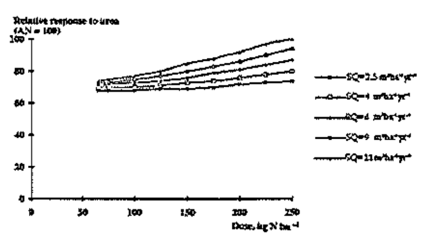

Figure 5. Comparison of growth response to urea and AN fertilizer mixes on different site classes and for different dosages. (Response to AN mix = 100) (From Pettersson, 1994a).

Empirical acidification effects of AN fertilizer on streams flowing through treated stands were demonstrated in the early 1980s (Möller, 1984). However, these effects were not seen when an alternative CAN mix (AN + 18% dolomite) was used (Nohrstedt, 1988). This resulted in the industrial forest enterprises again changing their fertilizer mix, this time from the boron-enriched AN mix to the boron-enriched CAN mix, which became the exclusive mix used in operational fertilization after the late 1980s. The CAN mix produces the same response as the purely AN mix (Jansson, 1985; Pettersson, 1994a).

Intervals between fertilizer applications

The industrial forest enterprises employed an interval of 5–7 years between treatments up to the end of the 1980s. Before this, re-applications were therefore performed before the response to the preceding treatment had ceased. At a standard nitrogen dosage of 150 kg/ha, the duration of the response varies between 7 and 11 years, depending on site class, tree species and local climate. Following the findings from studies on repeated fertilization, the enterprises extended the interval between treatments to 10 years or more.

If a repeat fertilizer treatment is carried out before the effects of the previous treatment have ceased, some of the potential additional growth response is lost (shaded area in Figure 6). If high dosages are used, the loss in increment can be even greater. The annual rate of increment is obviously greater under intensive fertilization regimes, but the cost per cubic metre of fertilizer-induced additional growth also increases with the intensity of the regime. If we compare the 10-year and 6-year intervals, we find that the marginal cost of the additional growth response induced under the 6-year regime is high—usually considerably higher, in fact, than the cost of buying the equivalent volume of timber on the open market (Pettersson, 1987). Intensive fertilization regimes are only justifiable for stands containing timber of high value. However, given the current recommendations of the National Board of Forestry on the total nitrogen dosage during a stand rotation, there is little scope for adopting an intensive regime.

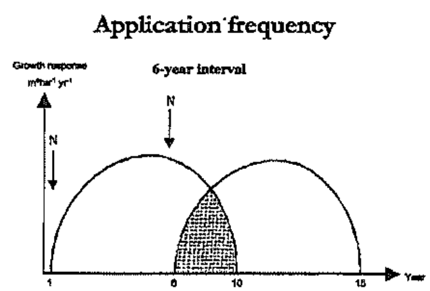

Figure 6. Illustration of the potential increment that is lost in a stand when subsequent fertilization is carried out before the response to the previous treatment has ceased.

Timing of fertilization

A vital question that needed answering in the early days of forest-land fertilization in Sweden was at what time during the year fertilizer should be applied to the land. A number of experimental plots were therefore established to find the answer. The studies revealed that the growth response was the same regardless of when during the growing season (April to September inclusive, depending on local climate) fertilization was performed (Möller, 1982; Pettersson, 1994a). When the fertilizer was spread on frozen or snow-covered soils in the winter, the growth response was much reduced. Fertilization can therefore be done throughout the growing season, although most fertilizer spreading on an operational scale tends to be performed between the beginning of May and the end of July.

Phased spreading and slow-release fertilizers

We have known since the beginning of the 1960s that only 20–40% of a nitrogenous fertilizer mix is taken up by the trees (e.g. Melin, 1986). Experimental studies were therefore initiated in the 1970s to find ways of increasing the nutrient uptake. A number of experimental plots were therefore laid out to determine whether the efficiency of fertilization—and, hence, the response to it—could be improved by splitting the standard dosage of 150 kg/ha (120 and 240 kg/ha in some trials) into a number of smaller applications spread over the year or over two or three consecutive years. Phased spreading of the fertilizer, however, mostly resulted in a weaker growth response than that occurring after a single application of the standard dosage (Pettersson, 1984, 1986 & 1994a).

Trials were also established to determine whether slow-release fertilizer mixes could produce an improved response. The mixes tested were sulphur-coated urea, and Osmocote, a plastic-coated AN-based NPK mix. But these slow-release fertilizers produced a clearly weaker response than standard urea or AN mixes (Eriksson, 1981).

Consequently, neither phased spreading nor the use of slow-release fertilizers has been adopted by the industrial forest enterprises.

Choosing suitable stands

To achieve the highest possible increment, stands in which fertilization is appropriate must meet the seven basic criteria shown in Table 1 (Pettersson, 1994a). On some mineral soils, the response to nitrogenous fertilization can be very weak or even nonexistent. This applies to grayish-brown podzolic soils and to Norway spruce stands on highly fertile soils having a site class with a mean annual increment exceeding 11 m³/ha. The growth response is also fairly weak in Norway spruce stands on drained mineral soils, with a humus layer consisting of a thick and well-humified peat layer. Such stands are therefore not suitable candidates for fertilization. Mineral soils on hardpan should also be excluded because of the weak potential response. It can be assumed that an inadequate supply of moisture will heavily restrict growth during dry periods on hardpan soils, and that this is a significant contributory factor to the weak growth response to fertilization that occurs on such sites.

Table 1. Basic criteria for selection of stands for fertilization.

1. Mineral soil (humus layer < 30 cm)
2. Podzolic soil type
3. Site class 2.5–9 m³/ha per year
4. After first commercial thinning (height > 12 m)
5. At least 80 % conifers
6. Vigorous, well-stocked stands of good quality
7. No thinning or final felling until response has ceased

To ensure that there is an adequate safety margin against a weak growth response, we recommend that Norway spruce stands on fertile soils with a mean annual increment above 9 m³/ha should not be considered for fertilization. In Scots pine stands on lean soils, the growth response will often be weak owing to the small volume of the standing crop and the low current annual increment. This is the reason for the lower site-class limit of a mean annual increment of 2.5 m³/ha. Stumpage value and current annual increment are decisive factors in the profitability of fertilization on sites with a low productive capacity.

In plantations and young stands, the response in volumetric increment to nitrogenous fertilization is heavily dependent on the level of development (Pettersson, 1985). The growth response will be weak (< 1 m³/ha) in plantations having a height of 1 m, whether the nitrogen dosage is 50 or 150 kg/ha. At a stand height of 5 m, the response to an AN dosage of 150 kg/ha will be approximately 10 m³/ha for Norway spruce and lodgepole pine (*Pinus contorta*), but only about 6 m³/ha for Scots pine. The peak response is obtained after the stand has reached a height of 10–12 m and it is this fact that forms the basis for the criterion that fertilization should not be carried out before the stand has been thinned (> 12 m).

In plantations and young stands, it is probably the volume of biomass in the roots and needles that is the decisive factor in the uptake of nitrogen by the tree and the benefit derived from it. It is highly likely that the stronger response occurring in young Norway spruce and lodgepole pine stands than in young Scots pine stands is attributable to the higher needle biomass in those stands. Yet in young stands of Scots pine or lodgepole pine, the response in height increment to nitrogenous fertilization is very weak, leading to inferior stem form (Pettersson, 1985). In Norway spruce stands, a significant response in height increment occurs when the stand height is only 2 m. Lodgepole-pine trees, most of which were planted in the 1970s and 1980s, are now growing on some 500,000 ha of forest land in the north of Sweden but, so far, no fertilization on an operational scale has been carried out in these stands.

The growth response in birch is both much weaker and of much shorter duration than in Scots pine and Norway spruce (< 50%) (Jonsson & Möller, 1976). This weaker response in birch is probably attributable to the annual renewal of the tree crown, and the associated loss of nitrogen in the leaf-fall.

Similarly, thinning or final felling of stands in which there is an abiding response will reduce the overall response per hectare, owing to the loss of the additional growth response. It is therefore important, with respect to stands of intermediate age class, to consider the thinning program when scheduling fertilization operations. In older stands, we have to consider the need for ensuring that there are always enough mature stands—in which there is no abiding response to fertilization—that can be selected for final felling.

Growth response and predictive tools

Generally, the highest percentage response in basal area and volumetric increment to nitrogenous fertilization occurs in stands growing on weak soils and with a low current annual increment. In these stands, the percentage response will usually fall within the 70–100% range over a period of 9–11 years, after a standard AN dosage of 150 kg/ha. The lowest percentage response (15–20%) occurs in stands growing on fertile soils and with a high current annual increment. The difference in the response in terms of m³/ha, however, varies little between stand types.

The percentage height increment after nitrogenous fertilization is often lower than the percentage basal area and volumetric increment. In Norway spruce and Scots pine stands in medium and older height classes, the total response in height increment will usually be between 40 and 70 cm at a standard AN dosage of 150 kg/ha. A one-off fertilization in these stands will not affect the stem form (form quotient) (Friberg, 1974). Nor do the current findings of ongoing studies on experimental sites indicate any change in the form quotient.

To maximize the profitability of fertilization, it is important to select the right stands and to ensure that a suitable fertilizer mix and dosage are used. For this we need reliable tools for predicting the growth response under different conditions and for assigning priorities to selected stands. Hitherto, needle and soil analysis have not been of use in predicting the response. The tools that we have developed over the years have instead been based on site class, stand factors and fertilization technique.

The first predictive tools for the effects of fertilization, which were presented in 1973, were in the form of prediction curves for growth response. The tool we use today was launched in 1994 and consists of predictive functions for volume increment over the five years following treatment (Pettersson, 1994a) and predictive functions for the total response and its duration and distribution over time (Pettersson, 1994b). These functions have superseded those from the 1980s, which also dealt with the response during the first five years (Rosvall, 1980), and the total response and its duration and distribution over time (Pettersson, 1980).

The material on which the new functions are based encompasses 961 plots from 234 experimental sites throughout Sweden. Latitude, altitude, site index (site-class factors), tree species, current annual increment (stand factors), fertilizer mix and fertilizer dosage were all found to be factors of significance to growth response and are therefore used as descriptive variables in the functions.

Somewhat simplified, the functions give the average growth response recorded in the sample plots under different conditions and fertilization techniques. The response in some of the plots was either much stronger or much weaker than the average determined by the functions. We therefore conducted a study, using meteorological data and soil analysis, to ascertain whether these deviating results could be explained by diverging weather conditions at the time the fertilizer was spread or by divergences in particular site-class conditions. Unfortunately, these studies threw

little light on the causes of the deviations in growth response (Pettersson, 1994a).

A standard AN dosage of 150 kg/ha in stands meeting the basic selection criteria gives a total response of 15–20 m³/ha in the north of Sweden, 13–18 m³/ha in central Sweden and 10–15 m³/ha in the south. An overview of the response in the north is given in Table 2.

Table 2. Total growth response to nitrogenous fertilization at a dosage of 150 kg/ha. Northern Sweden. (The response in central and southern Sweden is roughly 2 and 5 m³/ha weaker, respectively.)

Stand age		40 years		60 years		80 years		100 years		120 years	
Site class m³ha⁻¹ år⁻¹		AN	Urea	AN	Urea	AN	Urea	AN	Urea	AN	Urea
3–4	Scots pine	–	–	16	11	18	13	17	12	16	11
	Norway spruce	–	–	17	12	19	13	18	13	18	11
5–6	Scots pine	18	14	20	15	19	15	18	14	16	12
	Norway spruce	19	15	21	18	21	19	19	16	17	13
7–8	Scots pine	16	13	17	14	16	13	16	12	–	–
	Norway spruce	17	14	19	15	17	14	16	13	–	–

The duration of the response was longest in the north (8–11 years) and shortest in the south (6–8 years). The harshness of the climate increases with latitude and altitude, and nitrogen mineralization diminishes with increasing climate harshness. In addition, nitrogen deposition decreases sharply from the south to the north of the country. Also, there are usually more needle generations on trees growing in harsher climates. The generally greater nitrogen deficiency and larger number of needle generations occurring in the north probably account for the stronger growth response and duration there. The reason for the duration of the response being 1–2 years longer in Norway spruce than in Scots pine could be that spruce trees bear more needle generations than do pines.

Under similar conditions, the response is slightly stronger in Norway spruce than in Scots pine. The strongest response usually occurs in stands in the intermediate site class. A high current annual increment tends to strengthen the response, and the strongest response therefore generally occurs in the intermediate age classes (Table 2). During the development of the predictive functions, the stand-age variable was found to be insignificant as an explanatory variable. However, there is a correlation between age and current annual increment (which is included in the functions). The fact that a stand is of an advanced age does not render it unsuitable for fertilization—the decisive factors being the current annual increment and general vigor of the stand.

The correlation between nitrogen dosage and response must be taken into account in the choice of dosage. As regards the application of AN to poor soils, the increase in the response with increased dosage is roughly linear within the 70–250 kg/ha range (Figure 7). On poor soils, the response peaks at an AN dosage of 300–350 kg/ha, while on average-to-good soils, the increased response to dosages in the range of 150–250 kg/ha is heavily dependent on the site class. Because of the inevitable unevenness in the distribution of the fertilizer in practice, the total response is reduced somewhat (5–15%), particularly on average-to-good soils. This is attributable to the skewed relationship between dosage and response.

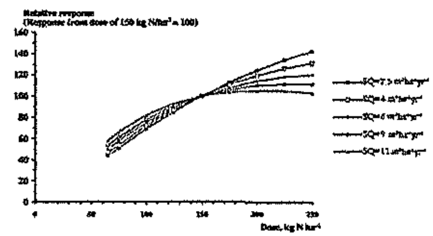

Fig. 7. Correlation between nitrogen (AN) dosage and the relative response for different site classes. (From Pettersson, 1994a).

Thus, when deciding a suitable average dosage for a stand, we need to consider the current relationship between nitrogen dosage and response for the site class in question, and the likely unevenness in the distribution of the fertilizer over the stand.

The accuracy of the predictive functions has been studied in several investigations of the growth response occurring in operational stands. All of the studies found that the response measured in the field corresponded well with the predicted figures (e.g., Pettersson, 1990b).

Planning, implementation and monitoring of operational fertilization

The careful selection of suitable stands, sound planning and good fertilization technique are the keys to good growth response. Many mistakes have been made over the years, e.g., in selecting stands and in the timing of fertilization in relation to logging plans, but improved procedures have obviously been developed subsequently.

A study that examined how evenly the fertilizer was spread over the stand in fertilization on an operational scale in the mid-1980s found the distribution to be very uneven (Aregger & Pettersson, 1986). On average for the stands studied, the predictive functions indicated a response that was 8% lower than if the measured dosage had been spread evenly over the site. In addition, the measured dosage deviated from the specified (planned) dosage in most stands. These findings stimulated the industrial forest enterprises to improve their planning procedures for fertilization and to introduce systems for monitoring the standard of fertilizer spreading.

In fact, knowledge on the unevenness of fertilizer spreading had existed since the 1960s, but had simply been overlooked. Extensive studies had highlighted how unevenly the fertilizer was distributed (Hagner et al, 1966), although there was no knowledge on how this affected the response.

Having relied on the stands database in the past, the forest enterprises now conduct field surveys on all stand types. Doubtful stands are surveyed on foot. Nowadays, it is also usual to inspect sites not only with regard to growth response but also for conservation reasons.

Usually, a number of stands can be excluded from fertilization treatment, thus saving unnecessary costs. Fertilizer contractors are given details of reserve stands in which any surplus fertilizer can be spread. This produces a much greater growth response than before, when any surplus fertilizer was spread in stands that had already been treated. In addition, it reduces the risk of unwanted nitrogen leaching arising from excessive dosages.

There are a variety of factors that contribute towards good spreading technique. The creation of even stand edges by excluding areas that are difficult to treat makes spreading much easier. Only good-quality fertilizer should be used. If the mix is damp, it will result in uneven distribution. Spreading by helicopter is suitable for large stands with regular borders, whereas tractors should be used in small, awkwardly shaped stands. There is roughly a fifty-fifty split in the use of these methods today.

The introduction of GPS-based navigation systems has greatly improved the spreading done by helicopters. There has been a marked increase in the proportion of treated land on which the fertilizer has been spread satisfactorily. Poor results caused by pilots becoming confused over the correct flight paths can now be completely avoided. Yet, for a number of interrelated reasons, the fertilizer is still not being spread as evenly as expected. The average treatment area has become much smaller in recent years, owing to the fact that most of the large stands have already been treated with the recommended maximum aggregate dosage. In addition, the digital instrument that assists pilot navigation displays how far the helicopter is off course in meters from the current flight path but does not indicate the directional deviation in degrees. This means that when the pilot makes corrections to get back on course, he has to zig-zag a little in order to resume the correct position and direction. Improvement of the navigational support system so that it displays deviations in degrees as well would therefore be beneficial.

There is a growing need to monitor fertilization treatment, partly to assist the planning work done by the forest enterprises but also to provide information to the authorities and the general public on how the treatment has been carried out. Thanks to satellite navigation, monitoring systems are now much more advanced and the work can be done with greater efficiency. An automatic monitoring system is in practical use today (Eriksson & Mattson, 1988). The system incorporates a navigation instrument that records the position of the helicopter when fertilizer is actually being discharged. Through the use of stored data and a mathematical model of the spreading pattern, the dosage at different points can be calculated (Figure 8). The system calculates the evenness of the distribution, the percentage area in which the dosage was above or below different specified limits, and the amount of fertilizer that was deposited inside and outside the site limits, respectively. Work on the development of a GPS-based system for tractors is now in progress.

Fertilization economics

Fertilization leads both to a greater volume of timber and to timber of larger dimensions. In addition to the increased volume of timber, the value of the entire stand also increases as the diameter of the trees grows. Thus, the financial benefit derived from fertilization consists of two elements: the response in volume increment and the response in diameter increment. The response in diameter increment can be broken down as follows:

1. Larger trees produce a greater sawlog yield
2. Larger sawlogs fetch a higher price
3. The felling cost per cubic meter is lower for larger trees.

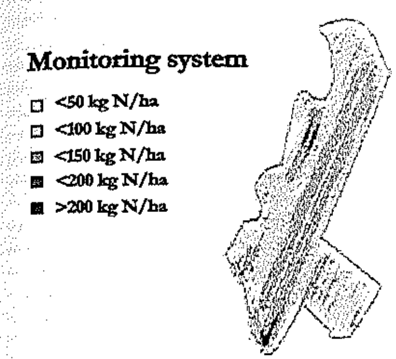

Figure 8. The spreading pattern in a real stand as calculated by the monitoring system. The greenish-yellow line marks the site boundary.

The diameter increment due to fertilization usually falls within the range of 0.4–0.8 cm. Of the additional revenue attributable to fertilization, 55–65% comes from the increased volume of timber and 35–45% from the increased value per cubic meter.

Regarding small holdings, as are typical in family-enterprise forestry, fertilization is mainly appropriate in stands scheduled for final felling 8–10 years hence. The return on an investment in fertilization for a stand selected for final-felling is 15–20% a year. If we assume that timber prices and logging costs will follow inflation—which is a reasonable assumption—the projected return on the investment will be realized. Which means that fertilization is a highly profitable activity.

Because large industrial forest enterprises can avoid interest charges on their fertilization costs, extensive fertilization programs based on repeat applications and starting in stands in the intermediate age classes are a financially attractive proposition. In 1960, one industrial forest enterprise, SCA, presented a model explaining how this can be achieved. It goes as follows:

The additional increment derived from the fertilization of stands in a given year is included in the company's timber budget for the year and is extracted from totally different stands in the same year. Thus, in the initial phase of a fertilization program, the total annual area on which final felling is carried out is increased and the company incurs additional silviculture costs attributable to fertilization. At the same time, an increase in the volume of the standing crop in the treated stands starts to accrue. After 8–10 years, final felling starts in stands that were fertilized first, which now contain timber of larger-than-usual dimensions. Gradually, an increasing proportion of final-felling stands will be those in which fertilization has taken place. Once the fertilization program has been widely implemented, it will no longer be necessary to perform final felling on a larger scale than usual.

The yield from the final fellings contains more timber per hectare and timber of larger dimensions. But an alternative is to employ a management policy based on shorter rotations, thus capitalizing on the financial benefit from fertilization.

To secure the highest return, extensive fertilization programs with intervals of at least 10 years between repeat treatments should be adopted. Under such programs, the production cost of the added volume of timber resulting from fertilization is US$10-$13/m³. This figure can be compared with the cost of buying stumpage—which is about $30/m³. Thus, for enterprises that are in a position to avoid interest costs on their fertilization programs, fertilization is a truly profitable undertaking.

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Appendix 1.

Environmental impact of nitrogenous fertilization on forest land

Unless stated otherwise, the following report of the environmental effects of nitrogenous (N) fertilization consists of a short summary and translation of Nohrstedt & Westling (1995).

The environmental side effects of N fertilization on forest land have had a strong influence on the practice of N fertilization in respect of the development of fertilizers and technical developments. Apart from pure research on N fertilization, the results also have a bearing on more general questions, such as the effects on soil acidification and anthropogenic N deposition.

Effects on the plant community

The addition of N tends to change the floristic composition of the site. These changes are most pronounced on intermediate sites. On lichen-dominated sites with a low productive capacity, N fertilization causes damage to the lichens but, since no other life forms are present that could take advantage of the decreasing cover of lichens, it does not result in changes in plant cover. On nutrient-rich sites, most species have adapted to a high N concentration and are less affected. However, since N fertilization increases the canopy cover, it is possible that the available light could be too low to sustain a high forest floor production (Nohlgren & Nohrstedt, 1994). On more-intermediate sites, there is a greater abundance of more-opportunistic plant species that react quickly to changes in interspecies competition.

In general, the adverse effects on mosses and lichens tend to be greater after urea fertilization than after AN or Ca-AN fertilization.

Effects on soil chemistry

After a single-shoot application of a normal dose (i.e. 150 kg of N ha^{-1}), the concentration of inorganic N in the upper part of the soil profile increases only during the first growing season. Most of the added N is incorporated into organic-bound N, with an attendant increase in the N concentration in the organic matter. When AN or Ca-AN were used, no long-lasting effects on N mineralization or nitrification could be detected following a normal application of fertilizer. Urea, on the other hand, could cause increased nitrification even after a single application. Nitrification can increase after final felling following repeated application of more than 480 kg of N ha^{-1}. This has been recorded for AN only, but most likely this effect could be found regardless of the nitrogenous fertilizer mix.

N fertilization causes a reduction in the turnover rate of organic matter (calculated on a weight basis) and increased litter fall. This is because the increased needle production results in a build-up of organic matter in the soil. This effect is probably the same for both AN, Ca-AN and urea. However, calculated on an area basis, the turnover rates of the organic matter in the soil are slightly higher in fertilized stands than in untreated stands.

All common N fertilizers—at reasonable dosages, at least—cause a slight increase in the pH of the humus layer. A slight decrease can be detected in the upper part of the B-horizon. The supply of exchangeable base cations is unchanged when AN or urea is used, but it increases noticeably when Ca-AN is used. The total acidity in the soil profile (i.e. proton (H^+) content) increases after N fertilization, regardless of the fertilizer mix. The main reason for this is the build-up of the humus layer. The amount of K and P available to plants decreases after repeated N fertilization

Effects on surfacewater

Chemical changes can often be observed in streams after N fertilization. These changes cover the both the acid/base status of the water (pH, alkalinity, and aluminum and base cation concentrations) and the inorganic N concentration. The magnitude and duration of changes to the surfacewater depends on the N-fertilizer mix, fertilizer free zones, the proportion of the groundwater discharge area that has been fertilized, and the site properties. The N dosage most likely also has an effect, but these questions have not been subject to any detailed investigation.

Fertilization with AN often results in acidification of the stream water. Investigations have revealed decreases in both pH and alkalinity. The decrease in pH usually has a duration of a few months, whereas the decrease in alkalinity can last for two or three years. The size of the decrease in alkalinity could be related to the pH in deeper horizons of the soil. An increase in the Al concentration was observed in a few investigations, and elevated concentrations of Mg and Ca generally also occur after fertilization with AN.

Fertilization with Ca-AN usually results in less acidic stream water. A pH increase of 1 to 2 units at most has been reported but no decrease in the pH has been observed. The Al concentrations have remained constant, whereas concentrations of Ca and Mg have increased. The changes that have been recorded have usually had a duration of a few months, but longer effects lasting up to a year after fertilization have been found.

Urea, in common with Ca-AN, has a less acidic effect on stream water; close to the fertilized area, the pH of the stream water can increase by one unit. Urea fertilization also increases the concentration of Ca and Mg in the water.

Fertilizer falling straight into a stream causes an immediate high concentration of inorganic N, concentrations of up to 100 mg/liter having been observed when AN or Ca-AN mixes have been used. Urea mixes, on the other hand, result in a far lower concentration of inorganic N. Elevated concentrations are usually recorded in runoff up to a few years after fertilization, regardless of the fertilizer mix used. Normally, less than 5% of the N added to the soil leaches into streams flowing through the treated site. In contrast, when fertilizer-free zones are left along the banks, a much reduced quantity of N leaches into the stream.

One recently detected side effect of N fertilization was a rapid increase in the concentration of Cd in the soil solution after fertilization (Eva Ring, pers. comm.). The increased solubility of Cd was caused by a transitory decrease in the pH of the soil solution. Further investigations in two catchment areas revealed the same effect on the soil solution: a rapid increase in the concentration of Cd in the soil solution but no elevated concentrations in the runoff (Högbom et al., 2001).

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Nutrient management concepts and practices in southern pine plantations

H.L. Allen, D.L. Kelting, and T.J. Albaugh[1]

Abstract

Current growth rates in pine plantations of 8 to 10 m^3/ha/year are well below what is possible in the southern United States. Growth rates exceeding 25 m^3/ha/year are biologically possible and financially attractive for a broad range of site types in the region. Improving stand nutrient supply through fertilization is one of the most attractive options to increase productivity, as nutrient limitations are very widespread. The area of southern pine plantations receiving fertilizer applications has increased dramatically. In 1990, fewer than 80,000 hectares were fertilized; however, in 1999, over 650,000 hectares were fertilized. The benefits of early phosphorus (P) fertilization on the poorly drained P-deficient flats have long been recognized. More recently, large areas of well-drained sites have also been identified as P-deficient. Growth gains averaging 3 to 4 m^3/ha/year are possible on severely P-deficient sites. The large increase in area fertilized has been due to increases in fertilization of intermediate-aged stands. Typically, a prescription of 225 kg/ha of nitrogen (N) plus 25 kg/ha of P is used. Growth gains averaging 30% (4 m^3/ha/year) over a six-year period are typical. Key challenges include: assessing nutrient limitations that are constantly changing, identifying sites where nutrients other than N and P will limit growth under intensive culture, and developing appropriate dosage-frequency prescriptions.

KEYWORDS: Productivity, Fertilization, Nitrogen, Phosphorus

Introduction

The southeastern United States produces more industrial roundwood than any other region of the world from a forest base that includes almost one-half of the world's industrial forest plantations (World Resources Institute 1996). Over the next few years, softwood harvests are expected to continue to increase; however, the land base used for wood production is expected to shrink because of population pressures and the lack of management by non-industrial private landowners. Even today, softwood removals exceed growth rates in many areas (Cubbage et al. 1995). Because of the scarcity of wood, stumpage prices have escalated to the point where they are high, relative to the world market, and are substantially higher than actual production costs.

Historically, forest landowners (both industrial and non-industrial) have focused on minimizing per hectare costs associated with plantation establishment and tending. This approach has resulted in millions of planted hectares with growth rates averaging less than 8 to 10 m^3/ha/year (~5 green tons/ha/year). These growth rates are substantially lower than many other forest plantations in the world. Fortunately, theoretical models (Sampson and Allen 1999, Landsberg et al. 2001), empirical field trials (Allen and Lein 1998, Martin et al. 1999, Amateis et al. 2000, Jokela et al. 2000,) and more recently, operational forestry experience show that these growth rates are well below what is possible in the southern United States. With investment in appropriate management systems, growth rates exceeding 25 m^3/ha/year (~12 green tons/ha/year) are biologically possible and financially attractive for a broad range of site types in the region. While per hectare costs increase with intensive plantation culture, the resultant increases in per hectare production rates coupled with the reduction in area needed to grow a given amount of wood, can substantially reduce production costs per ton (Allen 2001).

Concepts

What are the limitations to pine production in the southeast U.S.? It is clear that leaf area levels are so low in many stands that the capture of light is restricted resulting in poor productivity (Vose and Allen 1987, Albaugh et al. 1998, Jokela and Martin 2000). In addition, growth efficiency, the production of stemwood per unit of leaf area, is also less than optimum. Historically, water availability, whether too little or too much, was considered the principal resource

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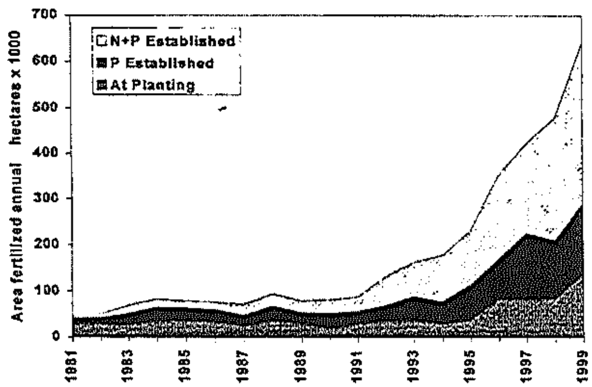


Figure 1. Area of southern pine plantations annually fertilized in the southeastern United States.

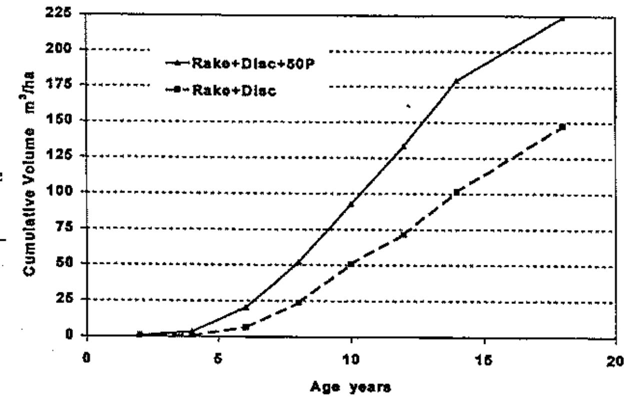
limiting pine productivity in the South. While this may be true for very young stands, our research has shown that soil nutrient limitations rather than light or water limitations restrict leaf area development, growth efficiency, and consequently, stand production (Albaugh et al. 1998, Sampson and Allen 1999). The good news is that nutrient limitations are much easier and less costly to ameliorate than water limitations. The key to optimizing leaf area and growth efficiency is to use the very best genetic material available and to provide the resources needed to allow the tree's genetic potential to be realized (McKeand et al. 1997). Forest managers are finally recognizing that intensive plantation silviculture is like agronomy; both the plant and the soil need to be actively managed to optimize production. Fortunately, financially attractive options exist to increase production through the management of both genetic and site resources. Improving stand nutrient supply through fertilization is one of the most attractive options as nutrient limitations are very widespread.

Why are nutrient limitations so common? Simply, nutrient limitations develop when a stand's potential nutrient use cannot be met by soil nutrient supply. Consideration of a stand's potential nutrient use and nutrient supply indicates a large disparity between nutrient needs and supply in southern pine stands (Allen et al. 1990). Typically, nutrient availability is rather high following harvesting and site preparation as these disturbances provide suitable conditions for rapid decomposition and release of nutrients from the accumulated forest floor and slash material. Use of nutrients by crop trees is minimal owing to their small size, low leaf area, and lack of site occupancy. However, as leaf area development and stand growth accelerates, use of nutrients increases rapidly. At the same time, the supply of readily available nutrients is being rapidly sequestered within the accumulating forest floor and tree biomass. Furthermore, as the canopy closes, the environmental conditions conducive to high nutrient availability are no longer present (Piatek and Allen 1999, 2001). Consequently, a stand's nutrient requirement for maximum growth generally outstrips soil supply (particularly for N) around time of canopy closure. As nutrient supply diminishes, leaf area production and, in turn, growth become regulated (and limited) by the available nutrient pool. It is not surprising then, that the majority of field trials in intermediate-aged southern pine stands (~8 to 20 years old) have shown strong responses to additions of N and P (Martin et al. 1999, Amateis et al. 2000). In young stands, the development of nutrient limitations is still possible when levels of available nutrients (particularly P) in the soil are low and the soil volume exploited by roots is small. In addition, as other silvicultural treatments (e.g., vegetation control and/or tillage) are used to improve water availability, crop tree growth and use of nutrients will be increased at young ages. Fertilization will then be needed to sustain rapid growth on all but the most fertile sites.

Fertilization practices

Management of pine plantations in the southeastern United States is undergoing revolutionary change. Intensive silvicultural regimes are now being implemented that include deployment of genetically improved planting stock, tillage, herbaceous and woody vegetation control, and multiple fertilizer applications (Allen 2001). The area being fertilized annually is indicative of this change. In 1990, fewer than 80,000 hectares of pine plantations were fertilized; however, in 1999, over 650,000 hectares were

Figure 2. Volume growth with and without P application at time of planting on a well drained loamy soil.



fertilized (Figure 1), a fraction of the over 12 million hectares of pine plantations.

The benefits of early P fertilization on the poorly drained P-deficient flats of the lower coastal plain have long been recognized. Volume growth gains averaging 3 to 4 m^3/ha/year (sometimes >100%) are possible on severely P-deficient sites. Because the duration of response to a single application of 40 kg/ha P may last for 20 or more years (Pritchett and Comerford 1982), P fertilization on deficient sites is viewed as an improvement in site quality. Site index gains (25-year base) of 2 to 4 meters or more are typical when P is applied at or near time of planting (Gent et al. 1986). More recently, large areas of well-drained sites on the upper Gulf Coastal plain have also been identified as P-deficient (Figure 2: Allen 1990, Allen and Lein 1998). Unlike the well-drained sites on the Atlantic coastal plain, many Gulf coastal plain sites have never been in row crops and, consequently, have not been fertilized.

Identification of stands in need of early fertilization has been based on landscape/soil type, soil and foliar tests, and experience (Jokela et al. 1991). The critical value for soil P below which a fertilizer response is expected is 6 mg/kg (Mehlich-3 extraction procedure). Critical values for foliar P concentrations vary by species and range from 0.09% for slash pine and 0.11% for loblolly pine (Allen 1987, Jokela et al. 1991). The sources of fertilizer P that are typically used include diammonium phosphate (DAP), triple superphosphate (TSP), and rock phosphate. DAP is now the most widely used source for fertilization at time of planting (NCSFNC 2000). Rates of application vary from 25 to 50 kg/ha of elemental P (125 to 250 kg/ha of DAP). In 1999, almost 140,000 hectares received fertilizer at or near time of planting (Figure 1).

By age 5 or 6, a plantation's potential to use N and P typically outstrips the available soil supply resulting in restricted leaf area development and growth (Allen et al. 1990). By time of canopy closure, stands are generally very responsive to additions of N or N+P rather than P alone, as long as gross P deficiencies were ameliorated at or soon after planting. Volume growth responses vary depending on stand/site attributes and the rates of N and/or P applied. Recent results from an extensive series of intermediate-aged fertilizer trials in loblolly pine stands indicate that over 85 percent of the stands fertilized were responsive to additions of N+P. Growth gains averaging 30% (4 m^3/ha/year) over a six-year period following a one-time application of 225 kg/ha N and 25 kg/ha P are typical (Figure 3). Responses of over 8 m^3/ha/year were observed at some sites. For the majority of stands, both N and P were deficient with responses to additions of N+P much greater than the additive effects of the two elements applied alone (i.e., N and P additions were synergistic).

In intermediate-aged stands, little response is typically observed to additions of P alone except on very P-deficient sites as indicated by low foliar P concentrations and very low leaf areas. Applications of ~200 kg/ha of DAP (labeled catch-up P in Figure 1) are typically used as the remedial treatment in these stands. Additions of N alone can actually be detrimental to growth on these severely P-deficient sites.

The large increase in area fertilized has been due primarily to the dramatic increase in fertilization of intermediate-aged

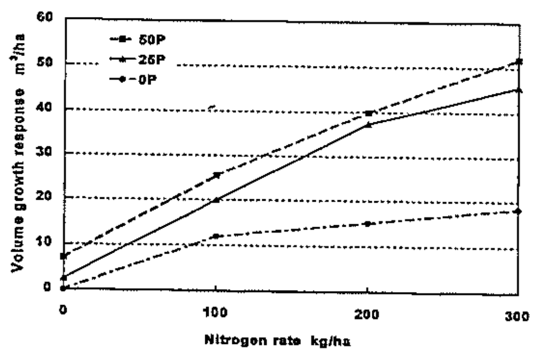


Figure 3. Volume growth response to N and/or P additions in intermediate-aged loblolly pine plantations.

stands (Figure 1). On most sites, a generic prescription of 225 kg/ha of N plus 25 kg/ha of P is used. Typically, this treatment is applied as a split application of DAP and urea to provide the additional N required to reach the desired N rate. Although most intermediate-aged stands will be biologically responsive to N+P fertilization, financial returns are strongly dependent on fertilizer cost, the product mix, and stumpage price that can be realized for the additional wood produced. Application of 225 kg/ha N plus 25 kg/ha P presently costs about US$190 per hectare. At this price, fertilization is a very attractive investment with internal rates of return exceeding 15% or more. Until recently, fertilization has been delayed until after the first or second thinning to maximize returns on investment. This is now changing as the need for nutrients earlier in a plantation's life is recognized and increasing wood values have made even early fertilization a very attractive financial investment.

The diagnostic techniques for identifying intermediate-aged stands that will be biologically responsive to fertilization have undergone substantial revision. In the past, stand attributes (e.g., basal area and site index), soil/landscape type, foliar concentrations, and experience were used together to identify responsive stands and prescribe the appropriate elements and rates to apply. Unfortunately, the ability to predict the responsiveness of an individual stand was limited. This situation has now changed with the application of recent research that quantified the linkages among stand productivity, leaf area, and nutrient availability (e.g., Albaugh et al. 1998). Differences between a stand's current leaf area and its potential leaf area are now being used to estimate responsiveness to nutrient additions. Quite simply, leaf area of a fully stocked stand (basal area >20 m²/ha) should be 3.5 or greater; otherwise, the stand is probably in need of N+P. The probability and magnitude of response will be greater at lower leaf areas.

Integrated silvicultural systems

Much effort is now underway to understand the interactions among the numerous silvicultural treatment options (McKeand et al. 1997, Allen and Lein 1998, Jokela et al. 2000). For example, the ability to acquire and utilize nutrients differs among species and among genotypes, with slash pine having lower nutrient use than loblolly pine. Consequently, loblolly pine is typically more responsive to intensive culture than slash pine. Where two silvicultural treatments affect nutrient availability and/or the allocation of nutrients to the crop trees in a similar manner, less than additive effects may be observed. For example, where both intensive vegetation control and fertilization result in greater nutrient supply, a less than additive response has been observed with slash pine on wet sandy sites. In contrast, the growth response to hardwood control and fertilization in loblolly pine stands on upland sites is typically more than additive. Without control, hardwoods also respond to fertilizer resulting in increased competition for light and water resources with pine crop trees.

Future challenges

The growth potential of southern pines planted in their native environment is very high, much higher than commonly thought just a few years ago. In the last five years, our expectations have increased dramatically. Our challenge now is to develop and implement the appropriate silvicultural systems to realize this potential in a cost-effective and environmental sustainable way. Key challenges from a nutrient management stand point include: assessing nutrient limitations that are constantly changing, identifying sites where nutrients other than N and P are limiting growth, developing the appropriate dosage-frequency prescriptions to ameliorate these limitations, understanding the impacts of intensively managed plantations within a landscape context, developing people capable of making site-specific prescriptions, and securing the capital sufficient to implement those prescriptions. The close linkages among the applied research, fundamental research, and continuing education efforts at North Carolina State University provide an excellent environment for addressing pertinent research questions and immediately incorporating research results into management strategies. These close linkages are the hallmark of our cooperative program, and coupled with our extensive field trial base, position us to continue a leadership role in developing integrated silvicultural systems approaches for plantation management.

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The potential for forest fertilization in eastern Canada

Ian K. Morrison[1]

Abstract

During the 1960s and 1970s, interest arose in eastern Canada in fertilizing semi-mature conifer stands as a means of addressing anticipated wood supply problems facing forest industry. Field trial-based research demonstrated gains, which could be expected mainly with jack pine, from fertilizer application. Responses were primarily to N, with applications of ca. 224 kg N/ha, mainly as urea, producing as much as 24 m3/ha of extra wood after 10 years. For various reasons, mainly financial, interest waned and fertilization never became operational. Now, faced with a diminishing land base available for timber management, yet no change in raw material requirement, foresters are considering new, more-intensive forestry practices to maintain or even increase current annual allowable cut levels. It is within a forest regulation or timber flow context that fertilization might be considered as an option to increase wood volumes in deficit age classes. A best fit occurs where mill capacity is available, markets exist, but output is constrained by lack of allowable cut.

Introduction

Starting about the mid-1950s, interest arose in various parts of the forestry world in using mineral fertilizers to increase timber production, i.e., to grow wood on already-existing stems (White and Leaf 1957, Mustanoja and Leaf 1965). Interest spread to Canada by the early 1960s (Armson 1967). There was substantial investment in research on the part of industry, led by Pulp and Paper Research Institute of Canada (PAPRICAN), and involving a number of forest companies. As well, there was activity by both federal and provincial governments. The Interprovincial Forest Fertilization Program (Anon. 1973) involved all provinces from Alberta to Nova Scotia. The Canadian Forest Service (CFS), as well as having its own programs (Hegyi 1974; Foster and Morrison 1983, Morrison and Foster 1990, 1995, Morrison et al. 1995), eventually assumed the PAPRICAN's role in the industry trials (Foster et al, 1986; Morrison, 1991; Morrison et al. 1976, 1977, 1981). Despite this, fertilization didn't become an operational reality in eastern Canada, as it did in other countries, or as it did in British Columbia.

Focus was on fertilizing semi-mature stands, mainly for pulpwood production, but also for other products, five or ten years prior to final harvest. The reason for the five- to ten-year time frame was to contain charges on investment. Preoccupation with carrying charges was, perhaps, one of the factors that led to decline in enthusiasm. That is not to imply that interest shouldn't be factored in. Rather, it was misunderstood by some as a straightforward alternative rate-of-return comparison. With soaring interest rates in the early 1970s, the whole concept of pulpwood fertilization was essentially dropped as uneconomical. The economics of fertilization, however, extend beyond simple return-on-investment.

In a well-regulated forest, the volume/age class distribution should result in a sustained and uniform flow of timber over time. If, for whatever reason, there were deficit age classes (perhaps extensive fires, or over-harvest in the past), volumes of those age classes might come up short at rotation time. It's within this forest regulation or timber flow context that fertilization might be considered as an option, i.e., a means of increasing volumes in deficit age classes near rotation time, or increasing tree sizes in the class following. Fertilization, however, is not the only option. An alternative might be to accelerate the regeneration phase, thus shortening rotations, giving additional annual allowable cut (AAC). But, if the need is not only for more volume, but also for stems of harvestable size, the number of alternatives decreases. Substitution, either with other species or with purchased wood, however, is still an option. There are benefits and costs to this as well. A second reason that fertilization didn't make the jump from research to practice in eastern Canada was timing. Interest in fertilization coincided with the environmental awakening of the 1960s and 1970s. Instead of coming down on the side of "plant food," fertilizers, in some minds, were lumped-in with "artificial chemicals." Another timing-related factor was the OPEC oil embargo of 1973. Fertilization was still a popular notion up till the embargo and increases in the price of synthetic urea.

The profitability of fertilization depends on a number of factors. First, it depends on response in relation to treatment and how reliable that response is. Also, it depends on the price of fertilizer and the cost of application. It depends very much on stakeholder perspective and how much the additional wood is wanted. Government forest departments garnering only stumpage might see fertilization one way. A firm with unused mill capacity and potential markets, but limited by shortage of AAC, might see it quite differently. It depends, as noted above, on other alternatives available, and finally, on financial accounting systems used, and how benefits and costs are apportioned.

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Response to fertilizers

The following account draws from three main sources. One is the Interprovincial Forest Fertilization Program. This was a uniform-design trial at a large number of locations from Alberta to Nova Scotia and carried out between the late 1960s and early 1980s (Weetman et al., 1987). The major source, however, is a large number of field trials conducted by the CFS in northern Ontario, mainly in semi-mature jack pine (*Pinus banksiana* Lamb.) stands (Morrison and Foster, 1990), with some in black spruce (*Picea mariana* (Mill.) B.S.P.) (Morrison *et al.* 1995). The third source involves trials initiated by the PAPRICAN in collaboration with various forest companies. The CFS assumed responsibility for a number of these when the PAPRICAN exited the silviculture field around 1970.

Operationally, in natural forest, fertilizers would be delivered from the air, either by helicopter of fixed-wing aircraft. Most research, however, was based on hand-fertilized ground plots. The standard of measurement is increase of gross (as opposed to net) periodic increment, expressed as m3/ha of "extra wood" produced in response to treatment. A second consideration, however, is diameter growth, i.e., mean final diameters of fertilized compared with unfertilized stands. Additional volume results from increases in breast-height diameter, increases in height, and possible changes in form, either greater diameters at the stem mid-point or at a point just under the live crown. Groot et al. 1984 noted a positive, though subtle, improvement of form in jack pine trees when fertilized with nitrogen (N) as urea, suggesting slightly greater volumes than hitherto had been estimated. On the other hand, fertilizer-grown wood may not be as dense as natural wood. Scott et al. 1982 reported a 6% reduction of average density of jack pine wood laid down during the first five years following urea fertilization. If the tree is destined for pulping, lower densities mean less pulp. If, on the other hand, the tree is destined for a volume-defined commodity, such as lumber, it may not matter, unless overall strength properties are affected. Only occasionally was form quotient or wood density factored into field trials due to difficulty of measurement.

Both stand-related and treatment-related factors affect response. Stand-related factors include species, site and age. Stand age, of course, was prescribed, in that the program focused semi-mature stands. Treatment-related factors include fertilizer, rate of application, when during the year, and weather conditions at, before or just after the time of application.

Species. The most comprehensive series of trials addressing species differences in response was that of the Interprovincial Forest Fertilization Program. Table 1 summarizes average ten-year total volume responses by species (or, in one case, a species mix) to nomi be focused on the best sites. With fertilization, the opposite may be true. Best responses, both in relative and absolute terms, seemed to be associated with lower site class sites.

Table 1. Ten-year mean total growth-over-control of species fertilized with 112 and 224 kg N/ha as urea in Interprovincial Forest Fertilization Program (summarized from Weetman et al. 1987).

Species	Installations	Ten-year growth-over-control 112 kg N/ha	224 kg N/ha
		m³/ha	
Jack Pine	29	6.2	10.5
Jack Pine – Black Spruce	7	10.0	16.1
Black Spruce	20	4.7	4.5
White Spruce	4	4.4	12.2
Red Spruce	3	5.5	7.2
Balsam Fir	9	4.3	6.6

Rate of Application. Figure 1 relates to a trial in a 55-year-old stand in northwestern Ontario. The best response was to N at 224 kg/ha, in this case, as urea. Similar results were observed in experiments elsewhere. Operational fertilization is frequently uneven. Armson (1972) reported that of 112 kg N/ha applied as urea by fixed-wing aircraft to a jack pine stand in northeastern Ontario, only roughly one third fell within +/- 25% of the prescribed rate with some patches receiving less than 20%, others almost twice the prescribed rate. It's been suggested that, since operational applications are to some degree uneven, with some patches receiving more, some less than average, somewhat under the maximum should be applied since, on areas receiving more than the average, fertilizer would be wasted. This is probably a level of sophistication beyond the science.

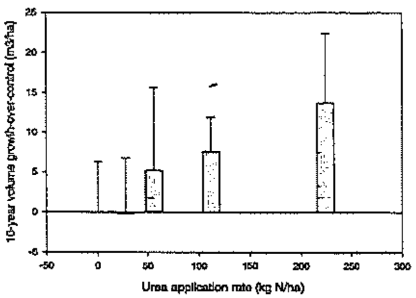

Figure 1. Ten-year total volume growth-over-control of 55-year-old jack pine forest in northwestern Ontario to different levels of nitrogen as urea (adapted from Morrison and Foster, 1990).

Different Nitrogen Carriers. In one experiment, four nitrogen fertilizers: urea, ammonium nitrate, ammonium sulphate, and urea-formaldehyde were compared. Basically, when N was held constant (at 90 and 224 kg N/ha), there was no significant difference in response (Table 2). As urea contains 46% nitrogen and ammonium nitrate, 33%, less urea would be needed for equivalent applications of N, which would lower the application cost. At present, bulk prices for urea and ammonium nitrate are about the same, so urea would be the less-expensive treatment. Availability, however, might be a factor.

Table 2. Ten-year mean DBH and total volume growth-over-control of 55-year-old jack pine forest in northwestern Ontario fertilized with different N-fertilizers (adapted from Morrison and Foster, 1990).

Fertilizer	Triplesuperphosphate Rate *kg N / ha*	DBH Inc. *cm*	Tot Vol. Inc. *m³ / ha*
Urea	90	0.32	15.9
Urea formaldehyde	90	0.13	14.2
Ammonium nitrate	90	0.30	18.2
Ammonium sulphate	90	0.35	19.0
Urea	224	0.40	24.6
Urea formaldehyde	224	0.27	20.3
Ammonium nitrate	224	0.45	24.5
Ammonium sulphate	224	0.40	14.2

Elements Other Than Nitrogen. Nitrogen was the element the lack of which was found to be most limiting to tree growth in the eastern boreal forest. Responses to other elements such as phosphorus (P) or potassium (K) were observed, but usually only when N demand was first satisfied. One exception concerned a wet-site black spruce forest where there was a suggestion of possible P-limitation (Morrison et al. 1976). The Interprovincial program featured five treatments in addition to control: N at 112 and 224 kg/ha; N at 224 kg/ha with P at 112 kg/ha, with K at 112 kg/ha or with both. While there was additional growth to P and/or K in some instances, results were sporadic (Weetman et al. 1987). Table 3 presents results from a typical N x P x K factorial experiment in jack pine. Analysis of variance (not shown) indicated that the result was almost entirely to N, with nothing either to P or K, or their interaction. A somewhat similar result was noted in a nearby N x P x Mg (magnesium) trial, though there was some indication in this instance of interaction between N and P (Morrison and Foster 1995).

Table 3. Ten-year total volume growth-over-control of 55-year-old jack pine forest fertilized with combinations of urea, triplesuperphoshate and muriate of potash.

Urea *kg N/ha*	Muriate of Potash *kg K/ha*	*0 kg P/ha*	*22 kg P/ha*	*45 kg P/ha*	*90 kg P/ha*
0	0	0.0	-7.4	6.7	-2.0
	8	1.7	6.1	10.1	1.4
	117	0.7	8.7	0.7	1.0
	175	5.4	7.8	7.7	1.3
151	0	7.1	18.5	10.8	16.4
	58	7.9	9.3	21.0	20.0
	117	16.8	25.0	10.8	18.2
	175	13.4	16.3	11.7	2.9

Fertilization Combined with Other Treatments. The other obvious mid-or late-rotation intervention is thinning. Two large thinning-fertilizing experiments were conducted in jack pine forests, and both produced similar results (Morrison and Foster 1990). In each case low thinning or "thinning from below" was used. Table 4 illustrates results from a N x P x thinning experiment in northwestern Ontario. Both fertilization and thinning promoted growth. In the case of thinning, individual tree diameter growth was better, but so was volume growth response expressed as a percent of residual basal area. Fertilization with N produced a strong response and, while there was no response to P alone, there was a significant N x P interaction. Interestingly, however, there was *no* interaction between fertilization and thinning. It had been anticipated that the two might interact positively—that thinning would facilitate crown growth—that trees with larger crowns would utilize fertilizer more effectively. That's not what was found, either here or in a similar experiment elsewhere. Basically, the results were additive. Presumably then, there would be no advantage in applying the treatments simultaneously, other than if they happened to coincide during normal operations. Perhaps delaying fertilization until the crowns had expanded might have been beneficial.

Table 4. Ten-year mean DBH and total volume growth-over-control of 55-year-old jack pine forest subjected to combinations of low thinning (T at 0, 20, and 40% BA removal), urea (151 and 303 kg N/ha) and triplesuperphosphate (45 kg P/ha).

Treatment	Mean DBH Inc. *cm*	Tot. Vol. Inc. *m³ / ha*
P 45	0.13	8.1
N 151	0.27	12.4
N 151 P45	0.30	11.4
N303	0.45	17.7
N 303 P45	0.32	11.0
T20	0.64	3.5
T20 P45	0.45	4.7
T20 N151	0.80	5.0
T20 N151 P45	0.80	7.1
T20 N303	1.77	15.8
T20 N303 P45	1.03	13.8
T40	0.71	-11.0
T40 P45	1.10	-5.0
T40 N151	1.40	-1.8
T40 N151 P45	1.43	0.4
T40 N303	1.63	9.7
T40 N303 P45	1.32	4.1

Timing of Fertilizer Application. Time of year is another variable. Spring applications were generally advocated for financial reasons. If fertilizer wasn't applied until fall, interest charges would have to be carried for an additional half-year. Is there a biological advantage? An autumn application presumably could have fertilizer in place so trees could take advantage of it when growth began the following spring. Results of a time-of-year trial again with jack pine are given in Table 5. The results were variable. There was some indication of better response to earlier as opposed to later applications; however, significant difference was confined to the May-September comparison at the lower application rate only. While the fall application meant that those plots had only nine of ten years to respond, differences should have established themselves by that point.

Table 5. Ten-year mean DBH and total volume growth-over-control of 55-year-old jack pine forest in northwestern Ontario to urea fertilizer (84 and 252 kg N/ha) at different times during the first growing season.

Month	Rate *kg N/ ha*	Mean DBH Inc. *cm*	Tot Vol. Inc. *m³ / ha*
May	84	0.15	7.5
	252	0.54	15.3
July	84	0.11	4.6
	252	0.28	7.8
September	84	0.11	0.8
	252	0.35	12.3

Also, on the subject of timing, one experiment was conducted with split doses, either all in the first spring, or the same amount, but half in the first, half in the second, or half in the first, half in the third, or split evenly among three years. It was hypothesized that trees would be better positioned to compete for later-applied nitrogen if they were first beefed up by a preliminary dose. Basically, however, there was no difference. While fertilizer costs would be the same and even direct application costs mightn't be much greater; ground control costs would probably militate against this approach.

Weather Conditions at Time of Application. Weather conditions at the time of application are also a consideration. It is well known that when fertilizers are applied, target organisms will capture some, but much will be immobilized in the soil. With urea, there's an additional problem: some will be converted to gaseous ammonia (NH_3) and lost into the atmosphere. A study was conducted to determine the fate of urea fertilizer applied to a jack pine ecosystem (Morrison and Foster 1977). It was estimated (ibid.) that, of 300 kg N/ha applied, the trees captured only 23%, with a further 1% captured by other vegetation. By the end of three years, 45% could still be found in the soil. Significantly, nearly 30% was estimated to have been lost to the atmosphere. This particular study was conducted just prior to a period of hot, dry weather, which is ideal for volatilization.

If hot dry weather is conducive to volatilization, what about cool wet weather? Among the industry trials established originally by the PAPRICAN, was one in jack pine forest in northwestern Ontario in which was observed a very good response to a NK fertilizer treatment, nearly 22 m³/ha of extra wood after ten years (Morrison et al. 1981). The treatment involved a fall application, and it had so happened that it had snowed 1–2 cm the night before application day. The application went ahead. The snow soon melted. Likely the melting snow resulted in a beneficial in-washing of fertilizer. Further, there was probably very little or no loss into the atmosphere. Unfortunately, it is not always possible to reproduce such situations. However, if possible, efforts should be made to time applications to coincide with periods of cool wet, as opposed to hot dry, weather. Other ways of addressing the urea volatilization problem include sulphur (S)- and plastic-coated urea prills. Foster and Beauchamp (1986) estimated NH_3 loss from S-urea as only 17% of that from regular urea, attributing the result to slower release resulting in lower initial pH increases in the forest floor. Sulphur- or plastic-coated urea, or urea with borax is more expensive, but might be considered.

Fertilizer Placement. A final aspect involves fertilizer placement. Aerial application is a straightforward surface broadcast. In agriculture, however, fertilizers are often ploughed in. In one experiment, a broadcast application was compared with applications similar in per area amount, either turned under in a furrow or buried in evenly-spaced holes While, with plantations, it might be possible to develop ground equipment to accomplish this, in natural stands furrow-placement or hole-placement might be impractical. No difference of response due to placement method was found in the experiment, however, suggesting that simple surface broadcast is adequate. Prill size should be considered, however. With some species, crown lodging has been a problem with aerial application. For forestry applications, heavier prills have been produced to alleviate this problem.

Environmental considerations

Environmental concerns centre mainly on contamination of water. Urea fertilizer, upon dissolution, produces two ammonium (NH_4^+)-ions. As above, trees will absorb some, some will be immobilized in soil and some may dissipate into the atmosphere. Organic-rich soils have high *cation* exchange capacities, which restrict mobility of NH_4^+, thus minimizing downward movement and opportunities for groundwater contamination. On the other hand, many soils tend to have low *anion* exchange capacities; hence nitrate (NO_3^-) ions are rendered more mobile and susceptible to leaching. Thus, there is greater risk of contamination with ammonium nitrate or other nitrate fertilizers than with urea. If the dose is low, however, the risk is contained. Probably the greatest danger involving aerial application is associated with over-flying watercourses and inadvertent direct application. Good ground control is essential. Over-flying errors are less a risk with jack pine than with some other species, since jack pine frequently occurs on sandy soils with low stream density. It could be more problematical with species that frequent wetter sites.

Financial considerations

Straight cost/benefit factors to consider would be response in terms of extra volume per fertilizer applied, price of fertilizer and cost of application. Equally as important, however, is how much the extra wood is needed, and what other alternatives are available. These are very much a function of who you are and where you are.

The price of urea fertilizer in bulk has recently been quoted at about $500 Cdn per tonne. Application costs are estimated at about 40 cents (Cdn) per kg. At that rate, a nominal application of 224 kg/ha of N as urea would cost about $438. If a real interest rate of 5% is assumed, the treatment by the end of ten years with compound interest would have cost $714. If, with jack pine, 15 m³/ha of extra wood were produced, each extra m³ metre would have cost about $48. A government forest department selling stumpage at anything *less* than that would lose money, though the government at large might capture some benefit *indirectly* in the form of tax revenue.

A private firm, however, could benefit from lower harvesting cost. Per volume, large trees are cheaper to harvest than small trees, regardless of harvesting practice or utilization standard. Gingras (1988) estimated that, in eastern Canada, for every 1-cm increase in stand mean DBH, harvesting cost would decrease by 10%. Assuming a final stand volume of 200 m³/ha and an average actual logging cost (not including stumpage or transport cost) of $25/m³, a stand mean DBH increase of 0.40 cm would result in a nearly-$200/ha saving to the firm. In itself, however, this is still short of the $714 total cost of treatment.

Consider, however, a private firm whose mill production is constrained by lack of allowable cut, yet with unused capacity and potential markets. First, they would, as above, capture benefit in terms harvesting cost reduction. More importantly, the *value* of additional wood to a firm *short* of allowable cut is different than to government or to a firm unconstrained by wood supply. Tucker (1974) invoked the notion of *conversion surplus* as a means of determining the value of extra wood. Conversion surplus is the difference between selling price and variable costs, and is used to pay fixed costs, with anything left

over being profit. A mill to survive must, in its product pricing, *at least* cover its production costs. Variable costs for paper manufacture would include wood cost, comprised of stumpage, logging and transport, plus mill costs. Fixed costs, on the other hand, might include amortization on the mill, front office costs, and so on. If a mill's production were limited by wood supply, and additional AAC could not be arranged, *all* variable *and* fixed costs would have to be projected onto the selling price of product produced from the current wood supply.

In terms of paper manufacture, jack pine in eastern Canada goes mainly into market pulp. The current selling price of Northern Bleached Softwood Kraft is about $975 CAD (or *ca.* $650 USF) per air-dry metric tonne. While costs vary from mill-to-mill, average total cost per tonne industry-wide is about $825 CAD, made up of $638 in variable costs, and $187 in fixed costs. Further, it takes just under of 6 m³ of roundwood to produce 1 tonne of Kraft pulp. Pro-rating onto a m³, the variable cost of manufacture, then, would be about $115, the fixed cost, $34. Given the current selling price of Kraft pulp, conversion surplus per m³ would be about $61.

Any *additional* furnish, then, would only have to bear *variable* costs (fixed costs having *already* been projected onto the original wood supply). This makes available the equivalent of up to *just under* the full value of the conversion surplus, $61/m³, for *anything* that procures additional furnish, fertilization included. It would be available to purchase wood or for use within the mill for more-efficient processes (which produce more pulp per unit of roundwood).

An evaluation of two actual treatments, one of average response, the other a very good response, is given in Table 6. The cost of treatment, assuming 224 kg N/ha and using current quotes carried for ten years, is $714. Benefits are realized at the end. In both cases, there were reasonable savings in terms of logging cost. Assuming additional furnish is worth *at least* the fixed cost component of the conversion surplus, $34, the more-average response results in a negative future value, the better response in a substantial future profit. If some of the profit component of the conversion surplus was foregone (some profit is better than no profit), the first response might be considered profitable as well. However, it would be unwise, given the variation of selling price, anywhere from $450 to nearly $900 USF for bleached Kraft over the last ten years, to expend the *full* amount of the conversion surplus on *anything*. However, the fixed cost component might be considered.

The foregoing, which used average figures, is intended as a framework for evaluating fertilization as a tool, rather than as a definitive statement on fertilization profitability. Obviously, if more volume could be obtained for the same amount of fertilizer or the same volume for less, or if the price of fertilizer or application decreased, or even if improvements were made in the mill, fertilization could be made *more* profitable. Other factors, such as wood on easy ground for harvesting or trees closer to the mill, also affect wood value.

Table 6. Net future value ($ Cdn) of 10-year responses to 224 kg N/ha as urea from actual trials in jack pine forest in northwestern Ontario.

Extra Wood	Final Volume	Mean DBH Increment	Treatment Cost	Logging Cost Saving	Extra Wood Value	Net Future Value
m³/ha	m³/ha	cm	$/ha	$/ha	$/ha	$/ha
13.8	207.7	0.34	714	177	466	-71
24.5	191.4	0.40	714	191	827	304

Summary and future directions

In summary, jack pine responds consistently and well, other species, less well. A good nominal dose might be 200 kg N/ha. Reponses seem generally better on poorer sites. There were minor responses to other elements, but only in combination with N. In terms of response, N form is not significant which suggests that overall cost of application will be the determining factor. Currently, urea is the cheaper fertilizer to apply per weight of N. Spring is likely the best period for application, though there wasn't conclusive evidence in support. Splitting applications didn't result in any advantage. To minimize volatilization loss with urea, time, if possible, applications to coincide with periods of wetter, cooler weather. Alternatively, sulphur- or plastic-coated urea prills, or urea with borax might be considered.

In short, there is a substantial body of results that suggests that under the right circumstances fertilization could be profitable in eastern Canada, at least with jack pine. In fact, greater and more-reliable responses can be expected to follow from more-careful stand selection, better timing and better technique. Extensive plantations, which started in 1960s, will be coming on line soon. These can be expected to be faster growing, hence more nutrient demanding. Before embarking on operational fertilization, however, it would be wise consider a new generation of field trials, aimed more at producing calibrating data than hypothesis-testing. Such trials could be much simpler than heretofore. For jack pine, it has been amply demonstrated that N is the main element to which response can be expected. Such trials, then, might utilize a very simple core design—perhaps 3 levels of N, probably as urea: *viz.*, control, 100, 200 kg N/ha—but should be well replicated so that managers could have confidence in growth-over-control projections. They should likewise be well distributed among various stand types on various sites. If defici-ncies of some other elements were suspected in particular instances, plots could be *added* but the core design should be retained. An addtional species to consider, however, might be trembling aspen (*Populus tremuloides* Michx.). In the 1960s, aspen didn't command much attention, hence was largely ignored. Utilization, however, is increasing. An aspen-mixedwood stand included in the Interprovincial series responded well to N, and even better to N with P and K, with only five-year results available. (Weetman et al. 1987). Inasmuch as industry would probably be the principal beneficiary of extra wood produced by fertilization, an industry-government partnership along the lines of the collaborative trials of the 1960s and 1970s might be appropriate in any new program establishment.

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Inland USA Pacific Northwest forest nutrition management

John M. Mandzak[1]

This paper is a brief review of forest nutrition and economics in that part of the Northwest United States comprising the States of Washington and Oregon east of the Cascade crest, Idaho and Montana west of the continental divide. The forests are similar in composition to much of southern interior British Columbia and parts of Alberta. The paper covers pre- and post-1980 forest nutrition investigations, the Inland Forest Tree Nutrition Cooperative, Industrial trials and operations, commentaries on economics, current and proposed investigations by Boise Cascade Corporation (BCC).

The author completed graduate studies in forest soils and mineral nutrition at the University of Washington and has since had almost exclusively industrial employment with Champion International for 17 years and Boise Cascade Corporation for 6 years, primarily in RandD and Silviculture. He is a founder of the Inland Forest Tree Nutrition Cooperative (IFTNC) (1981) and active participant.

The primary focus of RandD in these companies has been preparing for intensive silviculture and forest nutrition management on company lands. Support of these companies has been substantial for this work, but was often questioned particularly when they were operating in a public timber and old growth economy. Change is made more interesting by internal company cultures and history. The culture is still strongly influenced by parochial views, both biological and economic, that often question the importance and economic value of forest nutrition management and fertilization. Now, however, the public timber situation in the Inland Pacific Northwest has made intensive silviculture more nearly an industrial "survival issue." If you are familiar with the world literature, our experience is very much *deja vu* in that the development path seems to speed up when faced with immediate challenges.

Boise Cascade is not quite ready to support current intensive silviculture operations. It is now scrambling to finish up what ideally should have been previously more thoroughly developed.

We are rapidly putting into place site-specific investigations and prescriptions. Our strategy is to complete response calibrations of growth and yield models and incorporate the yield tables into our forest planning models as soon as possible.

Regional history of forest nutrition investigations

Some examples of forest nutrition investigations and workers in the region with whom you may be familiar include Loewenstein and Pitkin's work with fertilization and thinning prior to 1980 at the University of Idaho. At the University of Montana, Dr. Mark Behan investigated young stand fertilization of western larch and lodgepole pine. Dr. Nellie Stark conducted many studies in nutrient cycling and forest nutrition. Dr. Pat Cochran with the U. S. Forest Service PNW Station studied fertilization response of ponderosa and lodgepole pine to nitrogen and sulfur in central Oregon. There were of course many other USFS, academic and in house industrial studies.

In 1981, the Inland Forest Tree Nutrition Cooperative (IFTNC) was established at the University of Idaho. The current director is Dr. Jim Moore. At the time, another timber supply scare was being discussed. Concurrently, information was being received from the West Coast of Canada and the USA regarding the potential of forest fertilization to reduce supply problems. One major information source was the Regional Forest Nutrition Cooperative (RFNRP) whose successor was the Stand Management Cooperative (SMC). It was also well known that large industrial landowners on the coast had begun large-scale nitrogen fertilization operations. Ideally the cooperative would have started with nutrient cycling and multinutrient screening trials, but was led by limited resources, a sense of urgency and "conventional wisdom" to leap directly into wide scale regional design N fertilization trials in late rotation managed stands. Fortunately though, there were also various directly and indirectly supported research activities such as foliar analyses and special studies. The cooperative and especially its two active industrial partners are now close to having site specific prescriptions across the region.

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Major IFTNC projects

The four major projects undertaken by the IFTNC cooperators will be discussed below. They are the Original Nitrogen Trials, the Nitrogen and Potassium Retreatment Trials, The Forest Health Experiments and Seedling Fertilization. Also in recent years, the cooperative has contracted various studies for individual cooperators such as Screening trials for BCC.

The original nitrogen trials

These trials utilized an installation layout similar to regional design employed by the University of Washington cooperative. Approximately 90 Douglas fir and 30 ponderosa pine and grand fir installations were deployed over about a four-year period. All investigations were in "late rotation, managed stands" 40–80 years old. The project area was western Montana, Idaho and the states of Washington and Oregon east of the Cascade crest. The basic design was 6 buffered 0.1-acre fixed area plots per installation. Two control, two 200 LB N/acre as urea two 400 LB N/acre plots were standard. Unfortunately, from the point of view of the author, there were no multinutrient treatments. The plots were measured every 2 years for 6 years and at longer intervals out to 14–16 years. A fortunate decision was to undertake a foliar nutrition assessment of each installation after the first treated growing season. The technical committee was intrigued by the vector analysis methods developed by Gordon Weetman in British Columbia. It was hoped that whether or not economic response was obtained, the IFTNC would be able to understand why a particular installation treatment response was or was not obtained.

The general results of the original nitrogen trials were that the treatments successfully corrected foliar N deficiency. Growth response ranged from negative to very high across the project. There was, however, no clear relationship between needle response and subsequent growth response. Between the second year and sixth year measurements, we obtained in some instances responses that we have termed "Square Death"—most trees dead in square plots treated with nitrogen. This didn't occur on many installations but there were widespread indications of "problems" with the nitrogen only treated plots including effects ascribed to weather (breakage and blow down) pests and pathogens (root disease, bark beetles). From the foliar data "dilution effects" in foliar potassium concentration were discovered. Reclassification of installations by gross soil type (Geomorphic and Lithogic Units) indicated patterns of growth and mortality responses that were related to geology but not clearly understood. One analysis indicated that installations with control plots within the higher range of foliar K concentration were more likely to show decent net growth responses.

The nitrogen and potassium retreatment trials

These trials followed on the information above. The key to obtaining nitrogen response was hypothesized to be the avoidance of nitrogen fertilization induced potassium (K) tissue concentration dilution by addition of K fertilizer. A retreatment design for the original N trials was created that incorporated various N and K dose rates. At the same time the co-op became intrigued with the relationship between nutrition and root diseases. Armillaria root disease is very common in the region. Review of the agronomic literature emphasized the importance of good plant tissue K status in resistance to root rot diseases. The literature reported that plants susceptible to root disease tend to have more free sugar and lower concentrations of "defense compounds" such as tannins and phenols in root tissues. At about the time the K/mortality hypothesis was being advanced, it was time to install the Montana ponderosa pine trials. Instead of 400N, a 200N + 200K treatment was substituted. *Net* growth was significantly higher in the 200N+200K plots than in the 200N plots. The primary cause of mortality in the 200N plots was bark beetles. Virtually no mortality was experienced in control and 200N+200K plots.

Also, at about this time, trials investigating root disease mortality in managed Douglas fir were undertaken near Grangemont in North Idaho. The project sought to understand why such apparently thrifty, fast growing thinned stands were experiencing unacceptable mortality. Combinations of fertilization treatments were deployed. The progress of root disease, with and without fertilization and direct inoculation of roots with Armillaria is still being monitored.

The results of these N&K trials were as suggested above, response to nitrogen was more consistent when foliar K was high and when K fertilizers were added. An intensive investigation of soil parent materials, especially with respect to the ability to supply K continues today. Lithology maps and GIS map data layers have been prepared and improved over time. A coup was successful prediction and mapping of areas in North Idaho where pest and disease survey crews would find high incidences of root disease by utilizing lithology maps and mineralogy data.

The forest health experiments

The Forest Health Experiments were designed to try to determine by site type, what combinations of N and K fertilizer rates would lead to the best net growth (least mortality). A response surface design was deployed with 14-16 relatively large plots per installation. The larger plots were for better assessments of mortality. Multinutrient treatments were also added during the second and third establishment years of the experiment. The best-laid plans began to unravel immediately when during installation reconnaissance we found many (late rotation) stands that were too unhealthy for a forest health trial! The stands in certain site selection matrix types were already too broken up by root disease to allow selection of enough uniform fixed area plots! These studies continue in "somewhat unhealthy" site types today with the assistance of forest pathologists advising the co-op on disease issues.

Seedling fertilization

(for very unhealthy forests)

It became apparent that some sites never would have stand conditions uniform enough for standard replicated fixed area plot trials. So a "start over" strategy was devised to see if thrifty stands could be established and maintained over time. The hypothesis was that early attention to and correction of planted seedling nutrition might result in plantations that can resist various pests and pathogens, especially if nutrition is well managed over time. "Slow release" formulations were devised by the Scotts Company to work within the matrix of lithologies and nutrient elements investigated. Some lithogies were chosen for presumed good nutritional properties "good rocks" and others for the reverse "bad rocks." Each seedling fertilization installation is one of a "good rock," "bad rock" pair. Attention has been paid and continues regarding fertilizer formulations, release rates of "slow release" fertilizers, fertilizers incorporated in container seedling media and nutrient loading.

Frankly, the technical committee of the IFTNC has been struggling with unexpected results. One expectation was that seedlings planted on "bad rocks" would perform nearly as well as seedlings on "good rocks." That is generally not proving to be the case. Seedlings on the better lithologies seem to be benefiting from the fertilizer treatments with much lesser response on the poorer parent materials. Inadequate fertilizer formulations are suspected as the cause at this time. Boron is very commonly deficient in the region. There may not be enough of this element incorporated in the test fertilizer materials utilized as indicated by the seedling foliar nutrient data available.

Commentary on economics

The barrel analogy

The barrel analogy is that the growth of a plant is limited by the most limiting factor, such as a barrel's ability to hold water by its shortest stave (or lowest leak). You may have heard the presumption stated that water is the primary limit on growth, especially in Inland forests and since trees "are very sparing" in their use of nutrients that significant economic response to fertilization is unlikely.

Further it is also presumed that you apply only the "most limiting" nutrient elements, again for reasons based on diminishing returns economic arguments. In the author's opinion, these ideas, even though they have a germ of truth to them, have held back progress in nutrition management of Inland Forests. After all, the possibility of economically irrigating timberlands is remote, and trees can usually be shown to respond well to properly formulated nutritional amendments even in our summer drought forests.

The alternative is to try to experimentally supply the nutritional elements that the target stand is likely to need and optimize treatments downward with screening and response surface trials after determining the upside growth potential. The reason is, as Ingestad has pointed out, that not only proper concentrations but also favorable ratios of essential elements are required for good growth. Adding a deficient element, even the most deficient element without evaluating all nutrient elements is very likely to produce sub-optimal fertilizer prescriptions.

How you think about forest economics matters

Single stand or site type discounted cash flow analysis is engrained (at least in our region) in the forestry culture, especially of today's senior managers. They have been taught to be real penny pinchers. Their calculations have shown that stands cannot outgrow large, long-term intensive silviculture investments. The author agrees that with this logic, very little intensive silviculture "pencils out" in Inland forests. Have you heard these statements? (1) You should fertilize only late in the rotation because your money is tied up for only a short period like ten years. (2) Natural regeneration is preferred because it is free. High up front costs of plantations do not pencil out.

There is little exposure to or belief in utility of "Allowable Cut Effect" (ACE) or linear optimization "Forplan Economics."

In fact, since graduate school, I hadn't heard much about it until coming to BCC. This approach suggests that you model your forest with a forest plan optimizer such as Forplan and let the model help you decide which stands to fertilize and when to optimize NPV, growth, and allowable cut under current constraints. Key concerns are that there must be a full range of prescriptions, arrayed against biologically defined "analysis areas" (site types—not timber types). Growth and yield models must be site sensitive and result in accurate yield tables. The proper value of the land in our approach is its current market value as timberland. Discount rates must be sensible and there must be sufficient mature timber available for increased near term harvests. Very high required alternative rates result in liquidation scenarios with little or no silvicultural investment. Very low interest rates result in selling land for another use. Timberland is a secure investment. Reasonable rates of return say (8–10%) can result in sustainable forest management and investor satisfaction. The biological reality also is that young trees are more responsive to silvicultural treatments including fertilization which in allowable cut scenarios shifts treatments away from late rotation treatments.

Our experience with Forplan models in the Inland west and elsewhere show that our models "want to" raise the allowable cut of more mature timber and invest heavily in young stand establishment and silviculture. This again, is contrary to what single stands discounted cash flow models are likely to illustrate.

Industrial Trials—Post 1980–Present

Below is a very cursory review of the efforts of Champion International Corporation (when it was active in western Montana and Washington), Potlatch Corporation and Boise Cascade Corporation

Champion International—Western Montana, Washington

The author organized and contributed to various fertilization and vegetation management trials for that company. IFTNC was strongly supported. Best results in terms of growth response were obtained with multinutrient fertilizer formulations, especially with thrifty young stands concurrently released from competition with herbicides. (i.e. with "Weed and Feed" treatments utilizing multinutrient fertilizers and hexazinone based herbicides) (Velpar, Pronone trade names)

Potlatch Corporation—North Idaho

This organization is also a consistent IFTNC supporter. They were the first to go to operational fertilization in the northern Rockies. They first fertilized with N, then N+K, and are currently interested in investigating multinutrient formulations. Their approach typically has predominantly been to fertilize after commercial thinning or in lieu of precommercial thinning. This alternative to PCT is used primarily for stands that have grown past the ideal precommercial-thinning window. Stands are then scheduled for commercial thinning in a decade or so to finally adjust stocking.

Boise Cascade Corporation—Central Idaho, Northeast Oregon, Central and Northeastern Washington

BCC Screening Trials—by contract with IFTNC

As most of you know, screening trials utilize individual tree or very small plot experimental designs. The advantage is that you can quickly (in 1–2 years) determine *which* elements and the appropriate quantities required to be applied to alleviate deficiencies and maintain proper nutrient ratios. Needle samples are collected after one treated growing season. A graphical analytic approach is utilized termed "vector analysis" which effectively arrays nutrient concentration and ratio changes as well as needle biomass changes. These trials are not effective for long term, per acre response determination, but clearly defines what it takes in terms of nutrient elements, dose rates, site type and forest growth stage to "make the trees happy" in a given situation. The IFTNC has provided an excellent contract service for BCC.

1998 Idaho BCC/IFTNC Screening Trials

Our first deployment of the design worked out with IFTNC was with graduate student Jay Hayek in Central Idaho. We evaluated young stand nutritional status on extensive ID Region lithology types on grand fir habitat types. The lithologies were granodiorite, quartz diorite, gneiss, and basalt. There were two installations per lithology. The treatments were control, N alone, multinutrient "best guess" and "complete" fertilizer formulations. Seven PP, and one LPP installation with 10 trees per treatment, 40 trees per installation. The single tree approach was very helpful in that large units with young trees either planted or naturally regenerated are relatively rare due to reliance on partial cutting methods. In fact, it was sometimes difficult to come up with 40 suitable candidate trees for an installation. The results were very convincing that multinutrient formulations

work the best and that N alone does increase foliar biomass nearly as effectively.

1999-2001 Idaho BCC/IFTNC Screening Trials

Utilizing the same basic design, we expanded our investigations both within Idaho and to northeast Oregon and Washington. Fertilizer formulas were adapted based on insights from previous trials, and lithology. We also worked in herbicide and "Weed and Feed" treatments.

1999 BCC/DuPont Weed and Feed Trial

We utilized a large ponderosa pine plantation resulting from an 800-acre wildfire for a trial. At age 10, most planted trees were still present but under very strong competition primarily from Ceanothus and Ninebark brush. This is a typical scenario for which we wanted to develop weed and feed prescriptions with the best economic benefit possible.

The premises were that Herbicide/Fertilizer formulations are not new and that herbicide impregnated on fertilizer *should be* cheaper than the commercial product Pronone + Fertilizer. We also wanted to factor in N released as a result of competition control, and save money by using site specific multinutrient fertilizer blends without N. Previous trials in Montana with DuPont indicated that impregnated fertilizer was as effective as other application methods when hand applied to test plots.

The initial objectives of this investigation were to determine whether we could successfully blend, haul and apply impregnated materials using helicopter distribution and support equipment. In cooperation with DuPont and Wilbur-Ellis we obtained an experimental label for Idaho.

Test areas were chosen and treated in the spring of 1999 near Idaho City. In the author's opinion, no significant technical or financial obstacles were found to either mixing and aerially applying granular herbicide with prilled fertilizer or impregnating liquid hexazinone on to fertilizer prills. Mixing facilities, application equipment, regulation and supplier cooperation drives the economics and practicality of such systems. The investigation is ongoing with annual vegetation and growth plot assessments. Dramatic treatment effects have been noted.

BCC next steps

Nutrient cycle/Site type based nutrition "expert systems"

The objective of this work is to calculate fertilizer dose rates and costs given site type and stand growth stage utilizing nutrient budgeting with a spreadsheet program.

Herbicide/fertilizer: screening/response surface trials

The objective is to verify positive N fertilizer interactions with herbicides (greater efficacy) and determine the most economically effective vegetation control/nutrition treatments. This is a hybrid design with screening trials methods. Individual dose rates are determined by a rotatable response surface design calculation. Treatments will include control, hexazinone herbicide rates and N+multinutrient fertilizer rates

Long term growth and yield silviculture response monitoring

The objective of this project is to determine growth and yield responses of effective treatments over a long enough period that growth and yield models can more confidently be calibrated and programmed. Ultimately our Forplan model yield tables will better reflect actual yields. This will be accomplished both by installing monitoring plots in operational treatments utilizing protocols standardized by the IFTNC co-op. Similarly, site specific long-term installations will be established.

Stewardship investigations

The objective of several projects is to identify site specific environmental effects of intensive silviculture treatments on habitat, wildlife and water quality. Techniques to be employed include vegetation sampling over time, wildlife presence and breeding success. Lysimetry and water sampling will be employed to evaluate potential leaching of forestry chemicals and/or nutrients through soil profiles and into groundwater and aquatic habitats.

To support our fisheries studies we are setting up riparian fertilization trials to evaluate effects on water quality, fish habitat and food chains and validity of current and proposed BMPs.

Conclusion

As pointed out earlier in this paper, the IFTNC, Boise Cascade and other land management organizations in the region are scrambling to develop the information base needed to support economic use of fertilization in the Inland Pacific Northwest Region. Investigative methods employed have been successful here and previously in other regions of the world. This comes at a time with increasing economic, environmental and political pressures.

Fertilization of lodgepole pine in western Canada

R.P. Brockley[1]

Introduction

Extensive research has been undertaken in British Columbia and Alberta to determine the nutritional status of lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) and to document the effectiveness of fertilization in improving the growth of immature and semi-mature stands. These studies have confirmed that nitrogen (N) deficiencies are widespread throughout the region and that N additions, often in combination with other nutrients, often have a substantial positive effect on tree and stand growth. In the interior of British Columbia, promising research results, combined with forecasted timber supply shortfalls, have resulted in several large-scale aerial fertilizer operations during the past 15 years. To date, approximately 44,000 hectares of forests (mostly lodgepole pine) have been operationally fertilized in the British Columbia interior (B.C. Min. For. 2000).

To varying degrees, several government agencies, universities, and forest companies have been engaged in lodgepole pine fertilizer research in Alberta and British Columbia. Research strategies have combined short-term fertilizer screening trials (to diagnose specific nutrient deficiencies and rapidly evaluate various fertilization regimes) with conventional, fixed-area plot experiments that provide the area-based response data required in support operational forest fertilization investments. The purpose of this paper is to review these lodgepole pine fertilization research studies and to summarize the results.

British Columbia

The earliest documented fertilization of lodgepole pine in British Columbia was in 1963, when S.M. Simpson Ltd. (acquired by Crown Zellerbach Canada Ltd. in 1965) established two fertilization trials in 30- to 40-year-old stands of thinned lodgepole pine near Kelowna. Of the nutrients applied (N, P, K, S, and B), only nitrogen had a significant effect on tree growth (Strand and Lin 1969; Boyd et al. 1975). A follow-up study was subsequently established to test the effects of N fertilization, chemical thinning, and fertilizer + thinning on the growth of 30- to 40-year-old and 70- to 80-year-old stands. Applications of 112 and 224 kg/ha increased four-year basal area (BA) growth of 40-year-old lodgepole pine by 22% and 44%, respectively. For 80-year-old stands, respective basal area increases were 11% and 22%. There was no significant interaction detected between thinning and fertilization (Boyd and Strand 1975).

Following these early trials, there was virtually no further interest in lodgepole pine forest nutrition or fertilization until 1979, when Dr. T.M. Ballard (UBC) began a series of fertilization-related contracts with the B.C. Ministry of Forests, Research Branch. Based on extensive foliar sampling, he completed a regional evaluation of lodgepole pine nutritional problems in the central and southern interior, reviewed and developed methodology for the collection and chemical analysis of foliage samples, and developed a computerized method for nutrient deficiency diagnosis (Ballard 1982, 1985, 1986a). In addition, Dr. Ballard and his graduate student, N. Mahid, established four "single tree" fertilizer trials in 1981 to determine the effects of foliar application of N, Cu and Fe on the growth and nutrient status of lodgepole pine. Fertilizer solutions of copper sulphate, ferrous sulphate and urea were applied at different rates and combinations to the crowns of lodgepole pine at the four sites. Highly significant positive responses in shoot growth and foliar biomass production were reported during the second growing season. Foliar applications of all three nutrients were highly effective in elevating foliar nutrient concentrations, but the effects were short-lived (Mahid 1984; Ballard and Mahid 1985).

In 1986, a manual specifying guidelines for collecting, preparing, and analyzing soil and conifer foliage samples and for interpreting analytical results was published by the Ministry of Forests (Ballard and Carter 1986). This publication is still a primary source of information for silviculturists assigned the task of collecting foliage samples and interpreting analytical data in British Columbia.

UBC Fertilizer Screening Trials

Dr. Ballard's contract research in the interior of British Columbia coincided with the arrival to the province of Dr. G.F. Weetman, a renowned expert in forest fertilization from eastern Canada. In 1980, Dr. Weetman (UBC) was contracted by the B.C. Ministry of Forests, Research Branch to establish a series of fertilizer screening trials in young, thinned lodgepole pine stands in the interior of British Columbia. First-year increases in fascicle weight and foliar graphical vector analysis were used to assess the response potential of 17 stands to factorial combinations of N, P and K fertilizer. Each of 16 treatment combinations was applied to five circular, 0.01-ha miniplots. Results indicated there was considerable variation in the responsiveness of lodgepole pine to fertilization (Weetman and Fournier 1982). Eight of the 17 stands were moderately or very responsive to N additions; others were weakly or non-responsive. Most stands were unresponsive to nutrients other than nitrogen. For the responsive stands, increases in 1st year fascicle weight ranged from 8 to 60%, suggesting a strong likelihood of favorable stem volume responses. Subsequent remeasurement of 15 stands showed that 1st year shifts in fascicle weight generally corresponded with four-year BA response in 11 of the stands (Weetman et al. 1988). Nitrogen applied at rates of 50, 100, and 150 kg N/ha increased four-year basal area growth by 27, 41, and 46% over the control, respectively. Adding P significantly improved basal area growth in only two stands, while the effect of K was not significant.

Spillimacheen Experiments

A number of fertilization experiments were established in young (11- to 15-year-old), fire-origin lodgepole pine stands near Spillimacheen, B.C. in the early 1980s. The first of these experiments was a fertilizer x thinning experiment established by Dr. G.F. Weetman in the spring of 1980. Three levels of N (0, 50, 100 kg/ha as ammonium nitrate [AN; 34-0-0]) and three levels of thinning (unthinned, 800, 3000 stems/ha) were each replicated twice for a total of 18 fixed-area plots. In 1981, a similar experiment was established using ammonium sulphate (AS; 21-0-0) as the fertilizer source. Both fertilizer sources resulted in significant increases in fascicle weight in thinned plots (but not in unthinned plots) after one growing season, with AS showing the best response. However, the effects of fertilization on basal area increment were not significant after three years (Weetman and Fournier 1986).

In the spring of 1981, another fertilizer experiment was established at Spillimacheen to document the effects of nitrogen source on growth of thinned lodgepole pine. Four N sources (at an application rate of 200 kg N/ha) were tested: 1) ammonium nitrate (AN); 2) ammonium sulphate (AS); 3) urea (U); and sulphur coated urea (SCU). Each treatment (plus an unfertilized control) was replicated three times for a total of 15, 0.05-ha plots. Basal area increments in three of the fertilizer treatments (U, AN, and AS) were 40% greater than the control after three years. The response to SCU was not significant. Height growth was unaffected by fertilization (Weetman and Fournier 1986).

The Canadian Forest Service established two fertilization experiments at Spillimacheen in the early 1980s. The first experiment was established in early 1981 to investigate the efficacy of winter application of nitrogenous fertilizer on snow. Two replicates of "single-tree" circular microplots were destructively sampled after one growing season to determine the recovery of 15N in trees, understory and soil from three 15N-labelled fertilizers ([^{15}N]urea, $^{15}NH_4NO_3$, and $NH_4{}^{15}NO_3$), each applied at rates of 100 kg N ha/l (Preston et al. 1990). The remaining two replicates were destructively sampled in 1988 to document the long-term recovery and distribution of ^{15}N and to report on the tree growth response to the various fertilizer sources (Preston and Mead 1994). After one growing season, total recovery of [^{15}N]urea, $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$ was 93.3, 95.2, and 44.4%, respectively. About two-thirds of this amount could still be accounted for in plant biomass and soil after eight years. The respective recovery in tree biomass after one year was 10.1, 5.3, and 1.9%, with little additional ^{15}N uptake by trees in subsequent years. The reported tree uptake of applied N from urea was within the range reported for urea in other studies. However, tree uptakes from the ammonium and nitrate sources were generally below reported levels. The large losses and poor uptake of $NH_4{}^{15}NO_3$ were attributed to leaching and denitrification of nitrate during snowmelt (Preston et al. 1990). For this reason, the authors recommended that the application of nitrate on snow not be considered for fertilizer operations. Ring measurements from the two replicate trees per treatment indicated a 34% increase in stem volume increment in fertilized versus control trees after eight years (Preston and Mead 1994). There was no apparent effect of fertilizer source on tree growth.

In 1983, the Canadian Forest Service established another experiment near Spillimacheen, B.C. to document the growth response of lodgepole pine to urea and ammonium nitrate (both applied at 300 kg N/ha) applied on bare ground and on snow across three stand densities (Marshall et al. 1992). Urea was applied on bare ground in October 1983 and on 70 cm of snow in February 1984, whereas ammonium nitrate was applied only on snow. After three years, individual-tree volume increment was significantly increased by ammonium nitrate applied on snow in moder-

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Kalamalka Forestry Centre
Vernon, B.C.

ately thinned stands (2500 stems/ha) and dbh increment was significantly increased (up to 37%) by on-snow applications of ammonium nitrate and urea in heavily thinned stands (800 stems/ha). Height growth was not increased by fertilization and, in fact, may have been slightly depressed in the heavily thinned stand. The effectiveness of ammonium nitrate on snow relative to urea was surprising, given the poor recovery and uptake of $NH_4{}^{15}NO_3$ reported by Preston et al. (1990). The comparable, but relatively low, incremental tree growths from urea and ammonium nitrate were attributed to undetermined factors, including rapid fixation and microbial immobilization of ammonium N and other growth-limiting nutrients (e.g., B and S).

UBC Optimum Nutrition Trial

Sustained growth responses to repeated fertilization have been demonstrated in "optimum nutrition" experiments with Pinus species in eastern Canada and Europe (Weetman et al. 1995; Tamm et al. 1999). In 1982, Dr. G. Weetman (UBC) addressed the question of whether high growth rates of lodgepole pine can be sustained by repeated fertilization by establishing an optimum nutrition experiment near Okanagan Falls. Four levels of N (0, 50, 100, 150 kg N/ha as ammonium nitrate), applied alone and in combination with a "complete mix" fertilizer (P, K, Ca, Mg, S plus micronutrients), were applied to replicated treatment plots in a thinned, nine-year-old stand. Fertilizer treatments were applied four times between 1982 and 1988. After 14 years, mean tree volume in the treatment receiving the highest N application (525 kg N/ha over seven years) plus the "complete mix" fertilizer was 42% greater than in unfertilized plots. Conversely, tree growth was either unaffected, or slightly depressed, by repeated fertilization with N alone, likely due to induced S deficiency (Kishchuk et al. 2001).

Ministry of Forests (Forest Regions)

Several fertilizer screening trials have been established by MoF Regional staff during the past 15 years. Of these, only the results from a series of trials in 50- to 60-year old thinned, lodgepole pine in the Prince Rupert Forest Region have been reported (Yole et al. 1991; Trowbridge 1992). Based on dendrochronometer measurements, increases in six-year tree basal area increment averaged 64% following fertilization with a "complete blend" fertilizer. Average growth gains of 27% were obtained from fertilization with N alone.

In 1979, Les Herring (MoF, Prince George Forest Region) established two fixed-area experiments in an 18-year-old, severely repressed lodgepole pine stand at Fish Lake, near Prince George. A 2 x 2 factorial trial was designed to document the effects of mechanical row thinning (with and without selective hand thinning within rows) and two levels of N fertilization (0 and 150 kg N/ha) on the growth of the repressed stand. Another study tested a range of N application rates (200, 400 and 800 kg N/ha), broadcast and applied in concentrated strips, in an unthinned portion of the stand. Nineteen-year results from these studies are reported elsewhere in these proceedings (Farnden 2001).

In 1998, factorial combinations of thinning (unthinned and thinned) and fertilization (unfertilized and fertilized with a "complete blend") were applied to a 35-year-old, repressed lodgepole pine stand in the Rosita Fire, west of Williams Lake (T. Newsome, per. comm.). The results from this study have not yet been reported.

Ministry of Forests (Research Branch)

The widespread and serious N deficiencies reported by Ballard's contract research, combined with the likelihood of growth responses following N fertilization indicated by Weetman's screening trials, encouraged the Ministry of Forests, Research Branch to implement a large-scale lodgepole pine fertilization research program in 1981. Since that time, a large number of fertilizer "screening" trials, using various replicated "single-tree" or "mini" research plot designs, have been established by the Research Branch to diagnose specific nutrient deficiencies and rapidly evaluate fertilization response potential and the efficacy of different fertilization regimes (Brockley 1990, 1995; Brockley and Sheran 1994). In addition, 38 fixed-area plot experiments have been established to provide the area-based response data (m^3/ha of "extra" wood produced) required in support of operational forest fertilization investments. The results from fixed-area experiments have been extensively reported (Brockley 1989, 1991, 1996, 2000*a*; Mika *et al.* 1992).

Most of these trials have been established in 20- to 30-year-old stands. If not planted, all of these stands were pre-commercially thinned prior to, or at the time of, fertilization. Post-thinning stand densities range from 1100 to 2100 stems per hectare. The Research Branch has not conducted fertilization research in unthinned stands, where opportunities for crown expansion following fertilization are often limited and where competition mortality will likely reduce harvest gains. To date, there has been relatively little fertilization research activity in mid- to late rotation lodgepole pine stands. Because early stand density control was not undertaken, these stands are often in relatively poor biological condition (e.g., small live crown, high incidence of stem disease) and thus may have relatively poor fertilization response potential. However, current pre-commercial thinning activities in young stands, combined with extensive planting, will certainly create good opportunities for fertilizing older stands in the future. A small number of fertilizer trials have been established in young stands (10 to 15 years old). These are mainly short-term fertilizer screening trials and "maximum productivity" trials, where the effects of repeatedly fertilizing throughout the rotation are being documented.

Nitrogen fertilization

Foliar analytical data reported by Ballard (1982) and Weetman and Fournier (1982) indicated that nitrogen (N) deficiencies were widespread and serious throughout the interior of British Columbia. These findings were in agreement with previous studies in Scandinavia and North America where N had been clearly shown to be the nutrient most limiting the growth of northern temperate and boreal forests growing on mineral soils. Therefore, the initial series of fertilization trials established by the Ministry of Forests, Research Branch were designed solely to document the growth response of lodgepole pine to N additions (Brockley 1989, 1991). Figure 1 illustrates the cumulative distribution of pre-fertilization foliar N concentrations in the 52 fertilization research trials from which foliar information has been collected. The vertical axis indicates the proportion of all installations that have foliar N levels less than or equal to a particular foliar concentration shown on the horizontal axis. For example, 75% of the stands have foliar N levels lower than 1.15%, indicating moderate to severe N deficiency (Ballard and Carter 1986; Brockley 2001). Approximately one-quarter of the stands have foliar N levels lower than 1.00%, indicating severe N deficiency.

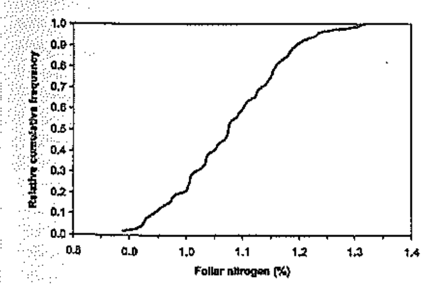

Figure 1. The relative cumulative frequency distribution of pre-fertilization foliar N concentration in lodgepole pine fertilization research installations (n=52) (Brockley unpubl. data).

Six-year growth response information is currently available for 31 research trials. Overall, lodgepole pine has responded quite well to N fertilizer applied at a rate of 200 kg N/ha. Basal area response was statistically significant ($p<0.05$) in 17 (55%) of the 31 installations (Brockley 2000). However, growth response following N fertilization was quite variable, with relative BA responses ranging from 5 to 77%. The relative cumulative frequency distribution of six-year BA response to N fertilization is shown in Figure 2. Growth response is expressed as a percentage of control plot BA increment over the six-year response period. For example, approximately one-quarter of the installations responded less than 15%, and about one-quarter responded more than 40%.

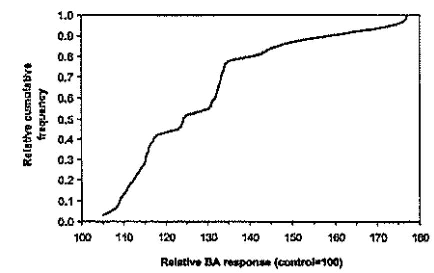

Figure 2. The relative cumulative frequency distribution of mean 6-year basal area response in lodgepole pine research installations after fertilization with 200 kg N/ha (n=31).

Six-year area-based growth response (m^3/ha of "extra" wood produced) has been analyzed for 17 fixed-area, lodgepole pine installations, of which three have been abandoned due to serious mortality and damage to crop trees (i.e., small mammal damage, snowpress) that all but wiped out per-hectare volume gains. Ten of the 14 undamaged trials responded significantly to N fertilization ($p<0.05$) over the six-year response period (Brockley unpubl. data). Total volume gains above control averaged 9.2 (range –0.5 to 20.4) m^3/ha for an application rate of 200 kg N/ha. In relative terms these responses averaged 29% (range –2 to 50%).

Despite generally favorable stem radial response, height response of lodgepole pine following N fertilization is relatively small. For thinned, fixed-area plot research installations, six-year height responses following fertilization with 200N averaged only 20 cm (range –23 to 60 cm) greater than thinned but unfertilized trees. In relative terms, average height response was 10% (range – 8 to 54%). For thinned stands, the timing of fertilization in relation to thinning affects the magnitude of height response following N fertilization. Comparison of installations thinned at the time of fertilization (Type 1) with adjacent installations thinned at least two years before fertilization (Type 2) indicates that Type 1 stands are generally more responsive to fertilization in both relative and absolute terms (Figure 3). These results indicate fertilization may help offset the short-term negative effects of thinning on height increment (i.e., thinning shock).

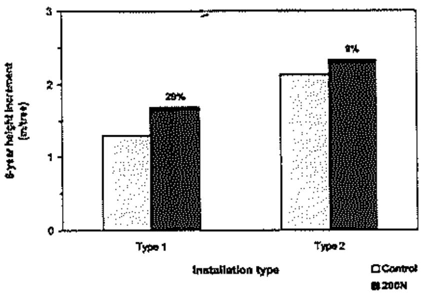

Figure 3. The effect of nitrogen fertilization on mean height increment in stands thinned at the time of fertization (Type 1; n=4) and adjacent stands thinned 2-3 years before fertilization (Type 2;n=4).

Nitrogen and sulphur fertilization

Foliar analysis data indicate that the S status of many lodgepole pine stands is marginal before fertilization, and that N additions result in further deterioration of S nutrition. Foliar N:S ratios often increase dramatically, and sulphate-S reserves are often depleted to extremely low levels—and indication that the added N may not be fully utilized in protein synthesis. The effects of N and N+S fertilization on the first-year fascicle weight and foliar nutrient status of young, thinned lodgepole pine were reported by Brockley and Sheran (1994). These screening trial results indicated that S deficiencies, either aggravated or induced by N fertilization, limited the responsiveness of some lodgepole pine stands to N additions. At four of seven locations, combined N and S additions improved the S status of fertilized trees and significantly increased the weight of fascicles produced during the first year after treatment compared with that achieved with N alone. In 1990, another screening trial was established to test the effects of N application rate, with and without added S, on the growth of lodgepole pine. Factorial combinations of N (0, 200, 400 kg N/ha as urea) and S (0, 50 and 100 kg/ha as S^0 and as ammonium sulphate[AS]) were applied to a thinned, 15-year-old lodgepole pine stand. When added alone, applications of 200 and 400 kg N/ha both had significant positive effects on tree BA increment after three years (39% and 24% above control, respectively) (Figure 4). Although 400N was apparently less effective than 200N (likely due to induced S deficiency), the difference between the two application rates was not statistically significant. Addition of S (100 kg/ha as ammonium sulphate) in combination with N resulted in significantly larger BA responses at both N application rates (66 and 60%, respectively).

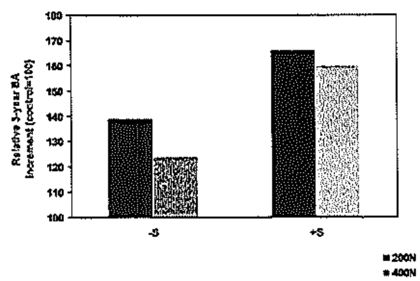

Figure 4. The effects of N application rate, with and without added S (100 kg S/ha as ammonium sulphate), on 3-year relative tree volume increment (control=100) (Brockley unpubl. data).

Six-year BA response information has been collected from a total of 17 "single-tree" and fixed-area plot trials in which the effects of N vs. N+S have been tested. In these 17 installations, the combined N+S application resulted in a larger mean six-year BA response than N alone (28 vs. 19%, respectively). Six (35%) of the 17 installations responded significantly to N alone; 88% (15 of 17) responded significantly to combined N+S fertilization (Brockley 2000a). As shown in Figure 5, a BA response of more than 30% was obtained in approximately one-half of the installations fertilized with N+S. A similar response was achieved by less than one-fifth of the stands fertilized with N alone.

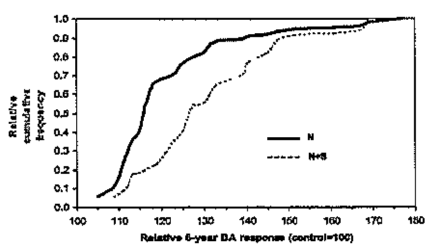

Figure 5. The relative cumulative frequency distribution of mean 6-year basal area response in research installations fertilized with N and N+S (from Brockley (2000)).

Six-year area-based volume growth response following N and N+S fertilization has been analyzed for seven fixed-area, lodgepole pine installations. However, one installation was severely damaged by top die-back caused by induced B deficiency. Five of the six undamaged installations responded significantly ($p<0.05$) to N fertilization and all six responded significantly to N+S (Brockley unpubl. data). The incremental gain between N and N+S was statistically significant in three of the six installations. The two installations in the ICH and MS biogeoclimatic zones responded well to N fertilization (13 and 20 m^3/ha of "extra" wood over six years, respectively), and did not respond incrementally to added S. For the other installations in the SBS, SPBS, and IDF biogeoclimatic zones, the six-year volume gains above control averaged 5.2 (range -0.5 to 11.9) and 11.4 (range 7.3 to 19.2) m^3/ha for N and N+S, respectively. In relative terms, these respective responses averaged 16% and 35%, respectively.

Examination of S properties of unfertilized soils and foliage from S-deficient and S-sufficient sites in the interior of British Columbia revealed that cycling of soluble-SO4 through organic-SO4 is likely the process limiting S availability on S-deficient sites (Kishchuk 1998). These results indicate that organic-SO4 is more actively cycling in soils and contributes more to S uptake than C-bonded-S. Total soil S levels did not differ between S-deficient and S-sufficient sites. Results also indicated that soil organic C may play an important role in the cycling of organic-SO4 and S availability. Organic matter losses resulting from repeated wildfires might explain low levels of soil organic C on S-deficient sites.

Other nutrient additions

Low foliar B concentrations are quite common in lodgepole pine stands throughout north-central British Columbia. Nitrogen fertilization further depletes foliar B levels, and has resulted in visible B deficiency symptoms (i.e., top die-back) in at least one fertilization research trial near Burns Lake (Brockley 1989) and in a nearby stand that was previously operationally fertilized (Brockley and Yole 1985). In another research trial in the southern interior, a combination of high rainfall and coarse-textured soil apparently depleted soil-available B and caused severe top die-back three years following N fertilization (Brockley, unpubl. data). Boron deficiency symptoms can develop very rapidly, and the resulting damage reduces stem volume increment and adversely affects stem quality and value. A small amount of B (e.g., 3 kg B/ha) added in combination with N (or N+S) has proven effective in preventing top die-back in lodgepole pine (Figure 6).

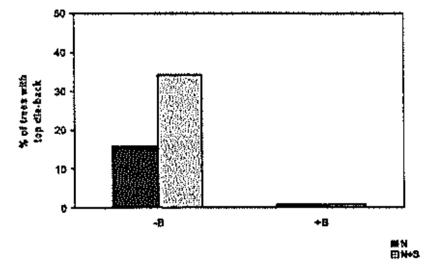

Figure 6. The effects of N and N+S fertilization, with and without added B, on the incidence of top dieback in a lodgepole pine stand near Golden, BC (Brockley unpubl. data).

Although dramatic, visual symptoms of B deficiency are relatively rare in the interior of British Columbia. However, subacute B deficiency (without visible growth disturbance symptoms) has been shown to reduce growth response following N fertilization. Results from a "single-tree" fertilization trial near Burns Lake showed that combined N and B application significantly improved growth response over that achieved with N fertilization alone (Brockley 1990). Average six-year stem volume gains were 20 and 34% for N and N+B treatments, respectively. The difference was largely due to reduced height increment (but no top die-back) of trees fertilized with N alone.

The occurrence of nutrient deficiencies other than N, S and B in lodgepole pine has not been systematically tested. A "complete mix" treatment has been applied in addition to N and N+S treatments in two fixed-area plot fertilization trials. In both trials, the "complete mix" fertilizer contained (kg/ha): 200N, 100P, 100K, 75S, 37Mg, 3B. After six years, there were incremental differences between the N+S and "complete mix" treatments in both trials, but the difference was statistically significant in only one trial (Figure 7). It is doubtful whether the additional growth gains are large enough to justify the higher cost of purchasing and applying a "complete mix" fertilizer.

Nitrogen source

The effects of urea and ammonium nitrate [AN] fertilizer on the nutrition and growth of lodgepole pine were evaluated at three locations in the interior of British Columbia over a six-year period (Brockley 1995). Because their effectiveness may be influenced by season of application, both spring and fall applications of these two sources were also tested. Lodgepole pine showed no clear preference for a particular

N source or season of application in this study. Despite the superiority of AN over urea in improving foliar N status (especially when applied in the spring), the stem growth response of fertilized trees in the three trials was not affected by differences in N source. In fact, spring-applied AN produced the smallest diameter and height increments at two of the study locations. These results clearly differ from Scandinavian experiments, in which AN consistently gives larger growth responses than urea (Moller 1992). These conflicting results may be partially explained by the negative effect of spring-applied AN on lodgepole pine foliar S status in the interior of British Columbia. Because spring-applied AN is often more effective than urea in increasing foliar N concentration, it is more likely to create a N:S imbalance and S deficiency, at least over the short term. An experiment was recently established near Prince George to test whether AN is better than urea at stimulating tree growth when accompanied by S additions.

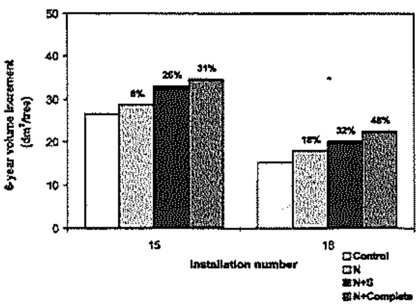

Figure 7. The effects of N, with and without the additions of S and a "complete mix" fertilizer, on 6-year tree volume increment in two fertilizer trials in central BC (Brockley unpubl. data).

Effects of post-thinning density

In view of the dramatic effects that thinning has on stand structure and subsequent development, it is likely that the intensity of thinning will also influence growth responses to fertilizer application. The effects of density on stand development and competition mortality following fertilization, and on the volume of "extra" fertilized wood available at harvest, are important issues. It is also important to document the effects of thinning and fertilization on wood quality factors such as specific gravity, branch size and stem taper. Although a number of different post-thinning densities have been used in lodgepole pine fertilizer research trials, they have not been tested at the same location. Therefore, given the confounding effects of site, pre-thinning density and stand age, definitive conclusions about the effects of fertilizer x thinning interactions cannot be made.

In 1992, factorial combinations of post-thinning densities (600, 1100, 1600 stems per hectare) and fertilization (unfertilized, fertilized) were applied to a 13-year-old, harvest-origin lodgepole pine stand near Williams Lake. After five years, the main effects of density and fertilization were highly significant for both individual-tree and area-based analyses (Figures 8 and 9). The fertilizer x thinning interaction was not statistically significant. In both relative and absolute terms, the effects of fertilization on tree and stand BA increment were greatest at higher densities after five years. This trial will be periodically refertilized and remeasured throughout the rotation.

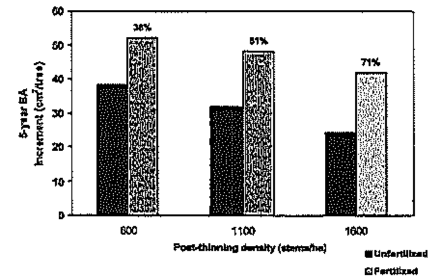

Figure 8. Effects of post-thinning stand density on 5-year tree basal area increment (cm²/tree) following fertilization (Brockley unpubl. data).

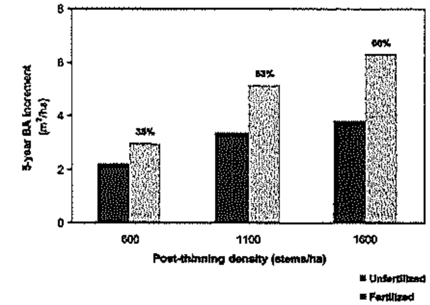

Figure 9. Effects of post-thinning density on 5-year stand basal area increment (m²/ha) following fertilization (Brockley unpubl. data).

Predictive relationships

Reliable predictors of fertilization response are needed so that forest managers can identify those stands that have the greatest growth response potential to N additions, as well as identify stands where the response can be significantly improved by adding other growth-limiting nutrients in combination with N. Previous studies in British Columbia have suggested that nutrient limitations and fertilization response potential can be estimated with reasonable accuracy from first-year increases in the fascicle mass of fertilized trees (Weetman and Fournier 1982; Weetman et al. 1988; Brockley 1989). The positive relationship between fascicle mass response and subsequent stemwood response is the basis of the "screening" approach to fertilizer response prediction. On the basis of statistical significance, fascicle mass response correctly predicted six-year BA response (or lack of it) to fertilization with N alone in 21 of 31 lodgepole pine research trials (Brockley 2000a). Overall, fascicle mass explained 34% of the variation in six-year BA response. However, approximately one-third of the installations in which fertilization with N alone significantly increased first-year fascicle mass did not show a significant BA response to added N. Also, fascicle mass differences between N and N+S were, on average, considerably higher than the differential BA responses, thereby over-estimating the long-term positive effects of S additions on tree growth. In fact, significant BA responses to added S did not materialize in more than one-half of the installations in which S significantly increased first-year fascicle mass over that achieved with N alone. Clearly, there is some risk of not recouping fertilization investment costs when the screening technique is used to select candidate sites for fertilizer operations or to make fertilizer prescriptions based on the statistical significance of fascicle mass response.

Brockley (2000*a*, 2000*b*) reported that pre-fertilization levels of foliar N or inorganic sulphate-S may be more reliable than the fascicle mass screening method for predicting whether or not a significant stemwood response will occur following N fertilization. In an analysis of 31 trials, an overall trend of declining BA response was observed with increasing N concentration in the foliage of unfertilized trees. Conversely, there was clearly a positive relationship between relative BA response and foliar sulphate-S. Individually, each of these foliar variables explained approximately one half of the observed variance in relative BA response between installations. When combined, N and sulphate-S levels in unfertilized foliage explained 68% of the variation in relative BA response to fertilization with N alone. Foliar nutrients were also useful for determining whether or not lodgepole pine would respond incrementally to S when added in combination with N. Stands in which pre-fertilization foliar sulphate-S was < 60 mg/kg and N/S ratio was > 13 did not respond significantly to N alone but always responded significantly to N+S. Conversely, a foliar sulphate-S level > 60 mg/kg combined with a N/S ratio of < 12 always resulted in a favorable response to N with no incremental benefit of added S. These results, combined with the fact that the screening method is more expensive and requires at least one year of lead time prior to operational fertilization, indicate that foliar nutrient assessment using pre-fertilization foliar levels of N, sulphate-S and N/S ratios may have greater utility than first-year increases in fascicle mass for assessing fertilization response potential and for making appropriate fertilization prescriptions.

Damaging Agents

Red squirrels (*Tamiasciurus hudsonicus Erxleben*) have been clearly implicated as significant damaging agents in young, fire-origin stands of fertilized lodgepole pine stands in the interior of British Columbia (Sullivan and Sullivan 1982; Brockley and Sullivan 1988; Brockley 1991). Feeding injuries are caused by the peeling and removal of bark from the basal (and sometimes upper) sections of trees. Although damaged trees are usually not completely girdled, sub-lethal injuries reduce growth response following fertilization, and damaged stems may be more susceptible to snow or wind breakage at the point of injury. In heavily damaged fertilizer research trials, the incidence and severity of damage is significantly higher in fertilized plots than in unfertilized plots, especially in stands that are thinned at the time of fertilization (Brockley 1991). Squirrel feeding injuries can be minimized by delaying fertilization for at least two years after thinning. Also, stands that have a low incidence of damage before fertilization will likely not suffer significant feeding injuries after fertilization.

The accumulation of snow in the fuller crowns of fertilized lodgepole pine may increase the likelihood of irreversible bending and breakage of trees in stands thinned at the time of fertilization, especially where average height/dbh ratio is high (>90). Snowpress damage rarely occurs in stands where fertilization has been delayed for two to three years after thinning (Brockley 1991).

"Maximum Productivity" Trials

A single fertilizer application typically produces only a temporary increase in growth (usually six to nine years). To what extent intensive, repeated fertilization can increase productivity and thus mitigate reductions in AAC that may result from a shrinking working forest land base is a question of some importance to forest managers. Beginning in 1993, a network of six "maximum productivity" research installations has been established on benchmark lodgepole pine sites in the interior of British Columbia. These installations will provide valuable information on the effects of repeated fertilization on harvest volumes and on various ecosystem processes and non-timber resources. Each of the plantations or juvenile-spaced, harvest-origin stands was 9-15 years old at the time of installation establishment. Each of six treatments is replicated three times for a total of 18, 0.164-ha treatment plots. The treatments are as follows:

1. Control (i.e., not fertilized)
2. NB – fertilized every six years with (kg/ha): 200N, 1.5B
3. NSB – fertilized every six years with (kg/ha): 200N, 50S, 1.5B
4. Complete – fertilized every six years with (kg/ha): 200N, 100P, 100K, 50S, 25 Mg, 1.5B
5. ON_1 – fertilized yearly to maintain foliar N concentration at 1.3% and other nutrients and nutrient ratios at "optimum" levels
6. ON_2 – fertilized yearly to maintain foliar N concentration at 1.6% and other nutrients and nutrient ratios at "optimum" levels

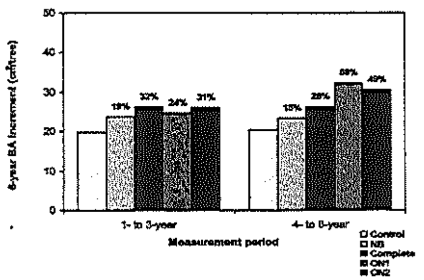

Figure 10. Effects of single and repeated fertilization on 6-year basal area increment in a lodgepole pine "maximum productivity" trial near Williams Lake, BC (Brockley unpubl. data).

Six-year basal area response in an installation near Williams Lake is illustrated in Figure 10. Over six years, the ON1 and ON2 treatments received 450 and 900 kg N/ha, respectively. Large quantities of other essential nutrients (350P, 350K, 225 Mg, 216S, 3B) were also added during this period. Results indicate that all fertilizer treatments were more-or-less equally effective in increasing growth during the initial three-year response period. However, the ON1 and ON2 treatments were significantly more effective than the other treatments in stimulating BA growth during the four- to six-year period. Interestingly, repeated fertilization at the ON2 level had a significant negative effect on height increment after six years (Figure 11). A number of ancillary studies are also being undertaken at selected trial locations to document the effects of repeated fertilization on understory vegetation biomass and diversity, litterfall quality and quantity, litter decomposition, fine root activity, and soil biota activity and diversity.

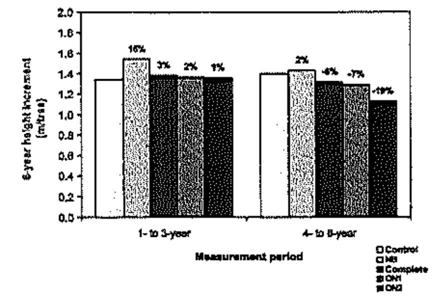

Figure 11. Effects of single and repeated fertilization on a 6-year height increment in a lodgepole pine "maximum productivity" trial near Williams Lake, BC (Brockley unpubl. data).

Alberta

Canadian Forest Service

The earliest documented lodgepole pine fertilization research in Alberta was in 1968, when the Canadian Forestry Service established a fertilization trial in a thinned, 72-year-old lodgepole pine stand near Rocky Mountain House. Three levels of N (0, 112, and 673 kg N/ha), three levels of P (0, 56, and 168 kg P/ha), and three levels of S (0, 28, and 84 kg S/ha) were tested in a randomized, incomplete factorial experiment. Fourteen treatments were replicated three times, for a total of 42, 0.04-ha plots. Bella (1978) reported a significant growth response to N but no additional response to P or S after seven years. The gain in merchantable volume averaged about seven m³/ha (30%) over the seven-year period.

In 1971, four fertilizer trials were established by the Canadian Forestry Service southeast of Hinton. The trials were located in unthinned stands of two stand ages (30 and 70 years old) on Coalspur (Orthic Gray Luvisol) and Mercoal (Podzolic Gray Luvisol) soil types. Incomplete factorial combinations of each of five levels of N, P, and S were tested in a central composite rotatable second-order design to provide a general predictive relationship between tree and stand responses and fertilizer levels. In addition to the 20 composite design treatments, four extra treatments were added to allow the analysis of results by two 2^3 factorials arranged in a randomized complete block design. All of the fertilizers were applied to circular treatment plots prior to the 1972 growing season. After 10 years, all tagged, living trees within treatment plots were remeasured. Three of the 10 tagged trees within each plot were felled to accurately determine tree volume increment.

Because of the inadequacy of the central composite design in evaluating tree and stand responses to fertilization (Yang 1983a), only the analysis of the factorial combinations were reported (Yang 1983b, 1985a, 1985b; Yang and Bella 1986; Weetman et al. 1985). Factorial analysis of 10-year volume increments of dominant and codominant trees showed different response on the two soil types to N, P, and S fertilization. Fertilization with N dosages of at least 188 kg N/ha resulted in significant tree volume growth responses in both 30- and 70-year-old stands on Coalspur soils. Little additional growth was obtained when P and/or S were added alone or in combination with N. On Mercoal soils, a combined application of 188N and 56S consistently gave larger 10-year tree volume responses than N alone in both 30- and 70-year-old stands. The effect of P on volume growth was not statistically significant. Fertilization improved 10-year total stand volume growth by as much as 31 and 34 m³/ha in 70-year-old Mercoal and Coalspur stands, respectively. These represent increases of up to 50% in periodic stand volume increment. However, net stand volume responses were less consistent than individual-tree responses because of mortality following fertilization in unthinned stands, especially in 30-year-old stands. Yang (1985b) suggested that thinning should precede fertilization in younger, unthinned stands.

In 1984, the Canadian Forestry Service established a fertilizer x thinning trial in a densely stocked, 40-year-old lodgepole pine stand southwest of Hinton. Factorial combinations of thinning (unthinned, thinned to 2100 stems/ha) and fertilization (0, 180, 360, and 540 kg N/ha, as ammonium nitrate) were applied to 72, 0.03-ha circular plots (i.e., eight treatments x nine plots per treatment). In addition to N, fertilized plots received 40 kg/ha of P and 40 kg/ha of S. Thinning and initial measurements were completed in the summer of 1994 and fertilizer was applied in the fall of 1995.

Applications of N at 360 kg/ha to thinned and unthinned plots, respectively, improved 10-year periodic height increment by 20 and 19%, and diameter at breast height by 29 and 34% (Yang 1998). Fertilization at 540N had a negative impact on height increment in thinned plots. Fertilization with 360N produced the largest stand BA responses in both thinned and unthinned stands after 10 years. Relative BA responses in thinned and unthinned stands were 21 and 36%, respectively. Relative 10-year stand volume responses to 360N were 25 and 29% in thinned and unthinned stands, respectively. In absolute terms, fertilization produced up to 23.0 and 17.1 m³/ha of "extra" wood on unthinned and thinned plots after 10 years. Yang (1998) indicated that fertilization at this level was optimal based on foliar and mensurational responses.

Alberta Land and Forest Service

In 1989, two fertilizer x thinning experiments were established in a 23-year-old, fire-origin lodgepole pine stand near Edson. In one study, factorial combinations of three thinning methods and three fertilization regimes were replicated four times, for a total of 36 fixed-area treatment plots. The thinning methods were: 1) no thinning; 2) selective tree thinning (1600 stems per hectare); and 3) simulated machine row thinning. The fertilizer regimes were (kg/ha): 1) 0N:0P:0K; 2) 250N:150P:200K; and 3) 500N:300P:400K. The second large fixed-area-plot trial tested three thinning methods and six fertilizer treatments. The three thinning treatments were the same as used in the first study. The six fertilizer treatments were (kg/ha): 1) 0N:0P:0K; 2) 0N:150P:200K; 3) 200N (as urea):150P:200K; 4) 200N (as ammonium nitrate):150P:200K; 5) 400N (as urea):150P:200K; and 6) 400N (as AN):150P:200K. Each of the 18 factorial combinations was replicated four times for a total of 72 fixed-area treatment plots.

The results from these two well-designed experiments have never been formally reported. In an unpublished report, however, the fertilizer main effects indicated about 50% increases in dbh increment over unfertilized treatments after three growing seasons. There was little difference between N application rates and N source[2]. These trials were recently remeasured by Weldwood of Canada Ltd. (Hinton).

[2] Takyi, S. Undated. Some trends in the response of a 26-year-old lodgepole pine stand to fertilization and thinning. Alberta Environment, Land and Forest Service, Edmonton. Unpubl. report.

Forest Licensees

Since 1997, Weldwood of Canada Ltd. (Hinton) and Miller Western Forest Products Ltd. have established approximately 50 fertilizer screening trials in mid- and late-rotation lodgepole pine stands within their respective operating areas. Urea and ammonium nitrate, alone and in combination with other nutrients, have been tested in both thinned and unthinned stands. Preliminary results from some of the Weldwood trials are reported elsewhere in these proceedings (Braun and Navratil 2001).

Weldwood of Canada Ltd. has also recently established nine fixed-area plot fertilization trials. Seven trials have been established in older, unthinned stands; the others in row thinned, 35-year-old stands. The following fertilizer treatments are being tested: 1) unfertilized; 2) 200N + boron; and 3) 200N + "complete blend." In addition, Weldwood has recently established 14 "paired-plot" fertilizer trials to document the effects of fertilization on mortality and stand differentiation in 40- to 60-year-old, repressed lodgepole pine (T. Braun, per. comm.).

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Incremental Silviculture of Lodgepole Pine

T. P. Sullivan[1]

Introduction

Managing and conserving forests for biological diversity has become a major objective for forested landscapes in North America. This objective may be achieved by a combination of practices that provide a variety of forest successional stages (including old-growth), tree species, stand structures and silvicultural treatments in a mosaic of habitats across a landscape. Perhaps the greatest opportunity to diversify forests lies in the vast areas of young second-growth lodgepole pine stands which are amenable to silvicultural practices that accelerate ecosystem development.

This brochure reports on two ongoing studies:

A—Ten-year results in pre-commercially thinned stands; and

B—Five-year results in thinned and fertilized stands.

Study A—Thinned stands of lodgepole pine

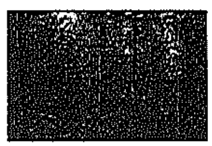
Young lodgepole pine stands are currently thinned to within a narrow range of densities in pre-commercial thinning programs (typically 1400 to 1600 stems/ha). Thinning can dramatically alter stand structure and the rate and direction of ecological succession. Hence, diversification of thinning prescriptions could have profound implications for wildlife habitat and biological diversity.

Low density stands can create early successional stages of herb and shrub layers. This provides forage and cover for several wildlife species. In addition, open-grown crop trees can simulate late seral and old-growth conditions. These stands are tailored to large diameter timber and quality products.

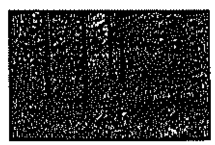
Stands of higher density provide important thermal, security and nesting cover for wildlife. Thickets and patches of dense pine provide important habitat for many fur-bearing species and their prey. These stands are well suited for wood volume production (construction lumber).

Study areas were located near Penticton, Kamloops and Prince George. Each study area had stands thinned to ~500 (low), 1000 (medium), and 2000 (high) stems/ha in 1988, with an unthinned juvenile and old-growth pine stand for comparison. The low-density stands were pruned (3 m lift) in 1992. Stand ages in 1988 were 17 years (Penticton), 23–27 years (Kamloops), and 15–20 years (Prince George).

Pre-commercially thinned lodgepole pine stands



500 stems/ha - 1988



Ten years later - 1998

1000 stems/ha - 1988

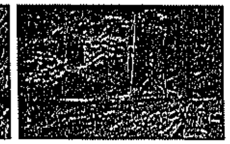
Ten years later - 1998

2000 stems/ha - 1988

Ten years later - 1998

[1] Applied Mammal Research Institute, Summerland, BC

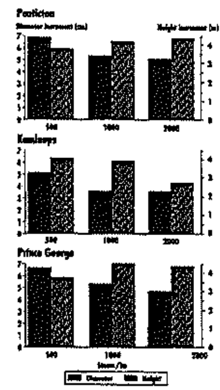
Old-growth pine stand



Growth and structure

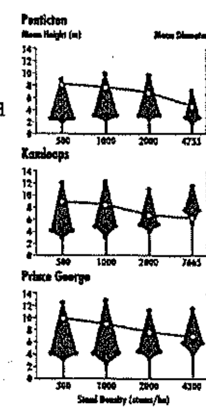
Diameter and height

- Mean diameter increment highest in low-density stands.
- Mean height increment similar in medium and high-density stands and both higher than low-density stands at Penticton and Prince George.
- Mean height increment similar in low- and medium-density stands, but higher than that in high-density stand at Kamloops.



Crown volume

- Mean crown volume higher in low- and medium-density stands than in high-density and unthinned stands.

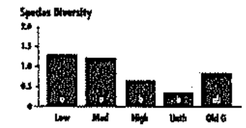


Coniferous trees

Tree crowns in low-density stand

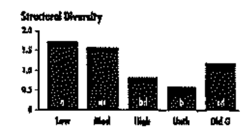
Species diversity

- More diverse component of coniferous species in low- and medium-density stands than in high-density and unthinned stands.



Structural diversity

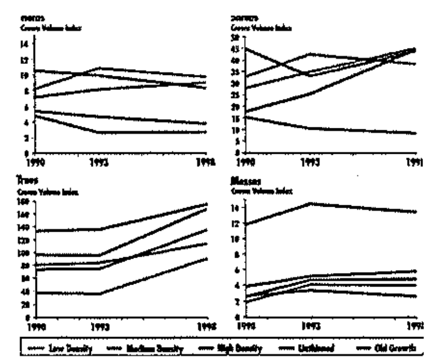
- Greater diversity within coniferous tree layers in low- and medium-density stands than in high-density and unthinned stands.



Vegetation

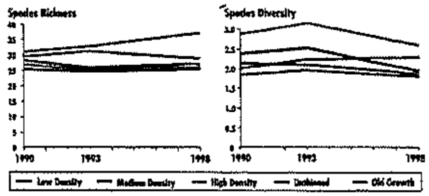
Amount of vegetation

- Similar herb biomass in 1990 but higher in all three thinned stands than in unthinned and old-growth stands in 1998. No difference in shrubs and trees. Mosses highest in old-growth stands.



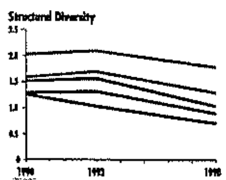
Total species diversity

- No difference in number of species but tendency for highest diversity in low-density stands.



Total structural diversity

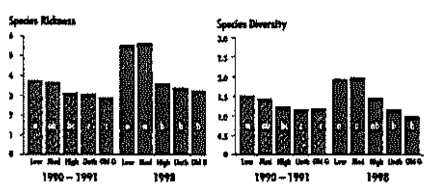
- No difference in number of layers of herbs, shrubs and trees but higher structural diversity in low-density stand than in medium-density, unthinned and old-growth stands in 1998.



Small mammal communities

Species richness and diversity

- Mean species richness highest in low- and medium-density stands.
- Mean species diversity highest in low- and medium-density stands.



Study A conclusions

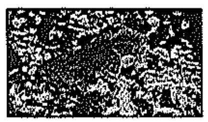
Ten Years Post-thinning

Low-density stands

- Diameter growth enhanced
- Crown volume enhanced
- High diversity of conifer species and stand structure
- Small mammal species richness and diversity high
- Old-growth structural features
  - snow interception for ungulate winter range
  - potential habitat for forest carnivores
  - diverse understorey
- Shorter rotations
- Few snags for wildlife
- Reduced wood volume, quality products.

High-density stands

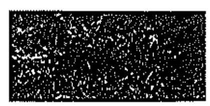
- Height growth enhanced
- More snags for wildlife
- Longer rotations
- High wood volume, sawtimber, pulp.



Red-backed vole

Deer mouse

Heather vole



Shrew

Short-Tailed weasel

Northwestern chipmunk

Long-tailed weasel

Meadow vole

Jumping mouse

Study B—Thinned and fertilized stands of lodgepole pine

Lodgepole pine responds well to conventional fertilization and potentially to optimum nutrition. This latter practice is designed to maximize the productivity of crop trees by adjusting the nutrient supply to the uptake requirements of the stand, thereby maintaining steady state nutrition. Annual nutrient applications gradually increase the nutrient delivery capacity of the soil to a level where the ecosystem is saturated. The ecosystem then cycles the nutrients needed for high production throughout the remainder of the rotation with little additional fertilization. Thinning and fertilization treatments applied over the whole ecosystem have the potential to significantly increase wood production and enhance stand structure and wildlife habitat diversity over time. This suggests that a continuous and diverse flow of wood products may be coupled with provision of diverse wildlife habitats and may also benefit livestock forage in understorey vegetation.

Overview of study area TFL 49, Riverside Forest Products Ltd.

Study B tested hypotheses that thinning and fertilization over a range of densities on large-scale units would enhance:

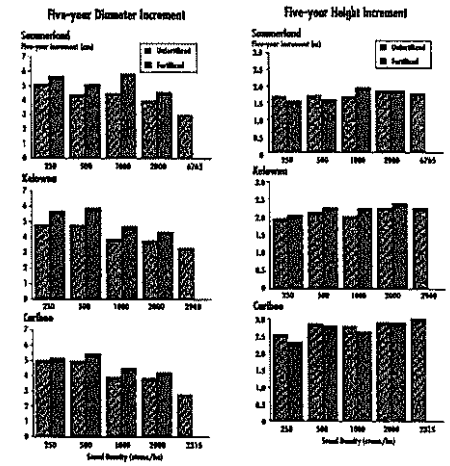
- Productivity of crop trees
- Stand structure attributes
- Species diversity of small mammal communities
- Relative habitat use by large mammals
- Forage for cattle.

Study areas were located near Summerland, Kelowna and Gavin Lake (Cariboo). Each study area had four sets of paired stands thinned to 250, 500, 1000 and 2000 stems/ha in 1993, with an unthinned pine stand for comparison. Stand ages in 1993 ranged from 12 to 14 years. Fertilization (optimum nutrition) of one stand of each pair was initiated in fall 1994 and repeated in 1996 and 1998. A cattle-proof exclosure was constructed in each stand to provide a measure of vegetation response in the absence of grazing by livestock.

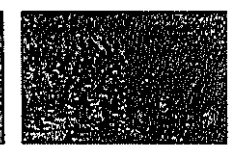
Growth of crop trees

Five-year height and diameter increments

- Diameter growth of crop trees faster in low-density and in fertilized stands.
- Height growth of crop trees faster in high-density stands.



Fertilized stands of 2000 stems/ha (on left) and 500 stems/ha on (right)

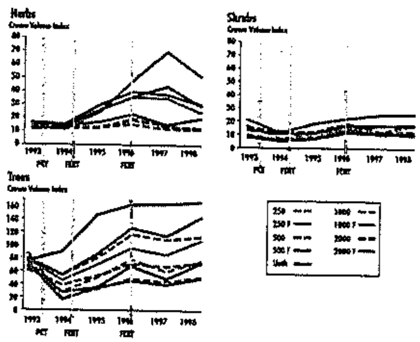


Fertilized stands of 250 stems/ha (on left) and 1000 stems/ha on (right)

Vegetation

Amount of vegetation

- Herbaceous vegetation increased in fertilized stands.

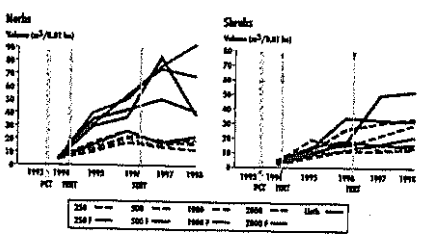


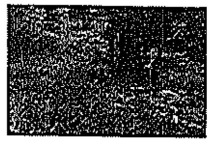
Vegetation in 250 stems/ha stands

Unfertilized *Fertilized*

Vegetation - Exclosures

- Herbs increased in exclosures in fertilized stands, providing forage for cattle.



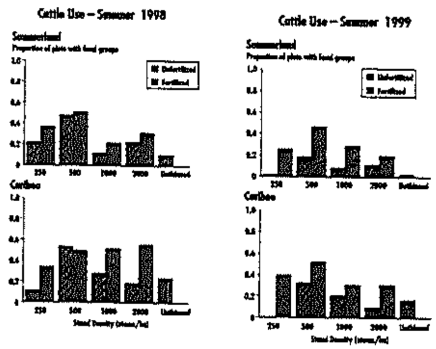


Vegetation inside (left) and outside (right) of a cattle exclosure

Cow foraging in fertilized stand

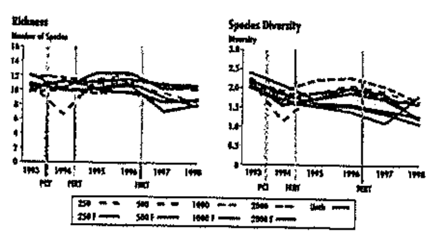
Cattle use

- Relative habitat use by cattle was greater in the low- than high-density and unthinned stands in 1998. In 1999, cattle used fertilized stands more than unfertilized stands.

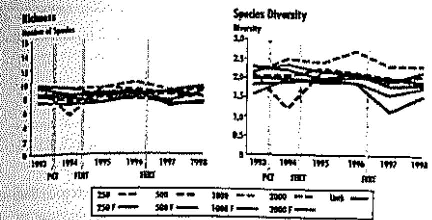


Species diversity – Herbs

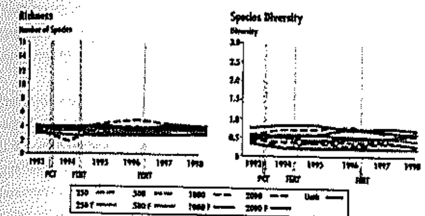
- At five years post-treatment, plant species richness and diversity not affected by stand thinning or fertilization.



Species diversity – Shrubs

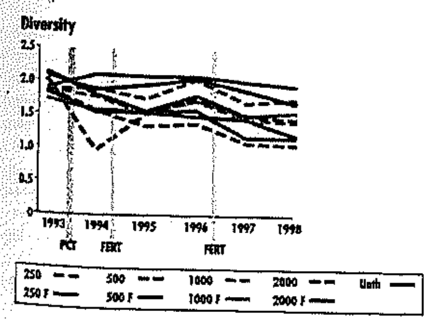


Species diversity – Trees



Structural diversity

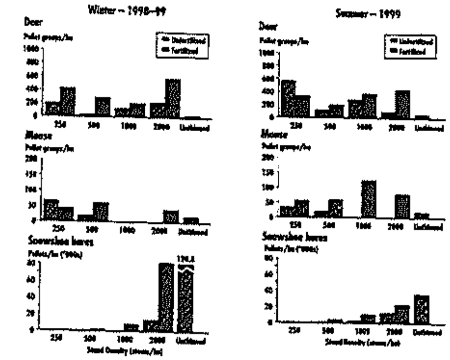
- Diversity of vegetation layers higher in low-density stands.



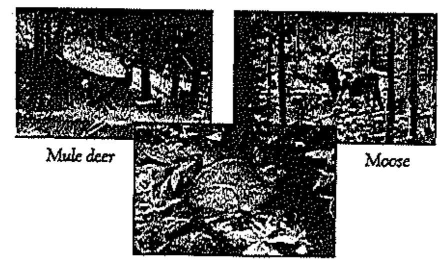
Mammals

Habitat use - Kelowna

- Relative habitat use by deer was similar across thinned and fertilized stands and tended to be higher than in the unthinned stands. Moose also followed this pattern



with use of all fertilized stands in summer 1999. Snowshoe hares preferred the high-density and unthinned stands.



Mule deer *Moose* *Snowshoe hare*

Small mammals

- Stand density and fertilization had no effect on mean abundance or species diversity of small mammals up to 1997. Abundance of small mammals peaked in 1994 and again in 1998. Total abundance appeared higher in fertilized than unfertilized stands in 1998.

Five years post-treatment

In general, silvicultural treatments such as pre-commercial thinning and fertilization do not negatively impact habitat productivity (vegetation biomass and structural diversity) or mammal communities, as indicated by the data collected in this study. Habitat quality and crop tree productivity will likely improve as these stands develop. A variety of silvicultural treatments using variable stand densities, fertilization and tree species in a "mosaic" of habitats across a "landscape" should provide for natural levels of biodiversity. Each habitat will have various groups of species; many different habitats and species can be expected at the large-scale landscape level. This approach uses "wildlife habitat diversity" as an indicator of biological diversity.

An additional component of this ongoing study is the comparison of biodiversity and sustainability in a mosaic of forest habitats (managed and unmanaged): young plantation, unthinned pine, pine thinned to 1000 stems/ha, pine thinned to 1000 stems/ha and fertilized, mature stand, and old-growth stand versus an unmanaged mosaic of forest habitats (mature and old-growth stands). Wildlife diversity is represented by trees and understorey vegetation (habitat structure), small mammal communities, and habitat use by large mammals.

References

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Sullivan, T.P., D.S. Sullivan, P.M.F. Lindgren, R.P. Brockley, and R. Winter. 2001. Influence of thinning and fertilization on stand productivity, habitat structure, mammal diversity, and range forage: 5-year results in young lodgepole pine forest. (In preparation).

Foliar analysis as a planning tool for operational fertilization

R.P. Brockley[1]

Introduction

Foliar analysis can be a convenient and cost-effective method for evaluating the nutrient status of forested sites. It provides an index of the amount of nutrients actually taken up by the tree and, as such, is based on the concept that the tree, not the soil, may be the best indicator of soil nutrient availability. By documenting foliar concentrations of individual nutrients, and overall foliar nutrient balance, foliar analysis reflects both soil nutrient availability and the degree to which trees require, or are capable of using, soil nutrients.

Lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) forests in the British Columbia's interior are commonly nutrient deficient, and foliar analysis is widely used by forest practitioners to evaluate their nutrient status as part of the stand selection process for large-scale fertilizer operations. Often with help from a forest nutrition specialist, foliar nutrient levels from collected samples are compared with published diagnostic criteria to confirm nitrogen (N) deficiencies, and to infer whether other nutrients will either limit growth response or become growth-limiting after N is added. Analytical results are often used to prescribe fertilizer formulations for candidate stands.

Foliar analysis is also used extensively by research scientists to interpret results from fertilization research experiments, the results from which are then used to refine foliar nutrient diagnostic criteria.

This paper reviews foliar analysis methodology and discusses ways in which foliar analysis can be effectively used as a planning tool in fertilizer operations.

[1] B.C. Ministry of Forests, Kalamalka Forestry Centre, Vernon, B.C.

Foliar analysis as an operational tool

When used properly and efficiently, foliar analysis can be an effective tool for planning and monitoring operational fertilization projects. Foliar analysis information can be used to: 1) diagnose possible nutritional reasons for poor quality or rate of tree growth; 2) identify stands that will likely respond well to nutrient additions; 3) prescribe fertilizer formulations to correct inferred nutrient deficiencies and stimulate tree growth; and 4) assess post-fertilization uptake of applied nutrients and foliar nutrient balance. However, stand nutrient status is only one of several factors to be considered when assessing the suitability and priority of candidate stands for aerial fertilizer operations. Foliar sampling should only be undertaken on sites that satisfy other forest- and stand-level selection criteria. For example, foliar sampling is a wasted expense if stand structure or health indicate poor fertilization response potential or if there are serious non-nutritional constraints on site productivity.

Foliar sampling guidelines

Nutrient concentrations in conifer foliage can be strongly influenced by factors such as crown position, foliage age, time of year, and sample handling. It is essential, therefore, to use standardized procedures when sampling and processing foliage; otherwise, a reliable comparison of measured foliar values with published interpretative criteria may not be possible. A manual prepared by Ballard and Carter (1986) offered guidelines for collecting, preparing, and analyzing foliage samples and for interpreting analytical results. Although no longer readily available, this publication is still a primary source of information for silviculturists assigned the task of collecting foliage samples and interpreting analytical results. In recent years, extensive research has been undertaken by the British Columbia Ministry of Forests to determine the nutrient status of lodgepole pine and to document the effectiveness of fertilization in improving stand growth. These research results have been used to refine foliar interpretative criteria and update guidelines for the collection and handling of foliage samples (Brockley 2001*a*).

Fortunately, standardized foliar sampling guidelines have gained general acceptance in British Columbia. These guidelines, applicable to most conifer species, are summarized below:

1. Collect foliage during the dormant season, preferably between October 1 and December 31.
2. Confine sampling to current year's foliage.
3. Collect foliage from between the top one-quarter and the bottom one-half of the live crown.
4. Confine sampling to dominant and codominant trees.
5. Do not collect foliage from trees with heavy cone production, or with insect or disease problems.
6. Do not collect foliage from trees that are situated close to unpaved roads, where foliage may be contaminated by dust.

Some scientists have argued that sampling should be done during the active growing season, when trees are under their greatest nutrient demand. However, foliar levels of many nutrients fluctuate dramatically during the growing season, making it difficult to reconcile foliar results with interpretative criteria. Dormant season sampling is recommended due to the relative stability of nutrient levels throughout this period.

Reliable interpretations of foliar analytical data depend on the assumption that the data represent the forest stand (or stratum) in question. To evaluate the nutrient status of candidate stands for operational fertilization, foliage sampling of 15 to 20 trees per stand (or stratum) should provide adequate levels of precision and confidence for most macro- and micronutrients (Ballard 1985).

After foliage is collected, a decision must be made on whether the foliage from each tree will be analyzed separately or composited by amalgamating with foliage from other trees. Although composite analysis does not permit assessment of within-stand nutrient variability, it will, in most cases, provide reasonable estimates of mean foliar nutrient concentrations for the stand in question. For routine diagnostic purposes, composite sampling is desirable because it requires a smaller sample size per tree and greatly reduces the number, and hence the cost, of chemical analyses.

Interpretation of foliar nutrient data

Interpretation of foliar nutrient data generally involves an assessment of the foliar concentration of individual nutrients relative to published "critical levels," in combination with an evaluation of overall foliar nutrient balance. This combined approach is based on the premise that the relative proportions of nutrients in the foliage are as important (or more so) than absolute amounts.

The critical level for a particular nutrient (or nutrient ratio) is generally defined as the foliar nutrient concentration (or ratio) below which a significant decline in growth occurs, assuming all other nutrients are adequately supplied. Published interpretative criteria, indicating deficiency and sufficiency ranges for individual species, nutrients, and nutrient ratios, are based on a wide range of field or greenhouse experiments. Brockley (2001) recently published updated foliar interpretative criteria for lodgepole pine.

Unfortunately, the interpretation of foliar nutrient data is not particularly straightforward, even when interpretative criteria are available. Foliar nutrient interpretations are subject to serious shortcomings when foliage is collected using non-standardized methodology, and when data are reviewed without knowledge, or consideration of, site and stand conditions. The current growth performance of the stand, environmental characteristics of the site, and other factors (e.g., insect or disease problems) affecting foliar nutrient status should always be considered when interpreting foliar nutrient data. Foliar analysis results can also be affected by differences in analytical methodology used for the extraction or determination of foliar nutrients. For most nutrients, methodological differences are likely too small to affect interpretation of nutrient sufficiency or deficiency. However, inter-laboratory comparisons have shown that differences between foliar N levels obtained from combustion and wet digestion methods are relatively large (Figure 1). For inorganic sulphate-S (SO_4), results with ion chromatography compare favourably with the hydriodic acid (HI) reduction-bismuth colorimetric method. However, results obtained with an inductively coupled plasma (ICP) spectrophotometer are generally much higher than those obtained with the other two methods (Figure 2). Fortunately, these inter-laboratory comparisons indicate that relationships between the results obtained with different analytical methods are relatively strong.

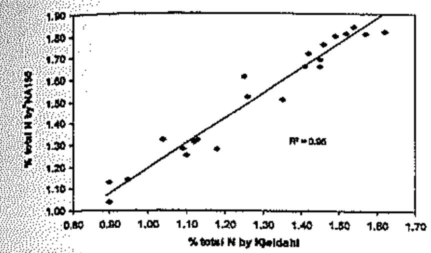

Figure 1. Relationship between foliar N concentration determined by combustion (NA1500) and wet digestion (modified Kjeldahl) methods.

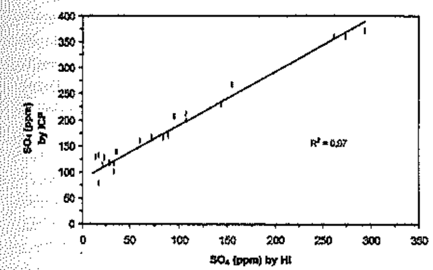

Figure 2. Relationship between foliar sulphate-S concentration determined by inductively coupled plasma (ICP) spectrophotometer and HI-deduction - bismuth colorimetric methods.

Even when the above complexities are adequately dealt with, intangible knowledge accumulated from years of foliar analysis and fertilization research experience can be an important part of diagnosing probable nutrient deficiencies and formulating fertilizer prescriptions. Because field practitioners often lack this experience, the Canadian Forestry Service and the B.C. Ministry of Forests have jointly developed a Web-based "Lodgepole Pine Foliar Nutrient Diagnosis and Fertilizer Advisory System" (Thomson et al. 2001). This interactive, knowledge based system was developed specifically for forest practitioners to facilitate reliable diagnosis of lodgepole pine nutrient status and formulation of appropriate fertilizer prescriptions for large-scale fertilizer operations. An advantage of a Web-based system is that it is accessible to most personal computers and can be easily updated to broaden its scientific and practical applications. Users of the system are prompted for various input information, some of which is used for diagnostic purposes and some of which is simply reformatted and printed to provide complete documentation of the foliar sampling project. The system uses the input data to generate five types of output:

1. administrative information (name, organization, analytical laboratory, foliar sampling date) and pertinent site/stand documentation (latitude, longitude, BEC subzone, site series, elevation, mapsheet, stand age, origin, site index);
2. tabulated foliar concentrations of individual nutrients and calculated nutrient ratios;
3. comments on input information that may affect nutrient diagnosis or fertilization response potential (e.g., age and crown position of sampled foliage, stand health);
4. complete foliar nutrient diagnosis for all macro- and micronutrients for which data are provided; and
5. recommended fertilizer prescription to correct inferred nutrient deficiencies.

The system uses functions developed from inter-laboratory comparisons to automatically adjust foliar levels of some nutrients to a standard from which interpretations are made using criteria suggested by (Brockley 2001*a*). Foliar nutrient interpretations are then used to develop customized fertilizer prescriptions to correct inferred nutrient deficiencies.

A link to the "Lodgepole Pine Foliar Nutrient Diagnosis and Fertilizer Advisory System" can be found at the Canadian Forestry Service, Pacific Forestry Centre Web site at http://www.pfc.cfs.nrcan.gc.ca/silviculture/.

Foliar N and S as predictors of growth response

Extensive foliar analysis and fertilization research has been undertaken by the B.C. Ministry of Forests to determine the nutrient status of lodgepole pine and to document the effectiveness of fertilization in improving stand growth. These studies have confirmed that N deficiencies are widespread throughout the region and that N additions often have a substantial positive effect on tree and stand growth (Brockley 1989, 1991, 1995, 1996, 2000a, 2000b). Elsewhere in these proceedings, Brockley (2001b) reported that seventy-five percent of stands from which foliar nutrient information has been collected have foliar N levels lower than 1.15%, indicating moderate to severe N deficiency.

Approximately one-quarter of the stands have foliar N levels lower than 1.00%, indicating severe N deficiency (Ballard and Carter 1986; Brockley 2001a). In an analysis of 31 fertilization research trials, an overall trend of declining basal area response to fertilization with N alone was observed with increasing concentration of this nutrient in the foliage of unfertilized trees (Brockley 2000a). Pre-fertilization foliar N explained approximately one-half of the observed variation in relative basal area response among installations. Six-year basal area response to fertilization with N alone averaged 42% in installations with less than 1.1% foliar N. However, the average growth response in installations with greater than 1.2% foliar N was only 13%. By setting the critical level at 1.2%, foliar N correctly predicted statistically significant 6-year basal area response (or lack of it) to N fertilization in approximately two-thirds of the installations in this analysis. Studies with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Scots pine (*Pinus sylvestris* L.) have also reported strong negative relationships between stemwood responses to N fertilizer and pre-treatment levels of N in foliage (Turner et al. 1988; Hopmans and Chappell 1994; Sikstrom et al. 1998).

In the interior of British Columbia, sulphur (S) deficiencies, either induced or aggravated by N fertilization, have been implicated in limiting the effectiveness of added N in some lodgepole pine stands. Growth responses have been enhanced on some sites by combining S with N in fertilizer prescriptions (Mika et al. 1992; Brockley 1996, 2000; Brockley and Sheran 1994). Studies with radiata pine (*Pinus radiata* D. Don) and Douglas-fir have used pre-fertilization foliar SO_4 to predict whether or not stands will respond to N additions (Turner et al. 1977, 1979). The usefulness of foliar SO_4 in predicting fertilization response is based on the constant ratio between total N and organic S in the foliage of conifers (Kelly and Lambert 1972). Any S in excess of that required to balance foliar N in protein formation accumulates in the foliage as inorganic SO_4. Therefore, in the absence of other nutritional or non-nutritional constraints, stands with inadequate foliar N and large reserves of foliar SO_4 (indicating S sufficiency) will likely respond well to N fertilization. Conversely, stands with low pre-fertilization SO_4 reserves (indicating S deficiency) will likely not respond to N additions even if foliar N levels indicate N deficiency. Brockley (2000a) reported a positive relationship between relative basal area response to fertilization with N alone and foliar SO_4 concentration in lodgepole pine. Pre-fertilization foliar SO_4 explained 55% of the observed variation in relative growth response among 31 installations. Six-year basal area response to fertilization with N alone averaged 47% in installations with more than 80 ppm SO_4 in unfertilized foliage. The average response for installations with less than 60 ppm of SO_4 was only 15%. By setting the critical level at 60 ppm, the amount of SO_4 in unfertilized foliage was 87% effective in predicting whether a significant basal area response would occur following fertilization with N alone. Elsewhere in these proceedings, Brockley (2001b) reported that sixty percent of lodgepole pine research trials from which pre-fertilization foliar nutrient information has been collected have foliar SO_4 levels less than 60 ppm. These data indicate that S deficiencies are relatively common in the interior of British Columbia and that foliar analysis can be readily used as an operational tool to identify lodgepole pine candidate stands that will be likely be unresponsive to fertilization unless S is added to the fertilizer prescription.

Brockley (2000a) presented a multiple regression model, using two independent variables (foliar N and SO_4), that explained 68% of the variation in relative 6-year basal area response of lodgepole pine to fertilization with N alone. Pre-fertilization foliar N and SO_4 levels, as well as N:S ratios, were also useful in predicting whether growth response can be increased by combining S with the added N. Lodgepole pine stands with less than 60 ppm of foliar SO_4, or N:S ratios greater than 13, generally responded poorly to fertilization with N alone, but almost always responded well to combined applications of N and S. On the other hand, stands with greater than 60 ppm of foliar SO_4, or N:S ratios less than 12, rarely showed large incremental S response. Brockley (2000b) presented tables in which pre-fertilization levels of foliar N, SO_4, and N:S ratios can be used to determine the likelihood of obtaining growth responses to fertilization with N alone, or N in combination with S. Clearly, pre-fertilization foliar analysis is a useful way to confirm the presence, and severity, of N and S deficiencies in lodgepole pine and to predict growth response potential following N additions.

Foliar analysis to document boron status

Foliar analysis has been useful in documenting the boron (B) status of lodgepole pine in the interior of British Columbia. Low foliar B levels are most commonly associated with morrainal soils derived from igneous rocks and subject to periods of soil moisture deficit during the growing season. These soil conditions have been described as being especially susceptible to B deficiencies (Wikner 1983; Stone 1990). Low foliar B levels have also been documented on coarse-textured, glacial outwash soils with low organic matter in the B.C. interior, where high rainfall may deplete soil-available B. On both these soil types, acute B deficiency symptoms (i.e., top dieback) have been induced by N fertilization (Brockley 1989, 1996) with resulting negative impact on

stem volume response. Similar symptoms have been reported following N fertilization of Scots pine in Scandinavia (Braekke 1983) and radiata pine in New Zealand (Will 1985). In the absence of visual growth disturbance symptoms, subacute B deficiency has also been shown to reduce the N fertilization response potential of lodgepole pine. Combined N and B application significantly improved height (and thus volume) response over that obtained with N fertilization alone (Brockley 1990).

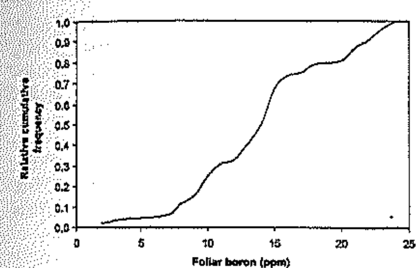

Figure 3. The relative cumulative frequency distribution of pre-fertilization foliar B concentration in lodgepole pole pine fertilization research trials (n=52) (Brockley unpubl. data).

Foliar analysis has proven to be an effective tool for identifying stands that are either B deficient or at risk from N-induced B deficiencies following operational fertilization. Where foliar B status is low or marginal stands can either be eliminated as candidates for operational fertilization, or a small amount of B (i.e., 2-3 kg B/ha) can easily be added to the fertilizer prescription. Figure 3 illustrates the cumulative distribution of pre-fertilization foliar B concentrations in 52 fertilization research trials in the interior of British Columbia. The vertical axis indicates the proportion of all installations that have foliar B levels less than or equal to a particular foliar concentration shown on the horizontal axis. Approximately one-third of the stands have foliar B less than 12 ppm, indicating the possibility of B deficiency, or deficiency induced by N fertilization.

Conclusions

Foliar analysis can be a reliable and cost-effective planning tool for fertilizer operations. In British Columbia, it is currently being used effectively to confirm N deficiencies and to identify stands in which other nutrients, most notably S and B, may have to be added to the fertilizer prescription in order to maximize growth response. A Web-based foliar interpretative system has recently been developed for lodgepole pine that diagnoses specific nutrient deficiencies and formulates fertilizer prescription to correct inferred deficiencies.

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An ecological approach to forest fertilization

Karel Klinka[1]

Abstract

Forest fertilization, like other silvicultural treatments, requires an ecosystem-specific approach for predicting potential responses to fertilizer treatments, and site classification for identification of potentially responsive sites. It is proposed that fertilization efforts should begin by gathering information on (i) the potential productivity of tree species on different sites, (ii) the variation of the potential productivity with site, and (iii) the environmental determinants of forest productivity. It is also proposed that a tree species will be considered potentially responsive if significant inter-relationships exist across a wide range of sites among site index, soil nutrients (primarily nitrogen), and foliar nutrients. This knowledge can then be utilized to select potentially responsive species and sites for fertilization. The proposed approach is demonstrated for coastal Douglas-fir and western hemlock, montane boreal lodgepole pine and interior spruce, and subalpine boreal subalpine fir, Engelmann spruce, and lodgepole pine. For each species, productivity data are presented and potential responses to nutrient (primarily nitrogen) additions are predicted and compared to the response obtained in fertilizer trials.

Introduction

Yield strategies require that potential productivity of all sites within a forest be fully utilized or even increased when the management objective is timber production. This implies a decision on whether to consider a sustained yield strategy, which is based on the site's carrying capacity without inputs of materials and energy, or an amplified yield strategy, which is a yield exceeding the original carrying capacity of the site which depends on such inputs. For long-rotation timber crops, Silen (1982) recommended sustained yield strategy with five tenets: (i) present soil fertility must be maintained or improved; (ii) the site must be occupied at all times by a full canopy of trees; (iii) the timber crop must be capable of using the site completely; (iv) growth constraints for timber crops should be relieved only when practical and feasible; and (v) trouble-free ecosystems should be maintained at low costs.

A large forested area usually consists of a variety of stands and sites, i.e., ecosystems. This variety will depend on the variability of climatic and edaphic conditions (site quality) and disturbance history. It is also self-evident that each tree species is adapted to a certain range of environmental conditions, and therefore, it will grow and respond in ways that depend on the ecosystems in which it grows. Thus, a rational forest management ought to be based on the ecosystem-specific (i.e., tree species- and site-specific) approach.

Depending on its environmental amplitude, any given forest site represents adverse, marginal, adequate, or optimal growing conditions for a given tree species. Under sub-optimal growing conditions the growth potential of a species will not be realized. The species may be more susceptible to damaging agents, and more effort may be required to establish and grow the species. Many forest sites impose constraints on tree growth that may be related to climate (temperature) and/or edaphic (soil moisture, nutrient, and aeration) conditions. There is little prospect that climatic, soil moisture, and soil aeration constraints can be relieved. Thus the manipulation and use of soil nutrient resources (i.e., nutrient management according to DeBell 1981) remain the only practical and feasible way to maintain or improve tree growth over the original carrying capacity of the site for some species, on some sites, and in some situations.

Nutrient management offers three options:

1. conservation of the soil nutrient resource (e.g., by preventing nutrient losses through selection of such practices and treatments that will have the minimum impact on tree growth);
2. optimization of the soil nutrient resource by (i) increasing nutrient availability and uptake (e.g., controlling decomposition of forest floor materials), (ii) increasing efficient use of nutrients (e.g., selection of tree species and genotypes), and

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3. addition or enhancement of the soil nutrient resource (e.g., fertilization and symbiotic nitrogen fixation).

The decision whether or not to fertilize a stand of a given species on a given site will depend on many factors. However, the primary consideration is the growth response to fertilization. Two fertilization objectives may be recognized: (1) growth stimulation or enhancement (typically through relief of nitrogen deficiency), and (2) growth rehabilitation (typically through relief of acute deficiency of a micronutrient).

Carter et al. (1998) concluded that forest fertilization research has provided few exacting tools or guidelines for diagnosing nutrient deficiencies and predicting responses to fertilizer treatments for a few tree species. Diagnostic research has focused on foliar and, less often, soil analysis using critical limits (e.g., van den Driessche 1974; Morrisson 1974; Ballard and Carter 1986), nutrient ratios (Ingestad 1974), and the concept of "nutrient balance" in methods such as the Diagnosis and Recommendation Integrated System (DRIS) (Beaufils 1973; Hockman and Allen 1990). These methods are generally applied in isolation from the other genetic, environmental, and stand factors that may influence nutrient levels, and consequently, they tend to be imprecise.

Prediction of fertilizer response, both in terms of predicting which sites will respond and predicting the magnitude of that response, has focused on empirical relationships. Examples of fertilizer response predictors include: site index (e.g., Miller et al. 1989; Shumway and Olson 1992; Carter et al. 1998), stand density (Allen 1983), soil properties (e.g., Shumway and Atkinson 1978; Powers 1980; Comerford and Fisher 1982; Peterson et al. 1984; Blake et al. 1988; Turner et al. 1988; Miller et al. 1989), foliar properties (e.g., van den Driessche 1979; Blake 1985; Turner et al. 1977, 1979, 1988; Timmer and Ray 1988), and vegetation types (e.g., Timmer and Ray 1988). Most researchers have used correlation, regression, or multivariate procedures to identify the "best" response predictors for their particular study. Predictive variables are normally subject to a wide variety of interactions with other stand structural and environmental factors limiting response predictions to rather broad generalizations.

Response to fertilization is a function of (i) the degree to which nutrients are limiting growth, (ii) the capacity of individual trees to respond to the addition of nutrients, (iii) the degree to which other factors limit growth, and (iv) the possible extrinsic effects of treatment (Carter et al. 1998). Recognition and examination of these factors is essential if response to fertilization is to be predictable. As the fertilizer response is the function of the species, site, stand history and structure, and the fertilizer itself, it is obvious that the response will be ecosystem-specific. The following discussion will focus on (1) the species and site factors, because the characteristics of responsive stands (i.e., age or tree size, density, and structure) are known (e.g., Ballard and Carter 1986; McWilliams and Carter 1995), and (2) nitrogen, because its deficiency is a nearly universal growth limitation (e.g., Zasoski 1979; Lavender and Walker 1979). Site index (m @ 50 yrs bh) will be used as the species-specific measure of forest productivity.

Efforts to fully utilize the productivity potential of forest sites and nutrient resource enhancement through fertilization ought to be based on knowledge of (i) the potential productivity of different tree species on different sites, (ii) the species-specific variation of the potential productivity with site, and (iii) the environmental determinants of forest productivity. It is also proposed that a potentially responsive tree species should exhibit strong and significant interrelationships among site index, soil nutrients (primarily nitrogen), and foliar nutrients across a wide range of sites. The stronger the inter-relationships, the simpler mechanisms of nutrient uptake; the weaker the inter-relationships, the more complex mechanisms of the uptake and response to nutrient additions. This knowledge can then be used to select potentially responsive species and sites for fertilization without the exact knowledge of nutrient requirements, mechanisms of nutrient uptake, and available soil nutrient levels. In this contribution, I shall present the available information on the potential productivity and productivity—site relationships for some Pacific Northwest timber crop species, and discuss implications of this information for potential growth response to nitrogen fertilization.

The prerequisite for the application of the ecosystem-specific approach is the development of site classification. If a forest, which consists of many different ecosystems, is classified into site units, then management of that forest can be simplified and, at the same time, given a sound ecological foundation. Forest ecosystems in any given site unit can be manipulated by the application of the ecological knowledge and experience relevant to that unit (Klinka and Feller 1984). The system of biogeoclimatic ecosystem classification uses three factors directly influencing plant growth as measures of site quality, as well as for defining environmental amplitude of plant species (Krajina 1969, 1972; Pojar et al. 1987). I shall relate climatic regime—represented by direct measures (e.g., actual evapotranspiration) or indirect measures (latitude, longitude, and elevation or biogeoclimatic subzone); soil moisture regime— represented by direct measures (e.g., water deficit or surplus) or field estimates; and soil nutrient regime—represented by direct measures (e.g., mineralizable-N) or field estimates (Klinka et al. 2000) to site index using analysis of variance, correlation, regression, and canonical correlation analyses. It is important to note that all these regimes can be easily identified; e.g., climatic regime can be identified from biogeoclimatic maps according to site location; and soil moisture and nutrient regimes can be estimated in the field using a combination of soil morphological properties, indicator plants (if present), and the methods described by Green and Klinka (1994).

Potential productivity of tree species, relations of site index to site quality and soil and foliar nitrogen, and potential responsiveness to nitrogen fertilization

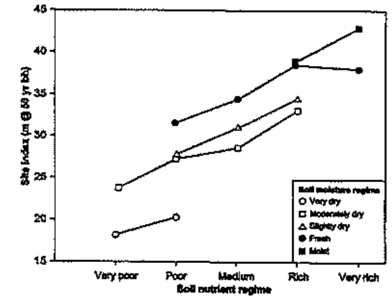
Coastal Douglas-fir on submontane cool mesothermal sites

Within a drier cool mesothermal climate of southern coastal BC (i.e., drier subzones of the Coastal Western Hemlock zone), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) site index predictably increased with increasing soil moisture and nitrogen, and foliar-N and needle mass were predictable from soil mineralizable-N (Table 1, Figure 1).

Table 1. Selected regression equations demonstrating the relationships between Douglas-fir site index and indirect and direct measures of soil moisture and nitrogen, and between foliar and soil nitrogen (n = 99) (from Klinka and Carter 1990). SI is site index (m @ 50 yr bh); VD, MD, SD, and F refers to very dry, moderately dry, slightly dry, and fresh soil moisture regimes, respectively; VP, P, M, R refers to very poor, poor, medium, and rich soil nutrient regimes, respectively; MminN is mineralizable-N in 0–30 cm mineral soil; WD is water deficit (mm); LMminN is natural log of MminN.

$SI = 34.6 - 24.0(VD) - 7.7(MD) - 3.0(SD) - 0.01(F)$	Adj $R^2 = 0.74$	SEE = 2.6 m
$SI = 35.5 - 13.2(VP) - 9.7(P) - 4.0(M) - 0.6(R)$	Adj $R^2 = 0.66$	SEE = 3.0 m
$SI = 21.7 - 0.046(WD) + 3.65(LMminN)$	Adj $R^2 = 0.63$	SEE = 3.2 m
$Foliar\ N(\%) = 1.073 + 0.008(MminN)$	Adj $R^2 = 0.54$	SEE = 0.12%

Site index increased linearly and consistently with increasing mineralizable-N, even on water-deficient sites. Given all these relationships, it can be implied that Douglas-fir within this climatic region, which represents the most favourable climatic conditions for its growth in British Columbia (BC), will respond in a predictable fashion to nitrogen additions even on water-deficient sites.



	Very poor	Poor	Medium	Rich	Very rich
Mineralizable-N (ppm)	7.3[d]	13.1[d]	25.2[d]	46.6[b]	170.5[a]
Foliar N (%)	1.14[a]	1.13[a]	1.19[a]	1.19[a]	1.24[a]
Mass of needles (mg)	470[b]	469[b]	479[b]	552[a]	610[a]

Figure 1. Douglas fir site index in relation to soil moisture and nutrient regimes in a dry cool mesothermal climate of coastal British Columbia, and the relationships between soil nutrient regimes, 0–30 cm mineral soil mineralizable-N, foliar N, and mass of 100 needles (n = 149) (from Carter and Klinka 1992).

Douglas-fir is one of the few species with large amount of information on fertilizer response (e.g., Carter et al. 1998; Gardner 1990; Omule 1990; Stegemoeller and Chappell 1989). This species has shown a relatively consistent response to fertilization with various sources of nitrogen. One of the most relevant studies is that of Carter et al. (1998) who established a fertilization experiment on a wide range of sites to examine 3- and 6-year crop tree responses to prescribed fertilizer applications. They found the greatest and most consistent responses to fertilization on water-deficient and nitrogen-poor sites, with relative and absolute responses being significantly negatively correlated with site index (cf. Shumway and Olson 1992) and measures of mineralizable-N (Figure 2). Even the stands on sites with optimum water supply with site index >35 m and relatively low foliar-N concentrations (1.2–1.3%) had a significant response, indicating fertilization opportunities even on high-productivity sites.

The information required by the proposed approach to forest fertilization agreed with the response of Douglas-fir to nitrogen fertilization. It can be concluded that (i) Douglas-fir is a highly responsive species to nitrogen fertilization and (ii) its response is predictable.

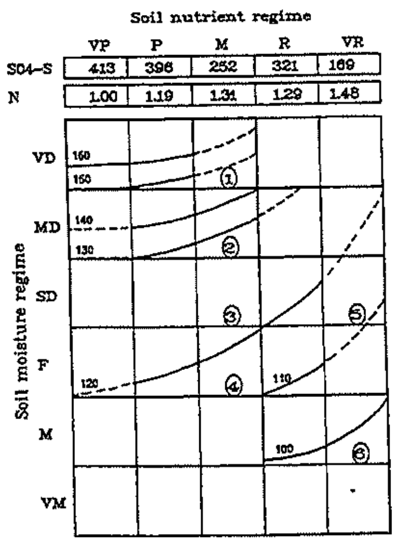


Figure 2. An edatopic grid showing six site types (outlined in boldface lines), pre-treatment foliar N (%) and sulphate-S (ppm), and isolines of relative basal area response indicating the third-year basal area response of Douglas fir to fertilization with nitrogen (from Carter and Klinka 1992). Dashed isolines are beyond the range of the study. Symbols for soil nutrient regimes are: VP— very poor, P—poor, M—medium, R—rich, and VR—very rich; symbols for soil moisture regimes are: VD—very dry, MD— moderately dry, SD—slightly dry, F—fresh, M—moist, and VM—very moist.

Western hemlock on submontane cool mesothermal sites

Kayahara (1992), Carter et al. (1992), Kayahara and Pearson (1995), and Kayahara et al. (1995a) studied relationships between western hemlock (*Tsuga heterophylla* (Raf) Sarg.) site index and analytical and categorical measures of site quality across a range of submontane sites in the Coastal Western Hemlock zone. Examination of the variation in site index along soil moisture and nutrient gradients showed no apparent relationships across a range that accounted for 80-90% of sites supporting productive growth of the species (Figure 3). Except for a steep increase from very poor to poor sites, site index peaked at medium sites and then it decreased to rich sites, with all study sites experiencing no significant water deficit or surplus. Of all chemical measures, only forest floor mineralizable-N, mineral soil C/N, foliar N, foliar S, and foliar N/P ratio had consistent but intrinsically non-linear (asymptotic) relationships with site index (Kayahara et al. 1995a). Western hemlock site index does not appear to increase consistently with increasing nitrogen availability, as the most productive stands were not associated with rich sites. Kayahara et al. (1995a) reviewed several possible reasons for the difference in this site index pattern compared to Douglas-fir.

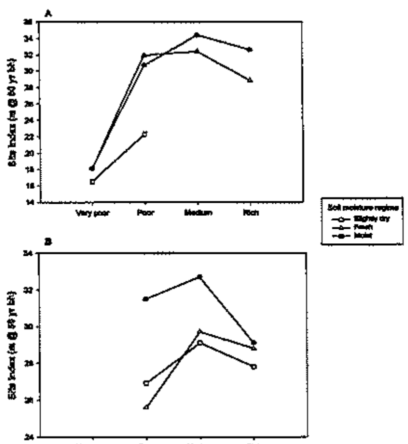


Figure 3. Western hemlock site index in relation to soil moisture and nutrient regimes across the Coastal Western Hemlock zone. A—from Kayahara and Pearson (1995); B—from Carter et al. (1992).

The relationship between western hemlock productivity and soil nutrients is unclear. While Krajina (1969) stated that it grows best on sites with a well-balanced, small-quantity supply of nutrients, Packee (1990) claimed that its site index increases with increasing availability of soil nitrogen. The presented variation in site index in relation to soil moisture and nutrient regimes, and the growth decline together with a poor growth form of western hemlock consistently observed on nitrogen rich and very rich sites (Figure 4) supports Krajina's assertion, and implies uncertainties in predicting its potential response to nitrogen fertilization.

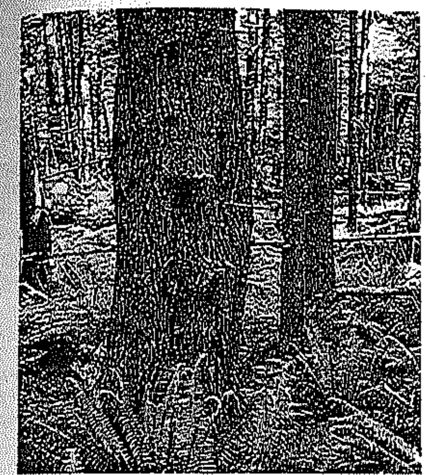


Figure 4. Distorted stem form of western hemlock growing on a nitrogen-rich site (Campbell River Forest District).

Indeed, western hemlock has responded very erratically to fertilization. Over the past 25 years numerous western hemlock fertilizer trials have shown responses ranging from negative to positive with no clear trends or agreed upon explanations and reliable methods of predicting a response to fertilization (e.g., DeBell 1975; Webster et al. 1976; RFNRP 1982; Stoegmoeller 1989; Weetman et al. 1989; Omule 1991; Chappell et al. 1992; Shumway and Olson 1992; Carter et al. 2001).

Carter et al. (2001) fertilized 44 stands across a range of sites in the Coastal Western Hemlock with nitrogen alone and blend fertilizer. After the first growing season, foliar analyses indicated that only two sites showed a significant increase in needle weight with the N-alone treatment, while seven sites showed an increase with the blend treatment. Three growing-seasons after the application of the fertilizer, only 12 stands showed a significant absolute basal area response to fertilization. Significant absolute basal area responses were found in stands growing across a wide range of site indices and soil moisture and nutrient regimes. Foliar N and P concentrations across all study sites (1.27% and 0.16%, respectively) appeared to be independent of site index. Pre-treatment foliar P concentration and post-treatment foliar SO_4-S concentration were the only explanatory variables that showed a significant relationship to relative basal area response among sites. While fertilizer responses were occasionally high, average responses were generally in the range from 5 to 10%. They concluded that (i) high values of foliar N suggest possibilities that nitrogen is not growth-limiting on many sites, (ii) successful fertilization will require application of multi-nutrient fertilizers, which is severely constraining to opportunities for economic fertilization, and (iii) western hemlock should be viewed as a high risk species for fertilization.

In the absence of a moisture deficit or surplus, there is an expectation that tree growth will respond positively to an increase of soil nutrients. Douglas-fir meets this expectation with site index increasing linearly with increasing soil mineralizable-N levels and foliar N concentrations that are strongly correlated with soil mineralizable-N levels. These relationships were not detected for western hemlock. Furthermore, the effectiveness of first growing-season fertilizer response measures for Douglas-fir has been supported by studies examining tree species that exhibit determinate shoot growth, but no such support exists for indeterminate western hemlock (Carter et al. 2001). The information required by the proposed approach to forest fertilization agreed with the results of fertilizer trials. It can be concluded that the response of western hemlock to nitrogen fertilization is unpredictable.

Lodgepole pine and interior spruce on montane boreal sites

Relationships between potential site index of lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Loud.) and interior spruce (*Picea engelmannii* Parry ex Engelmann x *P. glauca* [Moench] Voss) (including white and hybrid spruce) and analytical and categorical measures of site quality were studied by Wang et al. (1994), Klinka et al. (1994), Kayahara et al (1995b) in the Sub-boreal Spruce (SBS) zone of British Columbia, and by Brisco (2001) in the Boreal White and Black Spruce (BWBS) zone (Upper Foothills natural subregion) of Alberta. Site index of both species (i) increased with increasing soil water supply from water-deficient to fresh and moist sites and then decreased with increasing water surplus, and (ii) increased from very poor through very rich sites, with the rate of increase decreasing with increasing nitrogen availability. Increase in lodgepole pine site index along the soil nutrient gradient was consistently steeper than along the soil moisture gradient (Figure 5).

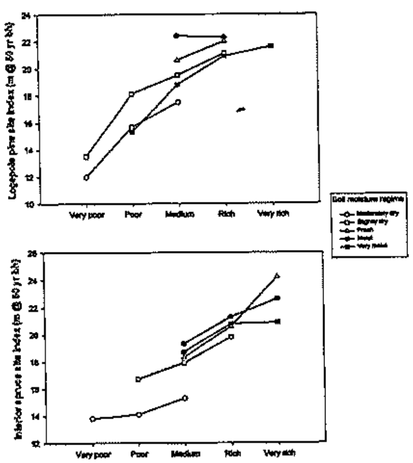


Figure 5. Site index of lodgepole pine (n = 235) (A) and hybrid spruce (n = 221) (B) in relation to soil moisture and nutrient regimes across the Sub-boreal Spruce zone (from Kayahara et al. 1995b).

Compared to interior spruce, lodgepole pine site index appears to improve with increasing nitrogen availability even on water-deficient sites. These trends are supported by regression analysis indicating that (i) soil moisture and nutrient regimes had a strong relationship with site index, and (ii) soil nutrient regime explained more variation in lodgepole pine than interior spruce site index (Table 2). The best quantitative soil measure related to site index of both species was forest floor and mineral soil C/N ratio, which explained about 40% in the variation of site index in both species.

Brisco (2001) characterized soil nutrient regimes by several nitrogen related measures (i.e., total N, mineralizable-N, and forest floor C/N ratio and P) and determined foliar nutrient levels in young lodgepole pine stands across a range of sites. He found (i) significant differences in needle mass and foliar levels of N, P, and S between soil nutrient regimes, and (ii) strong correlations between soil and foliar nutrient variables. In a relatively dry montane boreal climate (mean annual precipitation = 343 mm) of his study area, soil moisture regime accounted for 63% and soil nutrient regime for 32% of the variation in lodgepole pine site index. Taking into consideration all this information, it can be concluded that in the SBS and BWBS zones (i) both soil moisture and nitrogen are the major determinants of tree growth, and (ii) lodgepole pine and interior spruce will respond to nitrogen fertilization, with the response likely decreasing with increasing soil water surplus and availability of soil nitrogen.

Table 2. Selected regression equations demonstrating the relationship between site index of lodgepole pine (n = 93) and interior spruce (n = 55) and categorical and analytical measures of soil moisture and nitrogen (from Wang et al. 1994 and Klinka et al 1994). SI is site index (m @ 50 yr bh), VD, MD, SD, F, and M refers to very dry, moderately dry, slightly dry, fresh, and moist soil moisture regimes, respectively; VP, P, M, R refers to very poor, poor, medium, and rich soil nutrient regimes, respectively; CNff and CNms is carbon/nitrogen ratio of forest floor and mineral soil, respectively.

Lodgepole pine

SI = 8.90 + 5.25(VD) + 6.68(MD) + 9.04(SD) + 11.92(F) + 11.18(M) + 6.30(W)
Adj R^2 = 0.45 SEE = 2.4 m n = 93

SI = 20.23 − 7.98(VP) − 4.11(P) − 1.09(M) − 0.51(R)
Adj R^2 = 0.60 SEE = 2.0 m n = 93

SI = 34.2 − 0.27(CNff) − 0.30(CNms)
Adj R^2 = 0.36 SEE = 2.5 m n = 70

Interior spruce

SI = 4.30 + 3.67(VD) + 10.08(MD) + 13.59(SD) + 16.05(F) + 15.38(M) + 6.55(W)
Adj R^2 = 0.65 SEE = 2.5 m n = 77

SI = 22.89 − 16.74(VP) − 9.43(P) − 6.03(M) + 3.58(R)
Adj R^2 = 0.58 SEE = 2.7 m n = 77

SI = 36.3 − 0.32(CNff) − 0.41(CNms)
Adj R^2 = 0.41 SEE = 2.9 m n = 55

Similar to Douglas-fir, there is a large amount of information on the growth responses of young lodgepole pine to nitrogen fertilization (e.g., Cochran et al. 1979; Yang 1985; Brockley 1989, 1990, 1996, 2001). In general, lodgepole pine responds favourably to additions of nitrogen, particularly in combination with other nutrients detected to be deficient in foliar analysis.

The information required by the proposed approach to forest fertilization agreed with the response of lodgepole pine and hybrid spruce to nitrogen fertilization. It can be concluded that (i) both species are responsive to nitrogen fertilization, (ii) their response is predictable, and (iii) their responsiveness will decrease with increasing water surplus.

Subalpine fir, Engelmann spruce, and lodgepole pine on subalpine boreal sites

Information is very limited on the potential productivity of high-elevation trees species, how productivity varies with site, and what are the environmental determinants of tree growth. As expected, site index of all these three major timber crop species in the Engelmann Spruce–Subalpine Fir (ESSF) zone increased from water-deficient sites to its peak on moist sites, and then decreased with increasing water surplus. However, the relationship to climatic and soil nutrient conditions varied with species (Klinka and Chen 2001) (Figure 6).

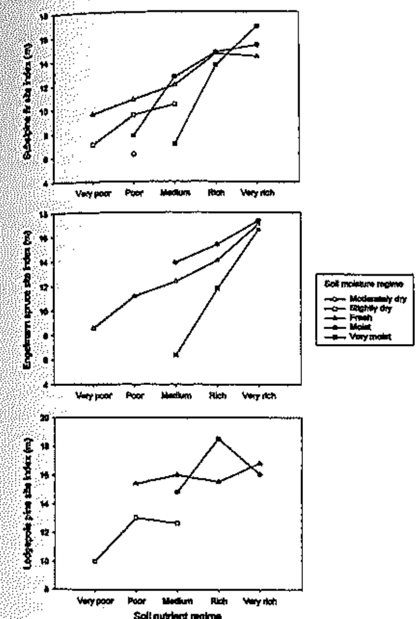


Figure 6. Site index (m @ 50 yr bh) of high-elevation subalpine fir (top), Engelmann spruce (center), and lodgepole pine (bottom) in relation to soil moisture and nutrient regimes in the Engelmann Spruce–Subalpine Fir zone (from Klinka and Chen 2001).

The most consistent linear increase in site index along a soil nitrogen gradient was detected for Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). In contrast, lodgepole pine site index showed no significant trend along this gradient. The variance in site index explained by regional climate (represented by biogeoclimatic subzones) was about the same for all three species, but the variance explained by aspect, used as a surrogate for local climate, increased from lodgepole pine (8%) to subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) (11%) to Engelmann spruce (24%) (Table 3). A similar but more distinct trend was detected for soil nutrient regime, which had almost no effect on lodgepole pine site index, a stronger, albeit still a relatively small, effect on the site index of subalpine fir (10%), and an even stronger effect upon Engelmann spruce site index (16%). Lodgepole pine was most strongly affected (44%) by soil moisture regime, which had a weaker effect on the site index of subalpine fir (18%) and still weaker effect on Engelmann spruce site index (9%) (Table 3).

*Table 3. Results of variance of the effect of biogeoclimatic subzone, aspect, SMR (soil moisture regime), SNR (soil nutrient regime), and SMR*SNR interaction on site index of subalpine fir, Engelmann spruce, and lodgepole pine in the Engelmann Spruce–Subalpine Fir zone (from Klinka and Chen 2001). Significant differences at P <0.05 (α = 0.05) are indicated in boldface print.*

Source	Sum of squares	Degrees of freedom	Mean square	F-value (α = 0.05)	P-value	Variance explained (%)
Subalpine fir						
Subzone	350.4	10	35.0	2.983	**0.0023**	13.1
Aspect	304.9	6	50.8	4.325	**0.0006**	11.4
SMR	481.6	6	80.3	6.832	**0.0000**	17.9
SNR	264.0	4	66.0	5.617	**0.0004**	9.8
SMR*SNR	15.1	7	2.2	0.183	0.9883	0.5
Error	1268.9	108	11.7			
Engelmann spruce						
Subzone	165.7	8	20.7	1.639	0.1327	8.9
Aspect	438.5	6	73.1	5.784	**0.0001**	23.7
SMR	167.4	4	41.8	3.311	**0.0162**	9.0
SNR	295.1	4	73.8	5.839	**0.0005**	15.9
SMR*SNR	27.0	5	5.6	0.443	0.8166	1.5
Error	758.2	60	12.6			
Lodgepole pine						
Subzone	86.4	7	12.3	2.810	**0.0162**	13.4
Aspect	50.7	6	8.4	1.923	0.0977	7.8
SMR	282.0	4	70.5	16.046	**0.0000**	43.6
SNR	2.4	4	0.6	0.134	0.9691	0.3
SMR*SNR	27.9	7	4.0	0.907	0.5096	4.3
Error	197.7	45	4.4			

Taking into consideration all the available evidence, it can be concluded that (i) climate and soil moisture are the major determinants of tree growth in the ESSF zone, and (ii) potential response to nitrogen fertilization will be none or poor, except on very poor and poor sites, likely increasing in order from lodgepole pine to subalpine fir to Engelmann spruce.

Summary

The ecological approach to forest fertilization was demonstrated for several softwood crop species of the Pacific Northwest. Available site-specific information on potential forest productivity and relationships among site index, soil and foliar nitrogen measures were examined, potentially responsive species and sites to nitrogen fertilization were predicted, and these predictions were compared to the response obtained in fertilizer trials. Except for western hemlock, predictions for low-elevation species were generally in agreement with the results obtained in fertilizer trials. The prediction made for high-elevation species, which indicated no or poor responses to nitrogen fertilization, could not be verified by fertilizer trials. The proposed approach could be used to identify potentially responsive species and sites for fertilization trials and serve as a framework for extending the results of these trials for operational fertilization.

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Forest fertilization in British Columbia: stand selection, types of fertilizers, delivery systems, and monitoring

Frank Barber

Abstract

The B. C. Forest Service began an operational fertilization program in 1978 that ran for five years. Roughly 37,000 hectares were treated, mostly on the coast. In 1985 the BC Forest Service began operational fertilization in the interior under the Federal Resource Development Agency (FRDA) agreement. The operational program has now been running in the interior for 15 years with approximately 172,234 ha fertilized. This paper highlights the BC Forest Service's Stand Selection Guidelines, types of fertilizers used operationally in the province, the two main delivery systems used in the interior, and how critical monitoring is at all stages of application, before, during and after.

The B. C. Forest Service has developed a Forest Fertilization Guidebook that is available at this web address (http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm). It provides more detail on how to develop and implement an operational fertilization program. The process has worked successfully in British Columbia for the past 15 years.

History of operational fertilization in B.C.

The B. C. Forest Service began an operational fertilization program in 1978 that ran for five years. Roughly 37,000 hectares were treated, mostly on the coast. The majority of fertilization in the province has been historically on the coast. In 1985 the BC Forest Service began operational fertilization in the interior under the Federal Resource Development Agreement (FRDA) I. From 1985 to 1990 a total of 55,573 hectares were fertilized in the province (30,774 ha coast; 24,799 ha interior), Under a FRDA II, provincially 27,527 hectares were fertilized (20,630 ha coast; 6897 ha interior). Under Forest Renewal British Columbia (FRBC) 52,288 ha have been fertilized provincially (41,041 ha coast; 11,247 ha interior) from 1995-2000. The provincial operational fertilization program has now been running in the interior for 15 years with approximately 43,309 hectares fertilized; 172,234 ha fertilized provincially.

The history of fertilization in the province of BC has been erratic. This has not provided stability for aerial applicators. Fertilization has been considered a "nice to" activity, and the first activity to shut down when there are down-turns in the economy. Aerial fertilization has been considered a non-labour intensive activity for which missing a year will not negatively impact stand growth. If maintaining timber supply or filling age class gaps is a high priority in your management unit then stability in your fertilization program is imperative. You must also have enough hectares in the appropriate age classes to significantly impact long term harvest volume.

Benefits from fertilization

Biological principles

Trees respond to added nutrients by increasing the rate of photosynthesis per unit of foliage area (Figure 1) and by increasing photosynthetic surface area through the production of more foliage and expansion of live crowns. These response mechanisms will apply regardless of the treatment objectives.

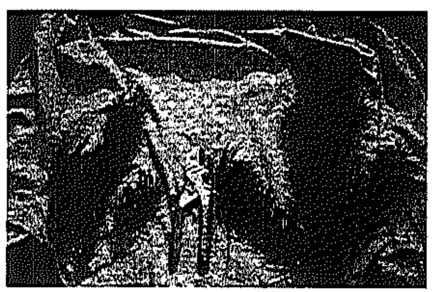

Figure 1. Increased foliar biomass and photosynthetic efficiency

Increased bole wood production during the first year after fertilization is primarily due to increased photosynthetic efficiency caused by higher foliar nitrogen concentration. However, foliar nitrogen levels of fertilized trees generally return to pre-fertilization levels after about three years. It is the increased foliage mass caused by increased needle size, number of needles per shoot, and number of shoots that results in enhanced bole wood production over the majority of the response period (five or more years).

This is why it is critical that crop trees have room for crown expansion following fertilization. If not, the growth response to fertilization will be limited to the short-lived increase in photosynthetic efficiency, rather than the prolonged response due to increased foliage mass.

The growth response to fertilization is largely dependent on the amount of the added nitrogen that is taken up by trees during the short period following treatment. In most forest soils, urea fertilizer is quickly converted to ammonium (NH4+) nitrogen, which is readily taken up by trees and other vegetation. However, the recovery of added nitrogen in crop trees is generally quite low, ranging from less than 10% to approximately 30%. Most of the added nitrogen is rapidly immobilized in soil microbial biomass and organic matter. The immobilized nitrogen is largely unavailable for tree uptake and is generally mineralized too slowly to have much practical value in improving the growth of crop trees.

Under certain conditions, significant losses of added nitrogen can occur from gaseous losses of ammonia (NH3). Volatilization losses will increase with high air temperature, wind speed, and soil pH. Volatilization can be minimized by timing nitrogen applications to coincide with cool (<10°C), calm weather with a high probability of rain in the next 24 hours.

Species response to fertilization

Research throughout the B.C. interior has shown that lodgepole pine is consistently deficient in nitrogen. Nitrogen additions often have a substantial positive effect on tree and stand growth. On sites with marginal sulphur status (<60 ppm foliar sulphate—S), fertilizer nitrogen response may be improved when sulphur is applied with the nitrogen. Induced boron deficiencies following nitrogen fertilization have also been documented. Boron deficiency causes top dieback which can have a large negative impact on stem value. The addition of a small amount of B in the operational fertilizer mix is generally effective in preventing damage. However, it is probably most cost effective to avoid fertilizing stands where pre-fertilization foliar analysis indicates a potential B problem (i.e., pre-fertilization foliar B <10 ppm).

There is currently limited fertilization response information for Douglas-fir in the B.C. interior. However, results from fertilizer trials in the Intermountain region of the United States indicate that N fertilization have produced consistent growth response over a broad range of site and stand conditions. Douglas-fir stands in northern Idaho have responded very well to N additions. In many respects, these stands are similar to Douglas-fir growing in the Interior Cedar-Hemlock (ICH) Biogeoclimatic Zone in south-central B.C. However, extensive fertilization should not be undertaken until research or operational trial results document positive results for wet-belt Douglas-fir in southern B.C.

Other species, including dry-belt Douglas-fir, black spruce, white spruce, western redcedar, western hemlock, and western larch, are recommended for trials only until more response information is available.

Fertilization and wood quality

Limited research exists on the impact of fertilization on wood quality of our interior tree species. One study conducted by FORINTEK (Forest Institute of Technology) by Jozsa and Sawadsky (1990) reported that a single application of fertilizer was not going to negatively impact lodgepole pine wood quality. Fertilization temporarily reduces wood relative density for 1–2 years, but not significantly. Under an optimum nutrition regime (repeat fertilization), however, research should be conducted to determine the impact on relative density.

Stand selection guidelines

Stand selection guidelines (Appendix 1) are intended to aid in the evaluation and selection of appropriate sites and stands for fertilizing to meet specific management objectives. The guidelines are ranked from most desirable (1) to least desirable (3) with some stands ranked as treatment Not Recommended (NR).

When assigning priority to a particular stand, as many factors as possible should be considered. Stands having average rankings of high or medium will receive greater preference for fertilizing, while areas with low rankings will be considered less suitable for fertilizing.

Stand selection criteria are broken down into three categories; biological, operational and strategical.

Biological factors

Species—those species that have research data quantifying positive growth response to fertilization are given highest priority. Operational trials are recommended for those species where data is limiting or non-existent.

Age and size—As with coastal species, preference should be given to fertilizing older stands in the interior, provided that live crowns are of favourable size and vigour, there is room for crown expansion, and that other forest level objectives do not take priority. Older, spaced stands and unspaced stands shown to have appropriate structures for fertilization (i.e., naturally occurring lower density or a suitable number of well-spaced dominants) or good potential for spacing or commercial thinning (i.e., healthy, vigorous crowns) may be assigned a high priority. However, the yield implications should be carefully considered before these stands are spaced or commercially thinned to provide fertilization opportunities.

Unfortunately, many older, unmanaged interior stands (e.g., age class 3 or 4 lodgepole pine) exhibit poor fertilization response potential. These stands often have unfavourable stand structure and low potential for response to spacing or commercial thinning. As such, combined fertilization and thinning treatments in older, unmanaged stands with questionable structure is recommended for operational trials only until their responsiveness to treatment is documented. Fertilization should probably be delayed 3–5 years after spacing or commercial thinning in these stands in order to allow the remaining crop trees to adjust to the new environment and develop sufficient new foliage to utilize the added nutrients.

Because of the unfavourable structure of many older stands in the B.C. interior, the highest fertilization priority is generally assigned to 15- to 40-year-old stands. As with coastal Douglas-fir, stands 15–20 years old should not be fertilized unless trees are at least 2 m taller than competing vegetation. Very young spaced stands or plantations (under 15 years) may exhibit a large relative response to fertilizer additions but a small absolute stem volume response due to their small stem diameter. The site occupancy of such stands may also be too low to efficiently utilize the applied fertilizer.

Stand density—The magnitude of fertilizer response is related to the space available for crown expansion. Stands selected for fertilization should have well-spaced dominant and codominant trees. This will often mean that stands will be spaced before fertilization. It is the decision to space a stand that must take precedence over fertilization. Therefore, choose stands for spacing whose treatment will meet higher-level objectives. These stands can then be candidate stands for fertilization.

Fertilizer treatment of recently spaced stands can reduce spacing shock. In most cases the best time to fertilize is at the time of spacing. Fertilization response data for lodgepole pine indicate that relative and absolute volume responses are generally larger for stands fertilized at the time of spacing compared to fertilization 2–3 years after spacing. However, fertilization should be delayed if one or more of the following factors exist:

a. The live crown of the remaining crop trees is of insufficient size (e.g., <30%) to utilize the added nutrients.
b. The height/diameter breast height (dbh) ratio of remaining crop trees is large enough to put trees at risk of toppling and breakage. Fertilized trees produce substantially more foliage the year following treatment, and the larger crowns increase the susceptibility of snow and wind damage. For Douglas-fir, it is recommended that the height/dbh ratio should be less than 85. No conifer stands with a height/dbh ratio greater than 100 should be fertilized. The same criteria apply for spaced lodgepole pine. Lodgepole pine stands with pre-spacing densities >10 000 have been shown to be especially susceptible to snow press where spacing and fertilization have been undertaken simultaneously. In these stands, risks can be substantially reduced by delaying fertilization for 2–3 years after spacing.
c. Fertilization should be delayed 1–3 years in situations where there is a heavy cover of fine thinning slash. Decomposition of slash can act as a "green manure," thereby providing a short-term increase in nutrient availability. A heavy cover of slash can also prevent fertilizer prills from reaching the soil, thus increasing risks of N volatilization losses.
d. In older age class 3 and 4 stands, fertilization should be delayed for 3–5 years after spacing or commercial thinning unless pre-treatment densities were below 4000 stems per hectare and there is no reason to anticipate any wind throw losses.

Soil moisture and nutrient regimes—Moisture and nutrient regimes of forest soils affect tree responses to fertilizing and must therefore be carefully considered.

The most reliable information on soil nutrient availability is obtained from foliar analysis. While evidence of chlorotic

tree foliage can indicate soil infertility, caution should be used in making interpretations based on these indications (see Crown condition).

Lastly, the plant community often reflects soil moisture and nutrient regimes. Use regional guides to relate plant associations to soil moisture and nutrient conditions.

Soil moisture - In the B.C. interior, sites that are slightly dry to fresh should receive the highest priority (e.g., submesic and mesic), with lesser priority assigned to drier (subxeric) and wetter (subhygric and hygric) sites. Because soil moisture, either by deficiency or excess, may exert the primary limitation on tree growth, fertilization of stands with very dry (xeric and very xeric) or very wet (subhydric) conditions should be avoided.

Nutrient regimes—Although benefits from fertilizing occur most consistently on infertile sites, very infertile sites (site quality is low) are unsuitable for treatment because natural growth rates are too slow. Avoid very rich sites also, since the soil probably contains adequate nutrients. Stands on poor and medium regimes should respond best, and therefore will be given the highest priority. Moisture and nutrient regimes are two of the main factors that determine site quality as discussed in the following section.

Site quality—Preference should be given to fertilizing medium sites (e.g., submesic to mesic soil moisture regimes and poor to medium soil nutrient regimes) in the B.C. interior. A lower priority should be assigned to good sites until such time that additional research information is available. Fertilization on poor sites will have low priority since site productivity is probably influenced strongly by inadequate soil moisture or extreme climate. Even where relative growth responses are favourable, the absolute volume gains on these lower productivity sites may be too small to make fertilization profitable. Fertilizer should not be applied on low sites.

Crown condition—The size and condition of live crowns provide an indication of the nutrient status and productive potential of stands. Considerations related to crown size and foliar characteristics are described below.

Crown size—In unspaced and recently spaced stands, evidence of many trees with short, narrow crowns suggests competitive stress is, or has been, strong. Application of fertilizer to stands in this condition will enhance crown expansion by stimulating growth of branches and foliage. Assign a priority to the treatment of these stands provided they meet the criteria described in the guideline in the section on stand density.

Foliage colour—Small, yellowish, and sparse foliage throughout the stand may indicate that one or more soil nutrients are deficient. In this situation fertilization may achieve a substantial growth response. However a chlorotic appearance may also be caused by drought or pathological conditions. In the absence of chemical analysis of soils or foliage, the interpretation of visual symptoms requires expertise and local knowledge. Look for other symptoms that may identify insect, disease or animal damage. Also consider soil conditions, ground vegetation, and rainfall patterns to infer drought.

If foliar appearance in a stand can be reliably interpreted to indicate nutrient deficiency and sufficient response is anticipated to make the treatment economical, the site can be assigned a high priority for fertilizing. However, an absence of visual symptoms does not preclude the possibility of growth limiting nutrient deficiencies.

Insects, disease, and small wildlife—The susceptibility of a stand to certain damaging agents may, or may not, be increased by fertilization. The degree of damage that can be accepted will vary by forest health factor and severity of impact. A forest health specialist should be consulted in situations where insect, disease, or animal factors may affect the priority rating of candidate stands.

Laminated root rot (*Phellinus weirii*) is the most significant fungal pathogen affecting growth and survival of Douglas-fir. On coastal sites, fertilization appears to have little effect on the incidence or spread of the disease. Minimally infected stands (<6% incidence of trees infected) close to rotation age may be treated. Fertilization of these stands may help them achieve harvestable size before they become severely infected. Evaluate immature Douglas-fir stands infected with laminated root rot and concentrate fertilizer operations on non-infected strata. Little is known about the effects of fertilization on the spread of other root diseases. However, N-fertilized Douglas-fir in the Intermountain region (Northern Idaho, Montana, and eastern Washington) is thought to be more susceptible to armillaria root rot (*Armillaria ostoyae*). Plans to treat stands that are infected with any type of root disease should be reviewed by forest health specialists.

The spruce weevil (*Pissodes strobi*) is the principal insect that may affect priorities for fertilizing in coastal immature Sitka spruce stands. Refer to forest health specialists for advice since increased levels of weevil attack following fertilization have been observed.

The western spruce budworm is found in parts of the Vancouver, Kamloops, and Cariboo Forest Regions. The implications of budworm infestations in relation to fertilizer programs cannot be generalized. Problems regarding specific candidate stands should be referred to forest health specialists.

In the interior, sharp increases of red squirrel feeding damage on lodgepole pine have been observed after fertilization. If any pre-fertilization damage is noted in the general area of the stand, consult regional forest health specialists and stand tending foresters for advice on whether to fertilize.

Operational factors

The following four operational factors should be considered during the evaluation of candidate stands.

- Location: Distance to haul the fertilizer affects transportation costs. Also, costs of future commercial thinning and final harvest are partly determined by hauling distances to manufacturing plants and markets.
- Access: Conditions of access also affect costs of transporting material and personnel in fertilizer operations, in addition to later expenses of hauling timber to manufacturing plants.
- Slope: Costs of future management (e.g., commercial thinning) and harvesting usually increase as terrain becomes steeper. Furthermore, flying over steep or irregular, contoured land may not be conducive to efficient and uniform aerial distribution of fertilizer.
- Project and Block Size: Project and block sizes affect efficiency and cost of operation. Large-scale programs (e.g., >300 ha) every 2–5 years are generally more cost effective than small-scale programs every year.

Strategic Factors

Forest level plans may require an increase in forest production in order to meet timber supply objectives. Specific age classes are targeted for fertilizing to achieve these objectives. A large-scale on-going forest fertilization program is necessary to help meet these objectives. In most cases the yield and value benefits of fertilization at the stand level are maximized by combining nutrient additions with a spacing treatment. Spacing will concentrate growth increases on fewer stems and provide growing space for the crowns of fertilized trees. Plan spacing treatments to first meet forest or landscape level objectives.

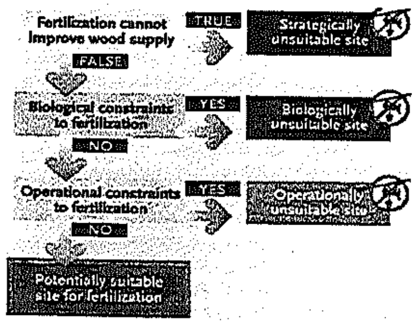

Figure 2. Stand Selection Guidelines

Types of fertilizers used in BC

There are two general classes of fertilizer: organic (e.g., sewage biosolids, fish morts, secondary pulpmill effluents) and inorganic. Most operational fertilization has focused on the application of inorganic fertilizers because of their known chemical and physical properties and their cost-effective means of application.

Only four elements are currently operationally applied through use of inorganic fertilizers on forests in British Columbia. These are N (nitrogen), S (sulphur), P (phosphorus), and B (boron). Nitrogen is applied in the largest amount with S, P, and B being added to ensure the benefits of the nitrogen fertilizer are not limited by deficiencies of other elements.

Supplements of nitrogen frequently improve growth of coastal Douglas-fir, lodgepole pine, and sometimes western hemlock. Urea ((NH2)2 CO) is currently the only fertilizer widely used by the B.C. Forest Service for operational applications. This is due to its good response history, ease of storage, availability, environmental effects, and high nitrogen content (46%) which minimizes application costs per unit area.

"Forestry grade" fertilizer (approximately 3–5 mm prill diameter) should be used rather than "agricultural grade" (approximately 2–3 mm prill diameter). Aerial distribution of forestry grade prills is more uniform and the larger particles penetrate the canopy more easily.

On the coast, urea (46-0-0) is generally the only fertilizer operationally applied to Douglas-fir forests. Fertilization with N + P has been effective in young western hemlock stands growing on substrates rich in decaying wood in the CWHvh subzone and salal prone sites at low elevations in the CWHvm subzone.

In the interior, S deficiencies may limit the responsiveness of lodgepole pine to N fertilization over fairly extensive portions of the Sub-boreal Spruce and Sub-boreal Pine–Spruce biogeoclimatic zones within the central and northern portions of the interior plateau. It is recommended that S be combined with N in the operational fertilizer mix when pre-fertilization foliar sulphate-S levels are <60 ppm. A forest grade blended fertilizer (35-0-0-10S) consisting of 58% urea (46-0-0) and 42% ammonium sulphate (21-0-0-24S) is currently used in the B.C. Interior.

Delivery Systems used in BC

There are two main delivery systems used in BC, the Bagging System and the Direct Delivery System.

Bagging system—This system is used for large operational projects where large amounts of bulk fertilizer are either transported by large trucks (B-trains) to a bagging site or the fertilizer is bagged at the rail head, then delivered to the staging site. A large front end loader with a boom arm is utilized to move and unload the bags at the staging area. The loader also contains a hopper or bucket which holds the prescribed weight of fertilizer to fill the spreader. Figure 3 demonstrates the process of transferring fertilizer from the bags into the spreader. This spreader is capable of holding 1500 kg of fertilizer.

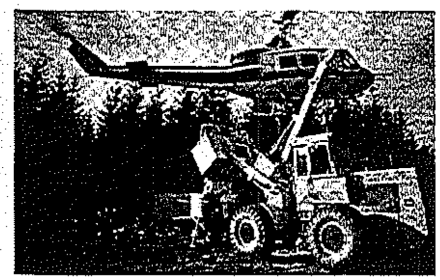

Figure 3. Bagging System—bags are unloaded into the hopper or bucket on front of the loader. The bucket is then emptied into the spreader under the helicopter.

Large landings and roads are required for this system for storage of fertilizer bags and for the large delivery vehicles to turn around. With this system, heliports are limited to large landings. This can significantly increase the helicopters travel time to and from treatment blocks. The bagging system is not used much any more as it is more costly, utilizes larger equipment, and requires large areas to stage operations.

Direct delivery system—This system is less costly, more mobile and uses smaller equipment. Bulk fertilizer is delivered from the rail head directly to the staging site. The large B-train trucks are unloaded by an auger system to smaller converted farm trucks (Figure 4). These smaller trucks can access smaller roads and get the fertilizer closer to the blocks being treated. These off-road trucks can unload directly into the spreader without the need for bagging. Figure 5 provides an example of a smaller off-road truck filling the spreader slung under the helicopter. The payload is less (1000 kg) but flying time is reduced by having these trucks closer to the treatment blocks.

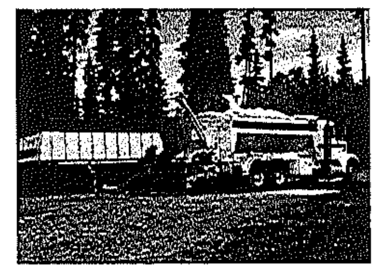

Figure 4. Unloading a large B-train by auger into smaller off-road converted farm trucks.

Figure 5. An example of loading the spreader bucket from an off-road truck using a metering bag or canvass hopper.

The Direct Delivery System is the main system used in BC. The equipment is smaller and less costly than the larger equipment needed in the Bagging System.

Monitoring

A fertilizing project should be monitored for compliance with any treatment standards set out in the silviculture prescription or stand management prescription (both are required prescriptions in British Columbia in order to carry out a stand level treatment). The following methodology is suggested for monitoring of aerial fertilizer applications. Application rate must be within 15% of target application rate.

Monitoring aerial application

To be effective, monitoring plans and procedures must be identified prior to initiating the contract. Major points to be considered when monitoring contractor performance:

- Check that loading sites are cleaned daily.
- Observe flight paths, flying procedures, and fertilizer spread from the bucket.
- Ensure that weather and visibility conditions do not adversely affect treatment effectiveness.
- Walk the block perpendicular to flight path to check for even coverage. Walking the block is essential to check for areas which have been missed or received too much fertilizer. Measure swath overlap to ensure the required overlap is occurring. The section on monitoring procedures gives procedures for swath overlap measurement.
- Monitor to ensure that fertilizer is not being applied outside block boundaries and in buffer strips. The boundaries and buffers must be walked to do this. The boundaries where the pilot must either turn on or off the bucket should be given particular attention.
- Keep track of the cumulative weight of fertilizer spread on the block of known area. This should normally be done by the contractor. By calculating the cumulative load weight for a given block and dividing by the known area of the block, you can determine the application rate. This calculation lets you know if the block received the correct amount of fertilizer. However, it does not confirm that this fertilizer was spread evenly. Walking the block and measuring the swath overlap are necessary to check for even spread.
- Monitoring a contractor's performance is easier if the application contract clearly identifies the standards required. A fertilization contract should detail start and finish dates, obligations of both parties, scheduling, standards of performance, payment, suspension and cancellation, fire prevention, liabilities, and operational specifications including provisions for environmental protection.

Monitoring procedures

Monitoring can normally be done by one person. If problems arise an extra person can be brought in so one person is in the landing and another in the treatment unit. Good communication with the contractor is a necessity. Monitoring must begin right away. Any necessary modifications to the application can then be worked out early with the contractor.

The uniformity of the fertilizer application is dependent on the spreader output rate, ground speed, swath width and swath overlap. The contractor should calibrate the spreader output rate and ground speed to obtain the desired coverage based on the swath width and target overlap. Monitoring procedures to check these factors are listed below.

Spreader output rate

The spreader output rate can be determined by timing how long the hopper takes to empty with a known weight of fertilizer. This should be done periodically throughout the application. The drop rate can vary with the fertilizer grade, type of equipment, and equipment wear. The spreader mechanism can be calibrated to obtain the desired spreader output rate.

Swath width

This width will vary with the spreader mechanism and grade of fertilizer. Within the range of altitudes flown during fertilization, swath width can be considered independent of altitude.

Swath width must be measured at the start of treatment to ensure proper application along buffers. Swath width can be easily measured by having the helicopter apply a swath across a logging road. With forestry grade pellets, some will be flung outside the swath. The edge of the swath is where the uniform distribution of pellets rapidly tails off to a few scattered pellets.

Ground speed

A constant ground speed is obtained by adjusting air speed to compensate for wind. For a given spreader output rate and swath width, the weight of fertilizer per area decreases

with increasing ground speed. An accurate reading of ground speed is possible with aircraft equipped with a global positioning satellite system (GPS). However, using the following techniques it is not necessary for the personnel monitoring the fertilizer operation to know ground speed.

Calibration

The contractor can modify the spreader output rate and/or the speed of the aircraft to ensure that the target application rate is being obtained. This calibration should be done at the beginning of the contract.

To check calibration:

1. Calculate the distance over which a known weight of fertilizer should be spread to obtain the target application rate for a single swath.
2. Measure out this known distance and clearly mark the start and end points so the pilot can see them.
3. Have the pilot fly the line and spread the known weight of fertilizer.
4. Check that the actual distance obtained provides an application rate within 10% of the target rate.

Example:
The target application rate and the swath overlap should be listed in contract specifications. The swath width can be measured as previously described.

Known:

- Target application rate: 450 kg/ha
- Swath width: 66 m
- Swath overlap: double coverage (50% overlap)
- Weight of fertilizer in hopper: 500 kg. Each swath provides half the target application rate (i.e., 450 kg/ha / 2 = 225 kg/ha). The 500 kg of fertilizer in the hopper should therefore cover 2.22 ha.
- 500 kg divided by 225 kg/ha = 2.22 ha or 22 222 m^2 (1 ha = 10 000 m^2)
- With a 66-metre swath, the distance necessary to provide the target application rate can be calculated.
- 66 m swath width swath length = 22 222 m^2
- swath length = 22 222 m^2 divided by 66 m
- swath length = 336.7 m

For this example, the actual distance flown can be between 303 and 370 metres. This will provide an application rate within 10% (plus or minus) of the target application rate for a single swath width.

If the application rate varies by more than 10% from the target, then the contractor should be responsible for further calibration. If the calibration is within 10%, then proceed with the application. During the operation, the area should be walked to check for even coverage (see Monitoring aerial applications) and the swath overlap should be measured.

Swath overlap

The pilot lays down fertilizer in parallel swaths. The second swath of fertilizer will overlap the first so that part of the ground is fertilized twice.

The aircraft must first be in the right place to deliver an accurate and consistent swath overlap. Variation from the target is likely if the flying is being done without the use of electronic guidance (e.g., transponders). The use of electronic guidance, to provide for line flying guidance should be a contract requirement.

With less than 50% overlap (double coverage), strips having double coverage alternate with strips having single coverage. To get even fertilizer distribution, there must at least double coverage over the entire area.

Measurement of coverage can only be done by standing under the aircraft during active fertilization.
Stand directly under the helicopter as it passes overhead. The fertilizer pellets will hit the ground and bounce like hailstones. Wear suitable clothing and eye protection. After they have stopped bouncing and before the aircraft returns, walk across the fertilized swath to the new outside edge where the unfertilized ground begins. Mark this edge with flagging tape. With forestry grade pellets, some will be flung outside the swath. The edge of the swath is where the uniform distribution of pellets rapidly tails off to a few scattered pellets.

On the next flight path, the aircraft will lay down another swath. As before, once the pellets stop bouncing, walk across to the new outside edge and mark it with a second piece of flagging tape.

Measure the horizontal distance between the two pieces of tape. Repeat this process for six consecutive flight lines to get five horizontal distance measurements. For slopes greater than 10% use a clinometer and slope tables to convert slope distance to horizontal distance. For slopes less than 10% hold the tape horizontally.

This procedure should be repeated until six consecutive edges have been identified and five consecutive horizontal distances measured. Then another location in the block should be chosen and a second sequence of six consecutive edges identified and five consecutive horizontal distances measured.

Average the overlap from the measurements. A variation of 10% or greater from the target overlap should be discussed with the contractor so further flight lines can be corrected.

Final application rate

The final check is a calculation of application rate based on the total weight of fertilizer applied and the area of the treatment unit. This check relies on the accuracy of the weighing scale used by the loader. If a check against this scale is desired, the cumulative loads for a given truck load can be checked against the Bill of Lading from the fertilizer manufacturer. The total application rate should be within 10%, plus or minus of the target application rate. Greater than 15% variation from the target application rate is considered unacceptable.

Guideline

- Measure swath width.
- Spreader output rate and/or the aircraft speed should be calibrated to ensure that the target application rate for a single swath width is achieved.
- Monitor field application to ensure there is at least double coverage.

Guideline

- Application rate must be within 15% of target application rate.

Monitoring water quality

When fertilization projects encroach on streams or water bodies, or occur in community watersheds, special precautions must be taken.

Water quality sampling

Water quality sampling is required in community watersheds and should be done when fertilizing near fisheries-sensitive zones. Samples should be taken before, during, and after treatment. Guidelines for sampling and analysis are provided in Forest Fertilization Guidebook (Appendix 4).

Heavy metals

Recently, concerns have been raised over heavy metals potentially being contained in fertilizer products (particularly for hand fertilization) imported into BC. Licensees and other applicators are responsible for meeting the requirements of the Fertilizer Act (Agriculture Canada). Licensees and other applicators should request the chemical composition of the fertilizer they are buying prior to purchase. Agriculture Canada has set standards on the amount of heavy metals that can be present in the fertilizer. These standards can be found at the following website.

http://www.cfia-acia.agr.ca/english/plaveg/fereng/guidee.pdf chapter 3

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Jozsa, L.A., and Sawadsky, A.C. 1990. Impact of Spacing and Fertilization on Stem-wood Relative Density and Productivity in Young Lodgepole Pine. Internal report prepared for the Ministry of Forests, Forest Practices Branch. 48 pp.

Ministry of Forests. 1995. Forest Fertilization Guidebook 57 pp. (http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm).

Appendix 1 - Stand selection guidelines for fertilization in British Columbia

Factors	Coast	Priority	Interior	Priority
Species	Coastal Douglas-fir (>80% stocking)	1	Pure lodgepole pine (>60%), lodgepole mixes (>60%)	1
	Coastal Douglas-fir (60-80% stocking)	2	Wet-belt or transition Douglas-fir (>80%) and Douglas-fir mixes (>60%)	2
	Western hemlock, spaced, <40 years	3	Other species - trials only (less than 50 ha)	trials only
	Sitka spruce	3		
	Transition Douglas-fir - sites receiving 30 cm or more annual precipitation	4		
	Other	trials only*		
	*research installations and operational trials			
Age	10-30 years from rotation end*	1	Age class 3 and 4 (40-79 years)*	1
	More than 30 years from rotation end	2	Age class 1 (upper 1/4 only, 15-20 years) and 2 (20-39 years)	2
	Trees < 2m taller than ground vegetation	NR**	Trees <2m taller than ground vegetation	NR**
	Recently planted stands	NR		
	* These stands must have favorable stand structure (i.e., adequate room for crown expansion and live crowns >30% or >6-8 m in length); otherwise trials only. ** An exception is when early fertilization is necessary to meet free growing or green-up requirements. Note: Fertilization of older stands should occur at least 10 years before harvest so the full benefit of increased growth can accrue.			
Stand density	Stands with well-spaced dominants and codominants*	1*	Stands with well-spaced dominants and codominants*	1*
	Stands scheduled for spacing within one year of fertilization	2	Stands scheduled for spacing within one year of fertilization	2
	Stands with unfavorable stand structure and no scheduled spacing within one year of fertilization	3	Stands with unfavorable stand structure and no scheduled spacing within one year of fertilization	3
	* Under certain conditions (see guideline in the section on stand density) fertilization should be delayed for 2—3 years after spacing. If other factors are equal, a pruned stand should take precedence for fertilization			
Moisture	Submesic, Mesic	1	Submesic, Mesic	1
	Xeric, subxeric	2	Subxeric, subhygric	2
	Subhygric, hygric	3	Hygric	3
	Veryxeric, Subhydric	NR	Very xeric, xeric, Subhydric	NR
	In general, avoid sites where moisture limits tree growth, either by deficiency or by excess.			
Nutrient regime	Sub-mesotrophic, mesotrophic (classes B & C)	1	Sub-mesotrophic, mesotrophic (classes B & C)	1
	Permesotrophic (class D)	2	Permesotrophic (class D)	2
	Subeutrophic - Eutrophic (class E)	NR	Subeutrophic - Eutrophic (class E)	NR
	Oligotrophic (class A)	NR	Oligotrophic (class A)	NR
Site quality	Poor and medium	1	Medium	1
	Good*	2	Poor and good	2
	Low	NR	Low	NR
	* Good site western hemlock is not recommended for fertilization.			
Insect, disease, and small wildlife damage	Less than 5% crop trees affected	1	Less than 5% crop trees affected	1
	5 -15% crop trees affected	2	5 -15% crop trees affected	2
	Over 15% crop trees affected	NR	Over 15% crop trees affected	NR
	Acceptable degree of damage may vary by pest and severity of impact. If in doubt check with forest health staff or stand tending forester.			
	Laminated root rot - not infected	1	Red squirrel damage	N R
	- infection centers	See section "Insects, disease and small wildlife"	Tomentosus - more than 5% area affected	NR
	Dwarf mistletoe - Rating 0* (no mistletoe)	1	Laminated root rot - not infected	1
	-Rating 1 or 2	2	- infection centers	See section "insects, disease and small wildlife"
	-Rating 3 to 6	NR	Armillaria - more than 15% area affected	NR
			- 5-15% area affected	Consult specialist
	* The Hawksworth six class rating system is used. Method is described in the Dwarf Mistletoe Management B.C. Guidebook.			
Access	Public highway and/or good forest road	1	Public highway and/or good forest road	1
	Forest roads requiring minor repairs or improvements	2	Forest roads requiring minor repairs or improvements	2
	Forest roads requiring major repairs or improvements	3	Forest roads requiring major repairs or improvements	3
	New road construction required or primary access by water or air	NR	New road construction required or primary access by water or air	NR
Slope	Less than 20%	1	Less than 20%	1
	20-40%	2	20-40%	2
	Coast -Over 40%	3	Coast -Over 40%	3
	Interior - Over 40%	N R	Interior - Over 40%	N R
Project and block size (relative to other stands being considered)	Larger (Project size >300 ha and/or Block size >50 ha)	1	Larger (Project size >300 ha and/or Block size >50 ha)	1
	Smaller (Project size < 300 ha and /or Block size < 50 ha)	2	Smaller (Project size < 300 ha and /or Block size < 50 ha)	2

Development of an operational fertilization program in mid-to late-rotation lodgepole pine stands. An industry testimonial[1]

Thomas Braun[2] and Stan Navratil[3]

Introduction

Background

Weldwood of Canada Limited, Hinton Division has been operating in Hinton, Alberta under a Forest Management Agreement (FMA) since 1955. The company harvests 2.2 million m^3 of softwood from a 1 million-hectare landbase, which is used to supply the fiber for both a pulpmill and a sawmill.

Weldwood's landbase is predominantly 80 to 120-year-old lodgepole pine. This strata accounts for approximately 44% of Weldwood's landbase. The age class distribution of pine leading stand types is illustrated in Figure 1.

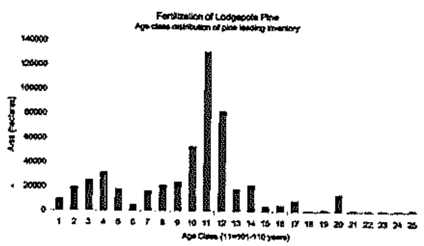

Figure 1. Lodgepole Pine leading stand types for Weldwood's Hinton FMA

In 1995 Weldwood of Canada Limited began an Enhanced Forest Management (EFM) program that focused on increasing the Annual Allowable Cut (AAC) of their Hinton, FMA area. Stewardship commitments, downward landbase pressures and a scarcity of purchase wood have encouraged Weldwood to look to EFM treatments as a means of growing softwood volume for less than what it would cost to buy it on the open market.

Of the treatments available, the fertilization of mid- to late-rotation lodgepole pine stands is one of the more attractive due to the availability of stands, the relatively low cost of treatment, the clear volume gains and the short investment period.

Weldwood's Fertilization of Mid- to late- (FML) rotation lodgepole pine program has been designed to implement a defendable, operational fertilization program before the submission of their next Forest Management Plan (FMP) in 2008. In order to complete this task, the program will develop a diagnostic system for candidate stand selection, quantify the volume and value increases from fertilization, and model the forest level effects of an operational fertilization program.

Methodology

Developing a FML program requires an understanding of the biological and economical limitations of the treatment. Research installations representing the strata of interest are being established to quantify the growth rates and yields following fertilization. This data will be used to adjust the existing yield curves and ultimately guide Weldwood's investment in fertilizer. Simultaneous to quantifying the biological response, an understanding of logistics, planning and implementation needs to be developed. Operational trials of a scale large enough to require standard operating practices are being scheduled to establish local expertise and a benchmark for costs. Weldwood's approach to the FML program is outlined in Figure 2.

[1] For the 2001 Fertilization and Economic Conference, March 1 and 2, 2001

[2] Weldwood of Canada Ltd., Hinton, Alberta

[3] SILFOR Consulting, Hinton, Alberta

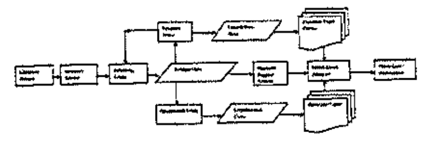

Figure 2. Weldwood's approach to an operational fertilization program

A review of existing research trials and literature revealed that the average volume gain from local fertilization trials in mid- to late-rotation lodgepole pine stands is approximately 20 m^3/ha; however, the variability of an individual stand's response to fertilizer can be quite high (Yang 1985a, 1985 b, Silfor 1999). This variability between stands and sites justifies a screening process that will identify stand and site factors limiting responses to fertilization. Ultimately screening will support the development of a local diagnostic system for ranking stand responsiveness to fertilization.

Since 1997 there have been 30 stands screened for response to fertilizer (Table 1 and Figure 3). Many of the stands did respond but to varying degrees. To combat the variability, Weldwood continues to screen stands with the intent of developing stronger predictive relationships. These relationships, the foliage response and growth data from across the FMA area, will form the foundation of the diagnostic system.

Table 1. Summary of stands screened by year.

Year & Season Fertilized	Number of Installations	Number of Plots	Age Range	Ecosites	Site Index Range
1997 Spring	11	165	104-114	UF d & e	10-17
1998 Fall	9	135	40-110	UF d & e	12-17
2000 Spring	10	200	40-100	UF b, d & e	11-20
Total	30	500			

Unlike stand density trials, the stand responsiveness to fertilization can be estimated within a year of treatment. This quick, simple and cost effective assessment is the product of screening plots or "miniplots" (Weetman et al. 1988, Forest Practices Code 1995). To date, Weldwood has exclusively used the miniplot approach to screen stand responses to fertilizer.

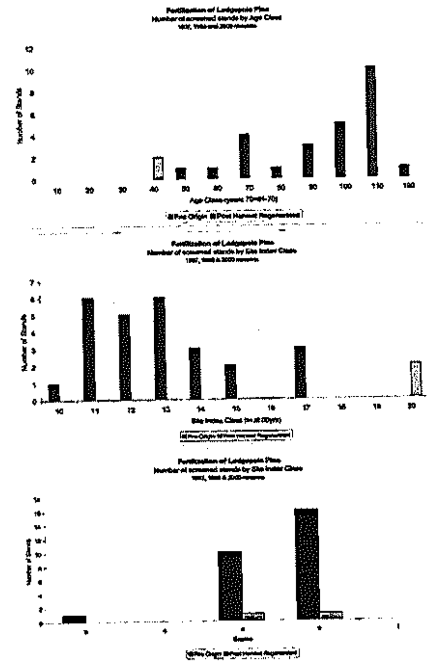

Figure 3. Stand and site types screened since 1997

In Weldwood's program, a stand is subjected to 3 treatments: a control, a nitrogen (N) based fertilizer, and a complete blend fertilizer. The fertilizer is applied within the miniplot, which consists of two-three adjacent dominant and codominant trees within a 5.64 m radius plot. The treatments are replicated five times within a stand. In most cases, the

Table 2. Listing of trials established on Weldwood's FMA from 1996-2000

Plot Type	Plot Intent	Number of Installations	Number of Plots
Fixed Area Experimental Research	Quantify growth rates and yields	9	102
Fixed Area Operational	Build our understanding of logistics an	5	26
Two Tree Miniplots	Screen stands for response to fertilizer	30	500
Two/Three Tree Screening plots	Test variations in research treatments	3	24

miniplots are fertilized in the spring so the foliage collection and analysis can take place in the fall of the same year. The analysis is comprised of needle weight response and foliar nutrient comparisons by vector analyses (Weetman and Fournier 1982, Timmer and Morrow 1984, Brockley and Sheran 1994).

In stands where there has been a positive response to fertilizer, research or operational fixed area trials have been established. As listed in Table 2, a total of 9 research trials and 5 operational trials have been established since 1997. Their intent is to build local growth and yield curves as well as an appreciation for costs and logistics associated with an operational fertilization program.

Additional screening plots, in which we are testing different fertilizer combinations, have been established in conjunction with fixed-area research trials. These plots are used for assessments of single tree responses to complement the results from fixed-area plot trials.

* The number of plots in each installation varied based on the number of treatments. Treatments were replicated 2-5 times depending on the type of installation.

Results

Baseline foliage nutrient status

The results from Weldwood's miniplots confirmed a widespread N deficiency in fire-origin lodgepole pine stands on Weldwood's FMA area. N deficiency in lodgepole pine stands has been reported previously in Alberta (Yang 1985a, 1985b) and is known to be widespread in lodgepole pine stands in the interior region of British Columbia (e.g. Brockley 1996).

Weldwood's finding of a widespread boron deficiency in lodgepole pine stands in the Hinton area is considered to be new information for Alberta. Boron deficiencies have been reported in British Columbia (Brockley 1990) and elsewhere, for example Scots pine in Sweden (Pettersson 2001, paper in this Proceedings). As a precaution, boron is routinely added to all fertilizer treatments. Table 3 lists the baseline nutrient status of 11, late rotation fire origin stands.

Table 3. Nutrient status based on foliar nutrients of 11 stands screened in 1997

Element	Average Concentration	Deficiency*	Distribution
Nitrogen	1.07 (1.02-1.14)	severely deficient	Widespread
Boron	8.6 (6.6-10.2)	deficiency likely	Widespread
Sulphur	0.111 (0.106-0.120)	N induced possible	Unknown
S-SO4-	128 (70-150)	N induced possible	Unknown
Potassium	0.49 (0.43-0.54)	slightly-moderately deficient	Unknown

*Deficiency rating is based on Ballard and Carter 1986

There is a possibility of inducing sulphur deficiencies through the addition of N but this may be localized since other comparisons, such as the N/S ratios, do not substantiate its general occurrence. However, Weldwood will continue to test this possibility. In the eastern part of Weldwood's FMA area foliage sulphur concentrations were found to be well above the critical levels, likely due to the proximity of gas and oil activities in that area. The fertilizers used by Weldwood were formulated according to the foliage analysis results, literature review and expert recommendation. Table 4 summarizes the composition and application rates of fertilizer used and tested in Weldwood's trials and screening program.

Table 4. Fertilizer types, compositions and rates used in Weldwood's trials

Fertilizer	Compositions (kg/ha)
Urea + blend	200 N - 100 P - 100 K - 37.5 Mg - 75 S - 3 B
Ammonium nitrate + blend	200 N - 100 P - 100 K - 39 Mg - 75 S - 3 B
Urea + boron	200 N - 3 B
Urea + sulphur + boron	200 N - 75 S - 3 B
Ammonium nitrate + sulphur + boron	200 N - 75 S - 3 B

Note: for nitrogen, our standard application rate is 200 kg/ha from urea however, we are testing an application rate of 400 kg/ha

Needle weight responses

In both the 1997 and 1998 installations needle weight responses following fertilization were significantly affected by fertilizer type and stand or site characteristics (total 20 installations, ANOVA performed for each year separately, p=0.05).

In general, the blend fertilizer treatment produced more consistent and greater needle weight responses as compared to N alone and N + Boron (B) treatments. Eighteen (90%) stands fertilized with blend produced a mean increase in needle weight greater than 10% as compared to the N treatment where only 15 (75%) stands responded by more than 10%. Similarly, ten (50%) stands fertilized with blend produced needle weight increases of 30% or greater whereas only 5 (25%) stands in the N treatments had responses greater than 30% (Table 5).

Table 5. Grouping of 20 screened stands by year and needle weight response on Weldwood's FMA

Year Fertilized	Fertilizer	Rate (kg/ha)	Needle Weight Response <110%	110-119%	120-129%	>=130%	Number of Stands
1997	N-Blend	200	2	3	2	4	11
1998	N-Blend	200	0	0	3	6	9
Total			2	3	5	10	20
			10%	15%	25%	50%	100%
1997	N-Urea	150	3	5	2	1	11
1998	N-Urea+B	200	2	0	3	4	9
Total			5	5	5	5	20
			25%	25%	25%	25%	100%

There was a wide range in needle weight responses between stands and sites. This is not surprising since responses to fertilization are subject to a wide variety of interactions between stand structural and environmental factors. However, Weldwood has also observed high variability of responses within stands and within treatments in the same stands. This variability is likely the reason we failed to prove statistically significant treatment effects despite strong trends showing treatment responses.

Statistically significant (p=0.05) treatment differences in needle weight responses were more frequent in the 1998 (all stands with application of blend fertilizer) installations than in the 1997 installations (in 3 stands out of 11 stands). The difference in response might be a result of relative stand ages, the 1998 installations are largely mid-rotation stands whereas the 1997 installations comprise late-rotation stands.

Weldwood's attempt to find relationships between stand responsiveness (needle weight response) and site or stand characteristics (ecosite, site index, stand density and stand age) did not reveal any consistent patterns. In Weldwood's limited sample there was a weak trend of decreasing needle weight response with stand age (R^2= 0.10). There was also a weak trend of increasing needle weight response with increasing site index (R^2=0.13) in N-urea treatments.

Weldwood also examined the relationships between needle weight response to fertilizer and the baseline foliar nutrients—the unfertilized foliage. These relationships were more pronounced but also inconsistent. In the 1998 blend miniplots, the first year needle weight response was significantly and positively related to N concentration in the foliage of unfertilized trees (R^2=0.50; p=0.03). Baseline N concentrations explained 50% of the variation in needle weight response to blend fertilizer (Figure 4). In the same stands, a N+ B treatment did not produce the same response and needle weight was not affected by the concentration of N in the unfertilized foliage.

In the 1997 N miniplots a weak trend of increasing needle weight with N concentration in the unfertilized foliage was present, (R^2= 0.18; p=0.18) but this trend was not observed in the blend treatments.

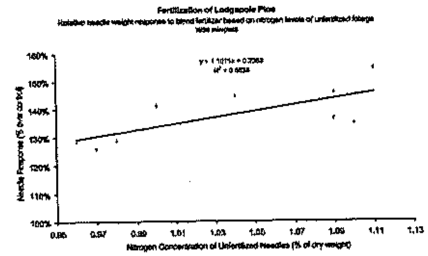

Figure 4. Relationship between relative needle weight response to a complete blend fertilizer and the nitrogen concentration of unfertilized foliage. From the 1998 miniplots, a complete blend fertilizer based on 200 kg/ha of nitrogen.

The relationship of the N concentration in the unfertilized foliage and the needle weight response following fertilization was strong and positive in both blend and N+B treatments (R^2= 0.61; p=0.01 and R^2=0.50; p=0.03, respectively).

On average, N foliage concentration was higher following fertilization with blend than with N or N+B fertilizer. Fertilization improved N foliage concentration from the severely deficient level to the slight moderate deficient level in most of the stands. However, fertilization never raised the N concentration status into adequate level (=1.5%; interpretation according to Ballard and Carter 1986).

Radial growth responses

Weldwood assessed the 4-year radial increment and basal area increment of 11 stands fertilized in 1997. Five dominant trees per treatment were sampled in each stand.

In this sample, which comprised 5 dominant trees per treatment per stand, 82% of the stands treated with blend fertilizer produced first year relative needle weight increases greater than 110%. In 68% of these stands the relative 4-year basal area (BA) increment was greater than 30%.

The first year needle weight response to N treatments explained 29% of the variation in 4-year relative BA response ($R2$=0.29; p=0.08). In the blend treatment, 82% of the stands had 4-year BA responses greater than 30% that appeared to not be affected by the magnitude of the first year needle weight.

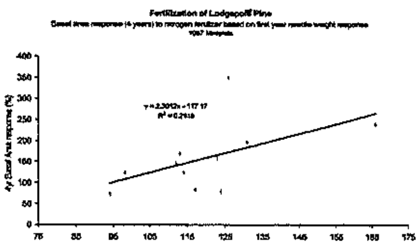

Figure 5. Relationship between relative 4-year basal area response and first year needle weight response to fertilization with nitrogen alone (150kg of N/ha)

Although the incidence of positive radial growth responses was high, the magnitude varied and the statistical significance of differences between the fertilized and control treatments was sporadic (3 out of 11 stands).

An example of a responsive stand is shown in Figure 6. The radial growth from the blend treatment improved in the first year after fertilization and continued to improve until the fourth year (last year of measurements). The growth response of the N treatment was slower finally showing a noticeable increment 4 years after fertilization, but of a lesser magnitude.

A finding of interest, and in our view, the source of variability in treatment responses, is the tree-to-tree variability in radial growth within treatments in the same stands. Figure 6 shows that despite the dominant crown class of the sampled trees and the positive mean treatment response (blend fertilizer in Figure 6[A]), there were trees within the treatment that had very minimal radial growth before fertilization and no growth response following fertilization (e.g. tree #3 in Figure 6 [B]).

It appears that senescing and stand differentiation processes inherent to fire origin, dense stands render some trees unresponsive to fertilization and physiologically less active. Based on Weldwood's limited sample it is estimated that 15–20% of dominant trees in fire-origin, dense, late-rotation stands may fall within this low vigour category.

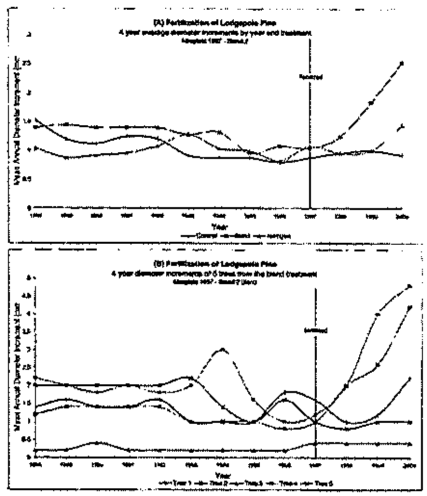

Figure 6. The annual diameter growths before and after fertilization in stand #2 of the 1997 miniplots. (A) Mean of five dominant trees per treatment. (B) Single tree growth in blend fertilizer treatment.

Observations from factorial thinning x fertilization trial

In the spring of 2000 a research trial focused on quantifying the growth and yield responses from commercial thinning and fertilization was established in a 70-year-old, fire origin lodgepole pine stand. The trial was designed as a factorial arrangement of six fertilizer treatments and two thinning intensities (control and 50% basal area removal).

Figure 7 shows the relative needle weight responses (unfertilized control=100%) one growing season after fertilization and thinning. Thinning alone did not affect first year needle weight. In contrast, fertilization in combination with thinning or fertilization alone significantly increased first year needles weight. On average, thinning and fertilization treatments produced a 36% increase in needle weight whereas the unthinned and fertilized treatments produced a 21% increase.

Application of 400kg/ha of N in different fertilizer combinations as compared to 200 kg/ha of N applications did not produce significantly greater responses. However, 400kg/ha

of N applications elevated N concentration in the foliage above the deficiency level (> 1.5%= adequacy level) in one unthinned treatment and in three thinned treatments.

400 kg/ha of N sourced in ammonium nitrate produced the highest needle weight responses and N foliage concentrations. We observed the differential response to N-urea and N-nitrate applications previously in the screening miniplots. Results from this and other trials in progress may support N-nitrate applications on some sites.

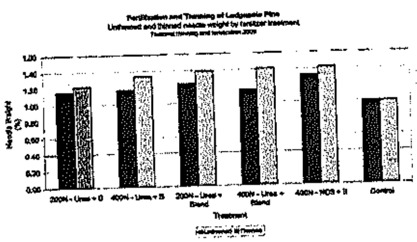

Figure 7. Means of relative needle weight one growing season after thinning and fertilization in the factorial thinning and fertilization trial.

Summary

To date, Weldwood's results from testing the stand responsiveness of mid- to late-rotation lodgepole pine to fertilizer have produced weak relationships between the needle weight responses and stand and site characteristics. Although the positive needle weight responses were frequent we could not isolate any strong relationships. This paper presented limited information on the relationships of first year needle weight response, a predictive variable, on radial growth and basal area increment. The short duration (time since treatment) and the limited sample size may be the root of the weak relationships, but the miniplots are the best available data until the fixed area research trials mature.

Large gains have been made during the last two decades in diagnosing nutrient deficiencies and predicting responses to fertilization in lodgepole pine (Weetman and Fournier 1982, Weetman et al. 1988, Brockley 1996, Brockley 1990, Brockley 1992, Brockley 2000, Yang 1985a, 1985b, 1998). With time the results from Weldwood's fixed-area trials and screening plots, together with other available information, will make the locally adjusted, site-specific guidelines for operational fertilization attainable.

To make any conclusions with such a limited sample is premature, but there are some preliminary observations worth listing.

Preliminary fertilizer observations

- A blend fertilizer, as compared to N-urea or N+B-urea, more frequently produced positive and higher needle weight responses.
- Needle weight responses were positively and weakly affected by N concentrations in the foliage of unfertilized trees (stand nutrient status) but strongly affected by the N concentrations in the foliage after fertilization.
- N deficiency was very severe on Weldwood's FMA area. One application of 200 kg/ha of N improved N foliar concentrations but not above the slightly deficient level.
- B deficiency was common and affected first year needle weight responses.
- Although rare, there are signs of N induced sulphur deficiencies. Further testing is required to confirm this.
- Relative 4-year basal increments greater than 30% were frequently observed on dominant trees that showed less than 30% relative needle weight increases in the first year after fertilization
- Failure of dominant trees to respond in radial growth, despite their positive mean treatment response, was frequent and as many as 20% of the dominant trees in older fire origin stands may not respond to fertilization.
- Dense, late rotation, fire origin lodgepole pine stands appear to have a higher variability in response to fertilization than what has been reported for thinned, younger, lodgepole pine stands.

Preliminary thinning and fertilization observations

- Thinning alone did not affect the first year needle weight response but did enhance the needle weight response in fertilized treatments.
- There were little to no differences in needle weight response between 200 kg N/ha and 400 N kg/ha applications.

- N applications in the form of ammonium nitrate produced the highest needle weight responses and the highest foliage concentrations of N.

Preliminary operational observations

- The observed variability in responsiveness across stands and sites further justifies the need for a FMA area specific diagnostic system to predict growth responses and prescribe cost effective fertilizer applications.
- Within a stand, the observed tree-to-tree variability in response to fertilization suggests that large sample sizes may be required to prove significant treatment differences in these older unmanaged stands.
- Results from Weldwood's thinning and fertilization trials support the findings that biological responsiveness of thinned stands is higher. Furthermore, greater financial returns from sawlog volume gains may be realized by fertilizing thinned stands as compared to total volume gains following fertilization of unthinned stands.

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Weldwood would also like to recognize the financial support from the Forest Resource Improvement Program of Alberta and the Association, without which we would be much further behind in our understanding of forest nutrition.

Operational trial—aerial fertilization

Kim Peel

Objective

The objective of this project is to address the question: can fertilization can play a significant role in increasing the site productivity on Lodgepole Pine stands in the Sub-boreal Pine–Spruce (SBPSxc) very dry cold biogeoclimatic subzone.

Location

The operational trial aerial fertilization project area is located in the Chilcotin Forest District of British Columbia, Canada. A total of 427 ha were treated in the SBPSxc biogeoclimatic subzone. Three separate areas with simple topography were treated. The application was carried out in mid-December with 15 cm of snow on the ground. During the six days it took to complete the project, the average temperature was minus 20 degrees Celsius. (The Canadian Way, eh!)

Planning

To ensure the most effective and the most efficient operational approach was employed, considerable time was spent ensuring that the design of the nine treatment units were suited to the application method, that good access for the fertilizer transport trucks was secured and that the identification of suitable fertilizer loading sites was secured.

Layout

The boundaries on the ground were designed to minimize any deviations from a straight line. This was done to accent the proficiency of the aerial application. Large orange plastic bags (80 x 120 cm) were attached to the trees at intervals of approximately 100 m along the easily identifiable boundaries. Also, all major corners and changes of direction were marked. Boundaries located around any sensitive areas, such as no treatment zones within the treatment area, were marked every 50m. Because the applicator aircraft would be flying up at speeds up to 100 km/h, effective treatment boundary marking is very important.

Although orange bags were used for marking the boundaries, white markers are preferred if the area is free of snow.

Operations

Office

Pre-work plan

Prior to the commencement of the operation, several pre-work sessions were held with the contractor to review all the operational aspects of the program. The sessions involved a review of the contract documents, the Ministry of Forests Operational Plan, the contractor contract book, the safety operating procedures, and the spill contingency plans.

On Site

Safety zone

A safety zone was established at each fertilizer loading site. The zone provided an exclusive operating area for the pilot and for the affiliated ground crew. The zone boundary was marked with high, visible ribbon and paint, and it extended about 50 m from the hopper loading point. This zone also included the refueling site for the helicopter.

Calibration

Prior to the actual application the "effective" application swath width needed to be determined. This was accomplished by having the helicopter lay a number of swaths over the existing on site roads within the treatment area. Because the ground was covered with snow, black plastic sheeting 2m wide and 40 meters long was placed on the ground to help highlight the swath coverage. The total swath width varied from 30 to 39 m, with an average width of 34 m. The average effective swath width was calculated to be 23 m.

Monitoring
Two main monitoring methods were employed to confirm the application rate and coverage. One method is based on the actual kilograms applied to a unit and the other is based on monitoring the treated area.

Determining the application rate based on the amount (weight) of fertilizer applied was accomplished by employing two separate approaches. One approach compared the actual weight of the fertilizer delivered as recorded by truck tare sheets against the dispersal bucket load records. The other approach incorporated pellet traps to capture the fertilizer as it was applied. The pellet traps were systematically located throughout the treatment unit.

The comparison of the truck tare sheets to the dispersal bucket load records worked quite well. However, the pellet trap approach proved to be unreliable due to the snow and the frost contamination of the traps and to the interception (exaggerated further by the snow and the frost covering the foliage) of the pellets by the tree foliage.

Determining the application coverage was achieved by employing three separate approaches: a navigation system, a pellet trap system, and a system of visual observations. The navigation approach used an on-board navigation system which tracked the flight path of the helicopter. The printouts from the system were used to confirm the area treated.

The pellet traps proved to be more useful in determining the area treated verses determining an application rate. Through the examination of the traps, it was possible to determine the area which under went treatment.

The on-ground visual observations by the field personnel aided greatly in confirming the application coverage. Two methods were employed: the field personnel were in the field during the actual application of the fertilizer and the field personnel observed the debits made by the pellets in the snow.

Pre-flight Overview
Daily flight plans were pre-arranged with the Project Manager and the pilot. Prior to the actual application, the Project Manager and the pilot flew the targeted treatment area(s) to confirm the application area, to highlight sensitive areas and to ensure the area is clear of any non-operational personnel.

Fertilizer and Equipment

Fertilizer
The prescribed fertilizer type for the project was a blend of ammonium nitrate, with ammonium sulphate and borax (34.2-0-0-9.7S-0.5B) in the form of agricultural grade pellets.

The fertilizer was transported directly to the loading site using B-train highway configured trucks with hopper tank trailers. The hopper design trailers were necessary for feeding the auger. Each truck delivery consisted of 41,000 kg of fertilizer.

Aerial Applicator
A Hiller 12ET helicopter was used for the project. The helicopter's total hp is 400 and its maximum lift is 545 kg. The average fuel consumption is 112 l/h and the top speed is 150 km/h.

Auger
A two-stage auger was used to move the fertilizer from the truck to the dispersal bucket. The auger incorporates a check scale so that every bucket weight can be accurately measured and tracked.

Dispersal Bucket
A "Western Aerial" designed dispersal bucket was used for spreading the fertilizer. The rated payload for the bucket configuration is 400 kg. The bucket incorporates a hydraulically operated mechanism with an electric switch that signals to the navigation system to start tracking the helicopter's flight path when the bucket is open.

Navigation System
The on-board navigation consisted of a Trimble AG GPS TrimFlight 3 system. The information gathered from the system is used to develop the flight path maps. The flight path maps can be generated on-site using compatible software and a computer.

Application

Logistics
The ground speed of the helicopter and the swath overlap are the two key variables that are used to control the application rate and the even distribution of the fertilizer.

The flying speed of the helicopter for this project was 60 to 100 km/h with an average speed of 80 km/h.

The swath width is predominantly a fixed distance; however, there is a wide range in the amount of fertilizer that reaches the ground within the width of the swath. Typically, the edges of the swath have a fairly light application rate compared to the area around the center of the swath which has a much heavier application rate.

To achieve the projects 570 kg/ha application rate within ± 10%, a 13 m swath overlap was required.

The dispersal bucket load weights varied from 300 to 400 kg through the fuel cycle, with an average bucket weight of 360 kg. This resulted in 0.63 ha treated per bucket.

Taking all these factors into consideration, the success of the project is largely dependent on the "skillful" mixing of the helicopter speed and the swath overlap.

The operations crew included the project site manager, the pilot, the ground crew coordinator, the auger operator, and the monitoring crew.

The project site manager was responsible for ensuring the contract conditions were being achieved, the coordination of the transportation trucks, the coordination of the helicopter fuel requirements and the coordination of the monitoring crew activities.

The pilot was responsible for ensuring the appropriate application rate is being achieved. The same pilot was used throughout the entire project.

The ground crew coordinator was responsible for tracking the fuel level/dispersal bucket weight ratios with the pilot, coordinating the transport truck setup and the hopper unloading.

The auger operator was responsible for ensuring the dispersal bucket was filled in a timely manner and for recording the number of buckets filled and their weight.

To ensure the flight operations were not disrupted, a lot of time is spent getting organized. This included having all materials and equipment in their proper place and ensuring the project personnel had a clear understanding of their roles.

Due to the cold weather conditions, the helicopter was covered with a tarp at the end of each day. The helicopter was heated throughout the night to ensure fluids and other important components did not get damage from the freezing conditions.

A motor home was parked on site to house the security crew as well as to provide a warm location for coordinating the flight activities.

Flight Operations
Each application flight consisted of the pilot hovering above the end of the auger and placing the dispersal bucket close enough to the end of the auger to enable the auger operator to pull the bucket in under the auger for filling.

Once the bucket was filled, the pilot lifted off and flew to the treatment area. The pilot applied the fertilizer along the predetermined flight line indicated by the navigation system. Once the bucket was emptied, the pilot returned to the loading area and the whole cycle started over.

The total average cycle time for most of the runs was roughly two minutes. The pilot could fly from 30 to 40 cycles before having to refuel.

Costs

The operational trial nature of the program resulted in costs over what would be expected for a "non-operational trial" fertilization program. The project total cost is $513.42/ha.

	Item	Cost	Cost/Ha	Percentage of Total Project Cost
1	Planning	$26,049.79	$61.01	11.9%
	Planning, site review, preparation of Stand Management Prescriptions, mapping, preparation of Standards Agreement, referrals & consultation, preparation of contracts and pre-work sessions.			
2	Layout	$11,523.96	$26.99	5.2%
	Access/Safety trails at Sister's unit.	$2,275.00		
	Standard Layout	$9,248.96		
3	Operations	$169,223.20	$396.31	77.2%
	Fertilizer and application	$140,335.00		
	On site monitoring	$24,458.45		
	Access improvement (snow removal)	$572.50		
	Monitoring staff	$3,857.25		
4	Program Follow-up	$12,433.51	$29.12	5.7%
	Mapping, reports & liaison	$12,433.51		
5	Total Cost Summary	$219,230.46	$513.42	100.0%

Concluding Observations

The project met the majority of the application target rates. All the treated units were within the allowable ± 10% variance, except for one small unit that had plus 14% variance.

The application of the fertilizer was carried out in an organized manner.

Communications between the ground personnel and the pilot is a key factor.

The cold weather and snowy conditions predisposed the use of pellet traps for confirming the application rates, but the traps were useful in identifying the treated and non-treated areas.

The cold weather did not restrict the performance of the helicopter, but did increase its lift capability.

Overlap widths can vary considerably due to the following: irregularly shaped treatment units, small units (less than 15 ha) and non-straight flight paths.

To further substantiate the actual application rate and coverage, it would be useful to incorporate an optical device along with the switching mechanism that activates the navigation system. This would ensure the navigation system is only tracking the application flight path while the fertilizer is coming out of the dispersal bucket.

The helicopter is well suited for treating: large and small treatment areas, areas with irregular boundaries and areas inter-dispersed with non-treatment areas.

The operational trial aerial fertilizer application project is 18% more expensive compared to previous non-operational trial aerial fertilization projects Lignum has employed. Although more expensive, this method's value lies is in its ability to confirm if fertilization can play a role in improving forest productivity of lodgepole pine stands in the Sub-boreal Pine–Spruce very dry cold biogeoclimatic subzone.

References

DWB Forestry Ltd. February 2001. Lignum Limited 2000 Fertilization Program Report Chilcotin Forest District.

Treating repressed lodgepole pine: a case of remarkable response

Craig Farnden R.P.F.

Height repression is a phenomenon that is frequently observed when lodgepole pine regenerates to very high densities, most commonly after wildfire. It is characterized by reduced height growth below that of the site potential; increasing levels of repression are typically observed with increasing establishment densities. On one such site near Prince George B.C, average densities at age 18 were 250,000 trees/ha, and height growth was roughly half what would normally be expected for similar ecosystem units. In 1979, a set of speculative trials was imposed on the site to test whether silvicultural treatments might be effective at overcoming this effect.

The subject stand originated after a 1961 fire on a broad flat glacial outwash plain. Soils on the site are gravelly with a low capacity for both nutrition and moisture retention. The regional climate is sub-boreal with cool, wet summers and cold, snowy winters.

Originally, a rather large and ambitious mechanical row thinning trial was planned for the site, with 14 of 21 treatment units over a 36 ha site being treated using a Hydro-Axe mower. This was subsequently replaced with a pair of smaller trials using only a portion of the original area. Combined, the two trials included 9 treatments randomized in 3 blocks, with a common set of pseudo-control plots located in the untreated surround. One of the trials investigated thinning and urea fertilizer in a factorial design, while the other utilized varying levels of urea fertilizer combined with two different patterns of application. A description of the nine treatments is provided in Table 1.

After nineteen years, dramatic differences can be observed between the untreated areas and various treatment plots (Figures 1 through 13). Most noticeable is the difference in heights, with the best treatments resulting in top heights that are now more than double the controls (7.8 m vs. 3.8 m). Large height growth differences continue to be evident, suggesting a shift in apparent site index (reference age 50 yrs at breast height) from 9.8 m on the controls to over 17 m on the best treatment.

Table 1. Description of treatments.

Treatment No.	Description
1	Row thinning – 2.5 m cut swaths interspersed with residual strips averaging 2 m.
2	Row thinning plus selective hand thinning - residual strips were further thinned using brush saws to a target spacing of 1 m x 1 m.
3	Row thinning plus fertilization – urea fertilizer was hand spread in a broadcast fashion at a rate of 150 kg/ha N.
4	Row thinning plus hand thinning plus 150 kg/ha N.
5	Fertilization with 200 kg/ha N as urea, applied by hand in a broadcast fashion.
6	Fertilization with 400 kg/ha N as urea, applied by hand in a broadcast fashion. Treatment resulted in immediate low to moderate levels of mortality (33%) related to nitrogen toxicity and snowshoe hare feeding damage.
7	Fertilization with 400 kg/ha N as urea, applied by hand in concentrated strips. Treatment resulted in immediate moderate levels of mortality (33%) related to nitrogen toxicity and snowshoe hare feeding damage.
8	Fertilization with 800 kg/ha N as urea, applied by hand in a broadcast fashion. Treatment resulted in immediate and severe mortality related to nitrogen toxicity and snowshoe hare feeding damage, with up to 60% of trees being killed.
9	Fertilization with 800 kg/ha N as urea, applied by hand in concentrated strips. Treatment resulted in immediate and severe mortality related to nitrogen toxicity and snowshoe hare feeding damage, with up to 90% of trees being killed.

Figure 1. Areas surrounding the treated plots were used as pseudo-controls. Top heights averaged 4.8 m with an apparent SI50 (based on the last 5 years of growth) of 9.6 m. Substantial self-thinning has occurred over 19 years, with densities reduced to an average of 43,000 trees/ha from 250,000 at the start of the trial.

Figure 2. Row thinned plots averaged 4.7 m top height with an apparent SI50 of 11.2. Despite the roughly 60% of the area that was cleared of trees in the treatments. Densities now are roughly 75% of those in controls, suggesting that row thinning has slowed the rate of self-thinning in the residual strips.

Figure 3. Hand thinning of row thinned plots provided modest gains, with average top heights increasing to 5.5 m and apparent SI50 values to 12.1 m. Densities remain higher than the treatment specifications would suggest (at 7800 trees/ha)—it is surmised that many of the existing trees grew from live limbs left on cut stubs.

Figure 4. Fertilization of row thinned strips provided similar height gains as hand thinning, with average top heights increasing to 6.2 m and apparent SI50 values to 11.7 m. Densities remained high, however, at 29,200 trees/ha.

Figure 5. Combining hand thinning and fertilization provided the largest gains observed for any of the treatments. Top heights averaged 7.8 m with apparent SI50 values of 17.2 m. These plots had none of the extra trees remaining that might have grown from cut stubs as in the row plus hand thinned plots—it is surmised that the fertilization promoted snowshoe hare feeding and almost total mortality on these low live branches.

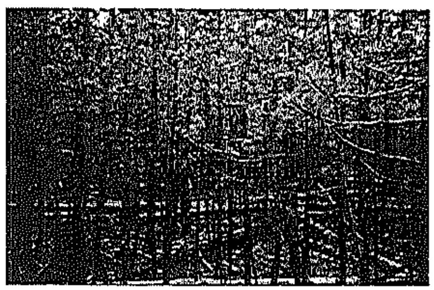


Figure 6. Fertilization at 200 kg/ha N provided virtually no gains in top height (5.2 m) or apparent SI50 (10.1) over the untreated areas, although there appeared to be a large gain in average height. There is less height variation in these plots than in the control areas, with a higher percentage of the 39,500 trees/ha having heights close to those of the top height trees.

Figure 7. Fertilization at 400 kg/ha N applied in broadcast fashion resulted in intermediate gains in top height (6.8 m) and apparent SI50 (12.2 m). Despite early mortality, densities remain high at 32,700 trees/ha.

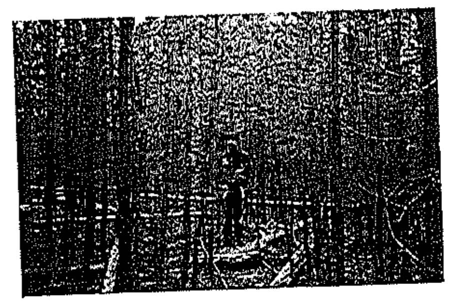


Figure 8. Fertilization at 400 kg/ha N applied in concentrated strips provided very similar results to the same fertilizer dosage applied in broadcast form, although with lower residual densities (top height = 6.6 m, SI_{50} = 13.4 m, density = 21,600 trees/ha).

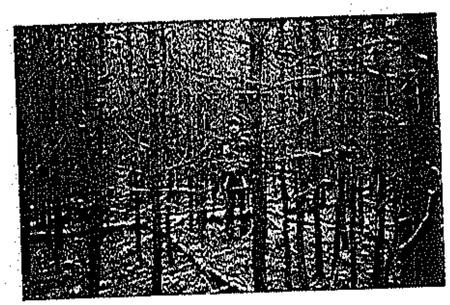


Figure 9. Fertilization with 800 kg/ha N applied in broadcast fashion provided growth performance approaching that of the row thin + hand thin + fertilizer treatment, with top heights averaging 7.5 m and an apparent SI_{50} of 16.5 m. Densities averaged 17,600 trees/ha.

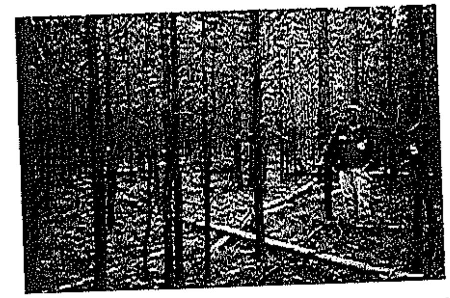


Figure 10. Fertilization with 800 kg/ha N applied in concentrated strips provided slightly less growth than the equivalent dose applied in broadcast fashion, with top heights averaging 7.1 m and an apparent SI_{50} of 16.3 m. Densities averaged 15,700 trees/ha.

Figure 11. Untreated areas in the fore- and left mid-ground are contrasted with a plot which received 800 kg/ha N, located in the right mid-ground.

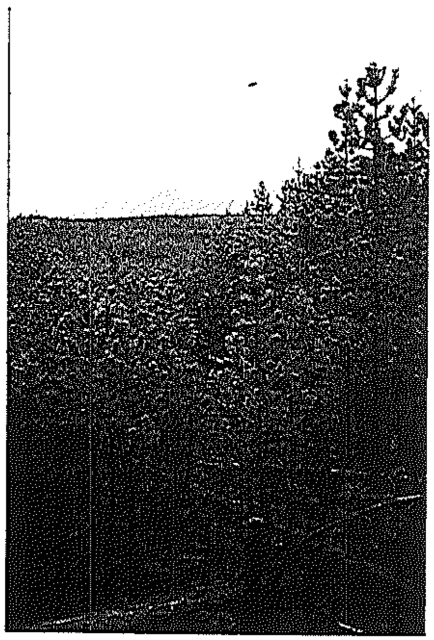


Figure 12. Untreated area on the left contrasted with a treatment plot on the right which received 400 kg/ha N. The post in the bottom center and the cut trail behind it mark the boundary of the plot.

Figure 13. A row thinned only area on the right is contrasted with a row plus hand thinned plus fertilizer plot on the left. The center row was not hand thinned, but likely received some fertilizer additions.

Several factors affect interpretation of the results of this trial. There can be no doubt that treatment had a large positive impact on stand growth rates, but the underlying causes of the responses are less certain. While thinning and fertilizing alone had only small effects on growth rates, the two treatments combined appear to have produced a relatively large response. When combined with thinning, for example, it only took 150 kg/ha N to contribute to the largest response observed, but 200 kg/ha without thinning N produced only a small response. Better growth responses to higher and higher doses of N in the nominally unthinned stand cannot be be attributed to the treatment alone, as large density effects were also observed in these treatments, at least partially attributed to the high snowshoe hare population at the time (see table 1).

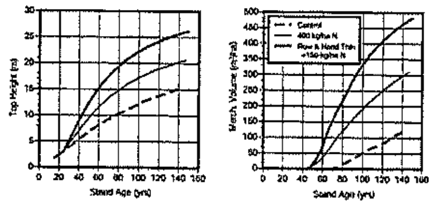


Figure 14. Yield projections can be extrapolated from the trial results assuming that current growth rates are indicative of long term trends. These projections were done using TIPSY, and assumed growth rates relative to height rather than age to adjust for the period of repression.

Figure 15. Large increases in height growth have been observed in a trial on repressed pine west of Williams Lake BC. The tree on the right was not treated, while the tree on the right received a complete nutrition blend of fertilizer. Each tree is being held at the branch whorl representing the top of the tree at the time of treatment. (photo courtesy of T. Newsome, BC Ministry of Forests)

While this trial offers significant hope for achieving large yield gains in repressed pine stands (Figure 14), rigid extrapolation of the results to other sites would be speculative at best. The only other similar trial known is in very early stages of monitoring, has produced similar or possibly even more dramatic results, but suggests that different treatments may be most effective. For that trial, which is located in the Cariboo Forest Region west of Williams Lake, BC, a fertilization alone treatment (Figure 15) has produced the best growth responses over two years, using a complete nutrition blend of fertilizer. Thinned and fertilized plots in that trial have observed growth rates well below that for fertilized only plots.

While it appears that additional work is required to refine prescriptions for treatment of repressed stands, there is considerable promise for improved yields. Despite high treatment costs, the gains from this type of treatment on a cost/benefit basis will be far greater than for almost all other silvicultural treatments, even if the yield improvements in Figure 15 are optimistic by a factor of 2. Work that is required prior to widespread operational application, however, includes a series of replicated trials on different sites to evaluate the best treatment options under a range of site conditions. Such trials could also evaluate various fertilizer screening methods for their effectiveness.

Author's note

A more detailed document on this trial is being prepared for journal submission. A copy either of the draft or the final journal article can be obtained from the author.

Forest Management, and Fertilization, in Context of the Strategy and Tactics for Creating the Future Forest We Want

G.L. Baskerville[1]

Forest management is a strategic process to create a future forest, with a dynamically changing pattern of stand types and stages of stand development, that supports a set of target values, at specified target levels, at specified future locations, at specified future times. The time horizon for forest level planning is of the order of centuries, and the spatial dimensions are of the order of hundreds of thousands of hectares. Stand silviculture is comprised of the local tactics, which can scheduled in a forest management plan as part of the means to achieving the forest level outcome defined in a forest management strategy. The time horizon for silvicultural planning is of the order of decades, and the spatial dimensions are of the order of tens or hundreds of hectares. Fertilization is a stand level tactical tool, which can be used in context of a forest level strategic plan.

The values that comprise the forest management objective, and the level of their availability, are functionally dependent on some combination of stand type, stage of stand development, and the geographic pattern of stand type and stage of development. Since trees grow, and stands develop, and both natural and human disturbance occurs from time to time, the conditions that support a value *cannot be* continuously available in one stand, at one location in a forest. By virtue of those same natural dynamics, the conditions to support a value *can be* continuously available in some stand somewhere in a forest.

The objective of forest management

The objective of forest management is to regulate the temporal-spatial pattern of stand types and stages of stand development, across a whole forest, such that each target value is, continuously available in an appropriate amount, with appropriate quality, at an appropriate location in the future forest. This biological goal must be economically realistic, in that the cost of management of the forest as a whole, must be acceptable to the forest owners in context of the benefits that will accrue to the owners, over time, from the forest. This "economic" condition commonly is a dominant determinant in decisions to manage a forest, and, in decisions that determine the level at which management will be pursued.

Two perspectives of forest management

1. Working from stand level actions, up to the forest. What might be called the "good tools" approach defines silvicultural tools that are deemed to possess inherent goodness, or inherent badness. In this context, management consists of using "good tools," and avoiding "bad tools." The good tools are applied in local stands, with the assumption that the emerging future forest, as a whole, therefore will be "good." This stand-oriented approach to managing a forest often does not involve explicit forecasts, and commonly only some individual stands are considered, again commonly, out of context of inherent natural stand dynamics. The key here is that the "goodness" that local actions possess is deemed to ensure that the designated, but rarely biologically defined, values will be present. This "rules for tools" approach is the antithesis of adaptive management because the presumption that using "good" tools will result in a "good" future forest precludes testable hypotheses about cause-effect in the future forest.

The good/bad classification of tools is the default choice in stand level management for many in contemporary society. Thus, clear cutting is "bad," selection cutting is "good," fertilization is "bad," and so forth. There is a tendency for tools to acquire/retain "goodness" where their use creates an acceptable appearance to the public view. Where tools possess this "goodness" by definition, there commonly is no analysis to identify where/how a tool creates, or fails to create, the actual target value outcome in a forest. That is, the value is presumed to be there by virtue of having used the "good" tools. Rarely in this approach is there a temporally/spatially explicit forecast of the future forest, or of the level of the target value in that forest. Adaptive management is not possible with a "rule for tools" approach, however, since the rules for tools are "right," adaptation is not relevant.

2. Working from the future forest back to stand actions. A functional approach to forest management design uses forest level models to mimic the temporal-spatial dynamics of stand types and stages of stand development, across a whole forest, over time into the future. This permits evaluation of a range of future forests that reasonably could be created by management over time, beginning with the existing forest. One of these reasonably possible future forests is chosen as the goal for forest management. From analysis of this forecast, a harvest level and a set of stand level silvicultural actions are determined. The actions, which have been reasoned to cause a target future pattern of stand types, and stages of stand development, to emerge over time, are taken in the appropriate stands in the forest, at the appropriate times, and with the appropriate strength.

With this approach, the emerging future forest is regularly assessed to determine both the degree to which the target forest structure/pattern is being approached, and degree to which that future forest continues to be an acceptable management target. This is based on explicit, and therefore testable, cause-effect hypotheses with respect to the effectiveness of "causes" invoked in management of the forest over time. The manager acts, and evaluates the results of his/her actions, in context of maintaining a specific temporal-spatial forest pattern whose dynamics ensure that all target values are available somewhere in the forest all the time. This approach is the essence of adaptive management.

A big communication problem

There are archetypal examples of both good, and bad, forest management in Canadian forests. However, no matter which of the above approaches is employed in a particular instance, public discourse on the quality of forest management tends to focus almost exclusively on the tools employed, and not on what the forest is becoming. That is, the focus is on the actions at the stand level, out of context of the role of those actions in "managing" natural temporal-spatial dynamics to create a defined target pattern of conditions in the future forest. This disconnect of biological logic from the choice of actions continues to be a major problem in management of Canadian public forests.

In most contemporary public discourse on forest management, the goodness/badness referred to above is presumed to be achieved, not by what results from the use of the tools, but rather from the nature of the tools themselves. Public discussion of the state of forest management rarely acknowledges that the determination of the goodness/badness of a tool logically requires a forest level context, long term, in terms of what forest is expected to result from the use of the tool. No one would assert that use of power planers and power saws in building a house, automatically means the resulting house is "bad." Equally, no one would assert that not using such power tools would result in the built house being "good." However, using mechanical harvesters, and fertilizing stands, regularly are said to ensure that the emerging forest will be "bad," and, that if horses were used the forest would be "good."

Putting management activities in context

Forest management is a classic example of the principle of "think global, act local." In the case of forest management, the rule is "think forest, act stand." In general, we handle the act stand part rather well. Also in general, we tend to do a very poor job of thinking at the level of whole forests. Forest level management is the orchestration of stand level actions, including harvesting, and silviculture, to regulate the emerging pattern of stand types and stages of stand development across a forest of say 200 000 ha, and over a time horizon roughly equivalent to two or three human lifetimes. Without technical aids, few people can visualize change in a 200 000 ha forest over a time horizon of 100 years into the future.

To manage a forest, it is necessary that all the players involved fully grasp the temporal spatial dimensions of the task. Failure in these respects commonly results in an approach characterized as "think local, act local." To the extent this happens, it means the process will manage what people do in individual stands as independent "management tasks," and, that the forest that ultimately will emerge as a result of these individual decisions cannot be forecast!

Functionality is essential in forest design. Anyone who has designed and built their own house will know that the quality of the built house, as an environment for a particular family, depends heavily on the functionality of floor plan for that family. It depends hardly, if at all, on what tools the carpenters used to build the house. That is, a functional context of the desired outcome is of over-whelming importance in judging the probable effectiveness of a tool before the fact. In forest management, the use of a stand level silvicultural tool must have a functional context in how intervening in a particular local stand will contribut

[1] Qualicum Beach, BC

to what the forest, as a whole, is to become over time in the future. In our forests, where public ownership dominates, the context of local (stand) actions, in forest level management, is extremely difficult for the public owners to grasp.

As an example of the above problem, I recall meetings about 25 years ago where discussion centered exclusively on how many trees had been planted. At that time bragging rights about forest management went to the province/company who planted the most trees. Indeed, the measure of "success" in forest management was solely the number of trees planted. No one questioned the concept of plantations, indeed, plantations were hailed as "ultimate good" by mangers and environmentalists alike. That may have been the last time they agreed on anything. Today we are more likely to hear that plantations are biologically sterile, and to be avoided. Neither approach was/is based on biological reasoning, with respect of what would be achieved in the future forest, by using this silvicultural tool. Neither approach was/is given forest context in a particular specific forest.

In building a house, we would not contemplate arguing each saw cut, each nail, each pipe, each bit of plaster, etc, in and of itself, out of context of how the house is expected to function. Rather, we create a plan for the finished house, and use this to evaluate the probable function of the completed house. The plan is debated, and modified as necessary to account for the foreseen needs of the future occupants. Once the plan is determined, the house is constructed, being mindful of various construction standards and building codes. All of this takes place within the span of one or two years on a tiny building lot. The principle is the same for managing a 200 000 ha forest on a time horizon of 150 years. To push that analogy, anyone who has built a house will know that shortly thereafter something, such as an unplanned child, can render the original house inadequate, and dictate immediate modification of the floor plan. That is not dissimilar to the "discovery" of a threatened species after a management plan has just been initiated, and which requires a change in the plan for the future forest.

The temporal-spatial dimensions are several orders of magnitude greater in the building of a future forest via management, as opposed to building house, but the principles involved are similar. When the final objective changes, whether it is in building a house or managing a forest, the strategic plan must be reviewed. If a functional temporal-spatial plan does not exist, reasoned evaluation, which could foster reasoned change, at reasoned cost, is virtually impossible.

What about the economics? Economic analysis of management at the forest level, logically should evaluate the gain in value from the whole forest that results from management of the forest, over a time horizon appropriate to managing the forest. This rarely is done. Economic analyses tend to focus almost exclusively on current stand level actions. That has the effect of making conclusions about cost-effectiveness of tactics, without reference to the strategy embracing the tactics, and, out of context of the strategic goal. This is an area of some contention.

Economic analyses at the stand level are appropriate, indeed prudent, in the selection of which of several possible local actions is likely to be the most cost-effective in achieving a defined future stand condition that is an essential target, at that location, in the forest as a whole. If there is more than one treatment option that can bring a stand from its current condition, to the future condition that is desirable in context of managing the forest as a whole, the most cost-effective treatment that achieves the target stand level condition should be determined and applied.

The need for owner understanding

It is not likely we, collectively, will achieve reasoned "design/construction" of our future forests until we, the public who own 90% of the forests, comprehend that a forest is temporally and spatially dynamic because the stands that make up the forest are themselves dynamic. Nor will we achieve reasoned design of future forests until those owners-users adopt a time horizon for management on the order of centuries, as opposed to annual stand silviculture budgets. That represents an enormous challenge in a world where surveys show that the time horizon of the average person is roughly equivalent to the number of payments left on their automobile.

The frequent advocacy of what is perceived to be "good" silviculture in a local stand, out of context of what the whole forest is to become, is perhaps the single greatest threat to effective management of Canadian forests. It is likely this will continue to be a problem in forest management for some time to come. Sadly, ENGOs who one would expect to be strong supporters of managing what the future forest becomes, have chosen to play obstructionist roles with respect to local actions being taken now, rather than take an active role in the design-creation of the future forest.

A forest management context

Putting fertilization into a forest management context, as opposed to a stand silviculture context is not difficult. Fertilization increases growth in a local stand. The value of that increase can be calculated in context of the stand, or it can be assessed in context of the role of that stand in making wood available over time through a forest level strategy. Economic evaluation of the increased volume available at the stand level often shows that the discounted costs of the volume increase due to fertilization, is not recovered in increased volume/quality when the stand is harvested. That is a stand management, or silviculture, conclusion. It is not a forest management conclusion.

Evaluation of selective fertilization in context of wood flow from the forest as a whole, as in an estate (forest level) model, often reaches a different conclusion, than does evaluation at the stand level. The estate model deals with all the stands in the forest, by placing them in a queue for harvest. This queue of stands determines the even-flow harvest volume that can be maintained. Commonly, the queue of stands for harvest can be limited in two ways. The ultimate limit is determined by the rate at which the sites in the forest support the growth of wood. A fertilization program would have to be massive to increase this level.

The second common limit on the availability of volume for harvest, relates to the rate of progression through a queue of stands for harvest. This commonly is constrained by availability of suitable stands only at one or a few future periods in the span of the forecast. Before and after the time period when the constraint acts, the harvest volume could be greater, and still be sustainable. This commonly results from the initial forest not having a balanced age-class structure having originated from historic natural disturbances. In these situations, whole forest analyses can identify the group of stands that are constraining the long-term harvest level. This examines the potential for specifically targeted silvicultural actions, such as fertilization of stands to move them up in the harvest queue, to relax the constraint and permit an immediate increase in the annual harvest level. Availability of this option (sometimes referred to as an allowable cut effect) depends primarily on the age-class structure of the target forest.

Conclusion

Because the forest is naturally dynamic, and ever-changing, forest management properly is aimed at regulating the dynamic temporal-spatial availability of the conditions required to retain the target values across the forest, over time. A reality of forest dynamics is that it is not possible to have any one value, associated with a stand type and stage of stand development, at one place all the time. The fact that trees grow, and stands develop, means the "floor plan" of a forest is continuously changing whether we try to manage it or not. Our management cannot override these natural dynamics. However, management can be designed to work with these natural dynamics to regulate what conditions will be at what locations in the future forest, at what times, thereby managing the availability of values.

Forest management must use knowledge of natural dynamics to evaluate, and select, actions that influence stand dynamics in a manner that ensures the continuously evolving forest retains all the values we desire. Clearly, the target values cannot be retained at one place in the forest, but they can always be available at some place in the forest. Management, including the use of fertilization, can influence how much of each forest value is available from time to time in the forest, where those values are available, and the quality at which those values are available.

Strategic factors affecting wood supply and demand in Canada

Tony Rotherham[1]

Opening Thought

In an ecosystem, everything is connected to everything else.

Barry Commoner

So it is in life and business.

World Forest Statistics

- Value of shipments
  $450 - 500 billion US
- Value of exports
  $150 billion US
- Number of Countries involved
  ± 120
- Canada has ± 20% of world exports

World Forest Statistics

- Area of closed canopy forest
  3.4 billion ha
- Area of plantations
  85 million ha and growing

	Volumes Harvested (billions m³) 1993	2010
Fuelwood	1.9	2.3
Industrial Roundwood	1.5	2.3

FAO

Factors Affecting Demand

- World population growth 6.7 → 11
- Per capita use
- Market access
  - *–international trade relations / agreements*
- Market acceptance
  - *–will the customer buy your product ?*
  - *–price, quality / technical specifications, delivery*
- Environmental performance
  - *–forest management / LCA / LCT*
  - *–Consumer preferences / product substitution / communications*

World Forest Statistics

- Area of closed canopy forest
  3.4 billion ha
- Area of plantations
  85 million ha and growing

	Volumes Harvested (billions m³) 1993	2010
Fuelwood	1.9	2.3
Industrial Roundwood	1.5	2.3

FAO

Factors Affecting Demand

- Technology and change
  –photocopies, e-mail, literacy, pc's
- World trends and events
  - *–Kyoto – climate change – living in a carbon-constrained world*
  - *–renewables vs. high energy content products – cement, PVC, etc.*

[1] Director, Forests, Forest Products Association of Canada

Factors Affecting Demand

- Manufacturing technology

Lumber Yield		Pulp Yield	
1970 - 180 fbm / m³		Sulphite	- 45 %
1985 - 220 fbm / m³		Sulphate	- 45 - 55 %
2000 - 300 fbm / m³		Groundwood	- 90 %
		TCMP / TMP	- 90%

- Paper
  - – Weights - grammage or grs. / m² ↓
  - – recycling rates ↑

Factors Affecting Supply

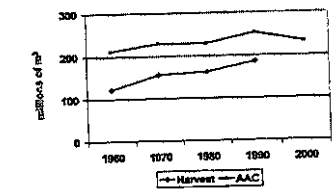
- Forest management environmental performance
- Social license to operate on public and private lands
- SFM and biodiversity are two top concerns for FPAC
- Credible communications / certification
- Natural disasters
  fire, disease, insects
- Impacts of climate change
  Fire ? Drought ? Warming ? Where ?
- Rates of Growth

Factors Affecting Demand

- Costs
  –logging,management, transportation
- Southern plantations
  –high yield, increasing areas
- Fibre quality
  conifer vs. deciduous
  long vs. short
- Paper machine size 2m → 8 - 9m
  600 ft / min → 3,500 ft /min
- Printing press size & speed up also

Canada's 8 forest regions, each with a characteristic mix of species – approx. 25 important commercial species

AAC vs. Harvest in Canada 1960 - 2000

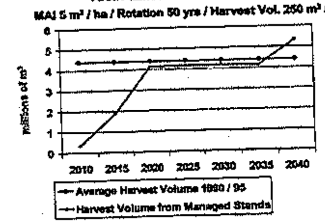


Factors Affecting Demand

- Human ingenuity
  - *–pulp from southern pines*
  - *–papermakers, printers / press manufacturers*
  - *– engineered wood products*
  - *– technological change, pc's, etc.*

Projected Harvest from Managed Second-Growth Stands

Area Planted PLUS Area Tended
MAI 5 m³ / ha / Rotation 50 yrs / Harvest Vol. 250 m³ / ha



Factors Affecting Supply

- Land base available ?
  244 / 232 / 210 / ? million ha
- Protected areas strategy
  12% -- more ?
- Forest protection campaigns
  - ancient forests - old growth
  - frontier forests - intact forests
  - roadless areas - well-developed secondary forests

Nova Scotia Silvicultural Treatments 1975 - 1995

Average Area Harvested 91 - 95 = 43,131 ha / vol. 4,400,000 m³

DATE OF STAND ORIGIN	TENDING	PLANTING	AREA TOTALS X 250 =	HARVEST VOLUME	DATE OF HARVEST
1960	1,334		1,334	333,500	2010
1965	7,451		7,451	1,862,750	2015
1970	16,526		16,526	4,131,500	2020
1975	15,285	1,425	16,710	4,177,500	2025
1980	12,978	3,705	16,683	4,170,750	2030
1985	10,000	6,584	16,584	4,140,000	2035
1990	10,000	11,255	21,255	5,313,750	2040
1995		7,186			

Strategic silviculture investments: an industrial perspective

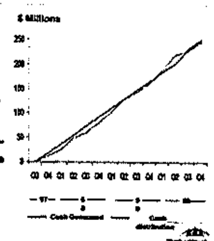
Larry Promnitz

SSI: An Industrial Perspective

- TimberWest Structure
- Strategic Parameters
- Public Land Investments
- Private Land Investments
- Acquisition Planning
- Timberland Investments

TimberWest

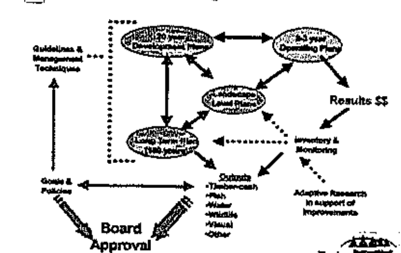
- Investment is based on timberland investment characteristics
- Essentially, 100% of cash generated is distributed to unit holders
- Each dollar is a choice of "give it to the unit holders" or "effectively use it for the unit holders"

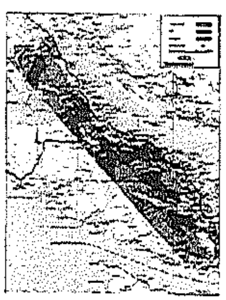


TimberWest

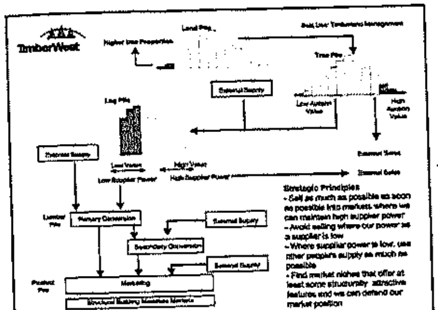
- Core asset - 334,000 hectares of private timberland on Vancouver Island (ISO 14001 and SFI certified)
- Came into existence June of '97
- Canada's only "private timberland investment vehicle"
- Unique structure similar to Income or Royalty Trusts
- Main direct competitors for similar investment dollars are US "Timber Companies"

Planning Activities



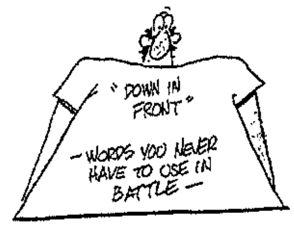


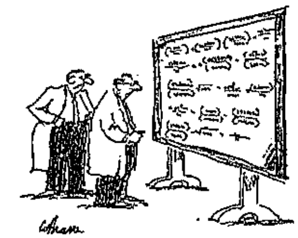
Director, Strategic Planning, Timberwest Forest Corp.



Key Silviculture Decision Areas

Stand Establishment	•Genetics •Reforestation
Early Stand Management	•Juvenile Spacing •Fertilization •Pruning
Late Stand Tending	•Fertilization •Commercial Thinning
Rotation Age	•Financial •Biological
Harvest Style	•Clearcut •Variable Retention •Habitat Conservation Plan





"That'll never work. You forgot to figure money into the equation."

What is Strategic ?

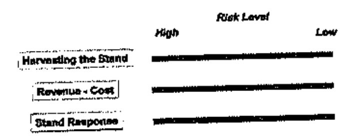
- Strategy
  The art of so moving or disposing troops as to impose upon the enemy the place, time and conditions for fighting as preferred by oneself
- Tactics
  Procedure calculated to gain some end
- Operations
  Work

Engaging in a "fair" fight demonstrates a lack of strategic skills.

The Concise Oxford Dictionary

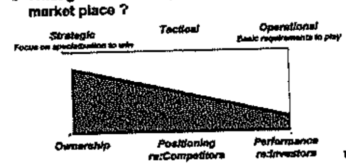
Silviculture Investment Criteria

Internal Rate of Return greater than "other" alternatives



What is Strategic ?

- What gives us a competitive advantage for investment dollars ?
- What gives us a competitive advantage in the market place ?



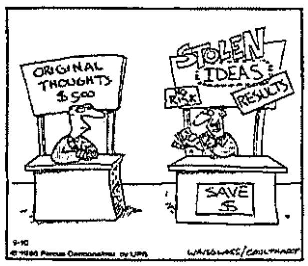
Key Strategies - Public Lands

- Government ownership of the land and the trees precludes "strategic" investments
- Meet basic requirements at minimum cost
- Uncertainty precludes company $ investments
- Public $ investments (e.g. FRBC)
  Only those practices that we believe are sound investments
  "Social Forestry" done at the government's request

Key Strategies - Private Lands

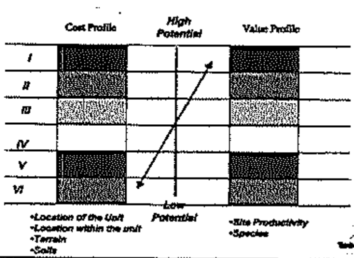
"Selective Intensification of Extensive Forestry"

- Key strategic focus is on stand establishment
  - Genetic improvement program
  - Excellence in basic forestry
- Late rotation fertilization as the primary "operating" investment
- Financial rotations, "Long Run Sustainability" (Company structure), Variable Retention (New)

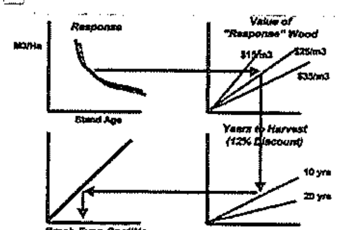


"This was one hell of a business idea, Frank."

Carrying Capacity for Investment



Douglas Fir Late Rotation Fertilization



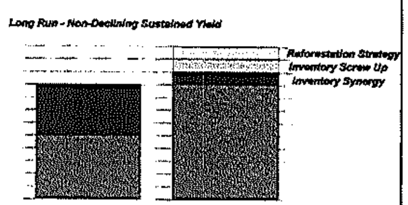
Douglas Fir Late Rotation Fertilization

Site Index	Harvest Age	Fert Age	Domestic Market IRR	Export Market IRR
40	50	40	26.8%	31.2%
35	55	45	22.1%	26.3%
30	60	50	17.2%	21.4%
25	70	60	9.9%	13.0%
20	80	70	5.7%	5.7%

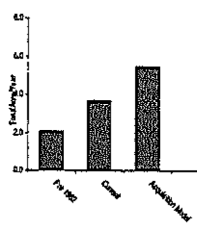
Yield Analysis

- Acquisition of TimberWest (6/97)
- Completed acquisition of Pacific (12/97)
- Initiated "Yield Analysis Project" (2/98)
  - Assessed and modeled (new) environmental aspects
  - Developed new mature inventory estimates
  - Developed new growth and yield models
  - Developed forest management impact estimates
  - Combined, corrected and standardized three inventory systems (BCFP, CFI, PFP)
- External audit completed (7/98)
- Board Approval (8/98)

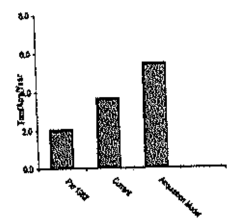
Yield Analysis - Results



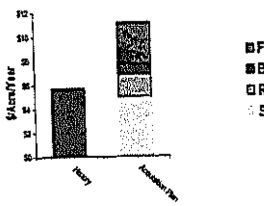
Southern Pine Yields Acquisition Modeling



Southern Pine Yields Acquisition Modeling



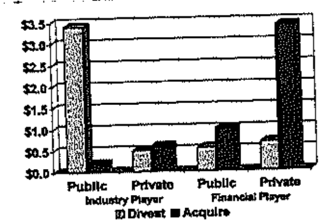
Southern Pine Yields Acquisition Modeling



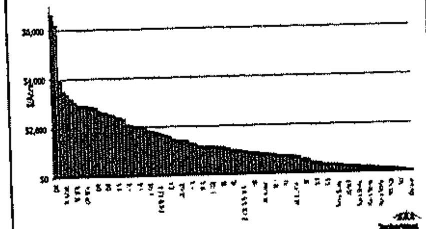
US Timberland Public Company Ownership

Company	U.S. Owned Hectares (000)
International Paper	4,895
Plum Creek	3,213
Weyerhaeuser	2,325
Willamette	690
Boise Cascade	939
Rayonier	891
Mead	848
Temple-Inland	690
Potlatch	611
Westvaco	537
Louisiana Pacific	383
Bowater	324
Crown Pacific	309
US Timberlands	177
Longview Fibre	160

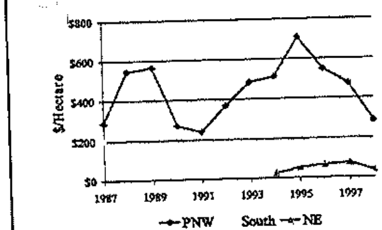
1998 - 1999 Timberland Transactions



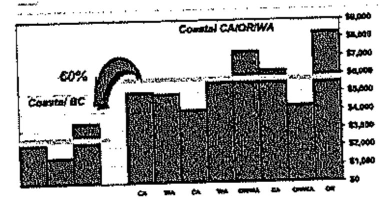
North American Timberland Transactions



Timberland Operating Income per Acre



Northwest Timberland Sales

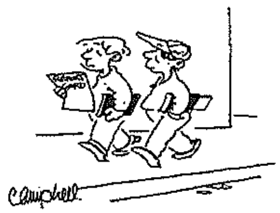


Private Timberland Cash Generation

(US $/Ha)

	1997	1998	1999	2000	Avg	Location
Pope Resources	$349	$333	$399		$360	Washington Coast
Crown Pacific	$345	$480	$341		$388	NW Inland and Coast
US Timberlands	$239	$261	$339		$280	Oregon Inland
Average	$311	$358	$360		$343	
TimberWest	—	$139	$168	$180	$162	BC Coast

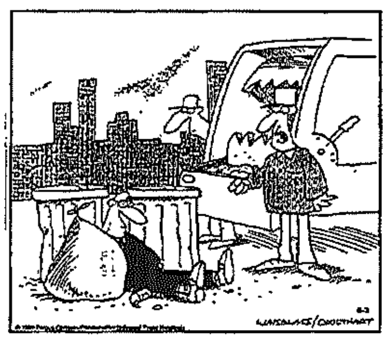
53%



"The problem with these average report cards is, it's hard to get them funded."

Timberland and forestry investment issues

- Political & Industry Environment
  - Legal Environment
  - ✓ Tax environment
  - ✓ Regulatory environment
  - ✓ Operating environment
  - ✓ Labor environment
  - ✓ Market access



"Hey look! A perfectly good forester."

Effects of fertilization and thinning on growth and value production of Norway Spruce

J. Klädtke and G. Kenk[1]

Introduction

Fertilization as a mean to improve tree and stand growth has been playing a role in Germany's forest practice and research for more than one hundred years (i.e. Hornberger 1908). At this time, forestry in a large area of Germany was faced with conifer stands, which were suffering from growth stagnation due to high stand densities, soils devastated by litter raking and covered with thick and inactive raw humus layers. As soon as the first convincing results in agriculture were achieved in the middle of the 19th century, it was evident that fertilization was taken up by forest practice and research, carried out in plantations as well as in older stands.

Whereas the aim of fertilization in plantations is to accelerate tree growth, especially height growth, in order to faster overcome risks like frost, browsing, etc., the aim in older stands is to improve volume growth and assortment structure.

Especially after Word War II, when large parts of the forests in Germany were exploited, fertilization was carried out to alleviate timber shortage, mainly in stands being 20 to 30 years below the age of rotation. Additionally, many experiments were established to investigate fertilization effects scientifically, and a short summary of the results of some of these experiments will be given in this paper.

Among the numerous fertilizer experiments in Baden-Württemberg, a trial in the Northern part of the Black Forest, "Norway spruce 337" is one of the most interesting. Started in 1952, it had been observed for 42 years and has been investigated very intensively by growth and yield specialists and soil scientists as well (Hausser 1961, Hausser et al. 1971, Evers 1990, Spiecker 1991, Spiecker et al. 1992, Klädtke 1999a). Therefore, this trial will be discussed in more detail, presenting the fertilization effects on diameter growth and value production and comparing them to thinning effects.

[1] Forest Research Station of Baden-Württemberg, Germany

Fertilization trials in plantations

Figure 1 shows the results of a fertilization experiment in Norway spruce plantations in the Black forest on poor sandstone (Norway spruce 378, Altherr and Evers 1981). The effects on height growth are striking—25 years after fertilization, mean height of the fertilized plots is up to 2 times higher than the control. Like in many other plantation fertilization trials under comparable growth and site conditions, the best results have been gained by a Ca and P resp. Ca, P, and N fertilization, but even fertilization with Ca only has significant positive effects.

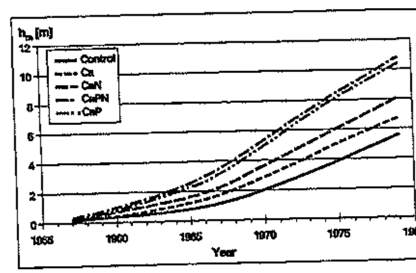


Figure 1: Height development in differently fertilized Norway spruce plantations (Altherr & Evers 1981).

In 1991, Evers and Gussone (1991) scrutinized the literature about fertilization experiments carried out in Norway spruce stands in Central and Northern Europe, 55 plantations in all. In spite of the extremely wide spread conditions in terms of climate, site, fertilizer composition, etc., only 2 out of the 55 experiments were without positive effects on tree growth. In 43 cases, the results have been considered to be good, and very good for the remaining 10 cases. It is interesting to mention that in some trials, red alder or lupines were mixed with Norway spruce, inducing positive growth effects too.

Although the effects of fertilization in plantations are generally more short termed, experiments with substances being rather stable in the soil, like calcium and phosphate, also may exhibit long term positive growth responses (Evers and Hausser 1973). Altherr and Evers report that Ca and P fertilization in plantations may increase volume growth up to 2.5 m³ per ha and year until the end of rotation (Altherr and Evers 1981, Evers and Hausser 1973).

Fertilization trials in older stands

Results from fertilizer experiments in Germany

Fertilization in older stands will increase volume growth and improve assortment structure. Therefore it is expected to have long-term effects.

Table 1: Results from fertilizer experiments in Baden-Württemberg.

Region	Age [yrs.]	Obs. Per. [yrs.]	Fertilizer	Volume Increment Response	Authors
Black Forest	53	13	NPCa	46%	Hausser et al. 1971
	51	9	NCa	33%	Aertz et al. 1964
Alp Foothills	48-68	10	NPCa	7-8%	Hausser 1977
	62-82	9	NPCa	18%	Hausser 1977
	60	8	NPCa	0/9%	Hausser 1977
Odenwald	48	14	NPKCa	35% [ls]	Altherr & Evers 1975
Swab. Alb	90	5	NPKCa	20%	Altherr, Evers & Lenser 1974

The figures in Table 1, derived from nitrogen fertilization experiments in Baden-Württemberg, show partly considerable growth responses. However, it gets evident, that these responses differ considerably under different growth conditions. On the rich soils of the foothills of the Alps with high nutrient supply, the effects of fertilization with nitrogen, calcium and phosphor are much smaller than on the poor sandstone soils of the Northern parts of the Black Forest. From their extensive investigation of European fertilization experiments, Evers & Gussone conclude that volume increment may be increased by fertilization by 2 to 3 m³ per ha per year on average.

According to this evaluation, the following factors are of high importance for the extent of increment responses:

- *Temperature and precipitation:* for Norway spruce in Central Europe, best fertilization results can be obtained at medium altitudes with high precipitation and moderate temperatures. Consequently, growth responses to fertilization in dry or cold regions are comparatively small. The closer temperature and precipitation are to the optimum for a tree species, the more important the nutrient supply of the soils is for the growth performance (Nebe 1968).
- *Edaphic processes and humus form:* Since the nutrient supply of the soils depends on the edaphic processes and humus form, these two factors are important for the efficiency of fertilization too. Fertilization therefore is most effective on poorer soils like sandstone and/or with poor humus forms like mor, moderate temperatures and sufficient precipitation provided. Soils devastated by litter raking, which was very common in the past in large areas of Germany, also belong to this category. On rich and on very poor sites, the efficiency of fertilization is minor. As a rule of thumb, best responses to fertilization can be expected on sites having an average volume increment between 7 and 11 m³ per ha per year. Based on 32 experiments, Fiedler et al. (1978) and Nebe (1981) published tables to estimate the additional volume increment of Norway spruce stands per 100 kg nitrogen applied, depending on site index and some climatic components. According to these tables, 150 kg N/ha are expected to induce growth increases from 3 to 17 m³/ha in 10 years, depending on the stand's age and site, with fertilization effects being better the lower the site index.
- *Thinning:* while the effects of climate, weather, soil, and site on fertilization results have been investigated rather comprehensively, there are only few studies in Germany including thinning in fertilization experiments. The results are rather vague and partly inconsistent due to the complex interactions of growth influencing factors. Therefore, based on the example of trial Norway spruce 337, a new approach has been developed to find out how a different thinning strategy would have worked in comparison to fertilization.

Fertilization Trial Norway Spruce 337

Site and Stand Description

Site		Stand	
Location:	Northern part of Black Forest	Beginning of the experiment:	1952 (age 67)
Altitude:	610 m a.s.l.	Last record:	1994 (age 109)
Precipitation:	Ø year: 950 mm	Number of records:	10
	Ø May-Sept.: 440 mm	Site index:	≈ 9-11 m³ x ha⁻¹ x y⁻¹
Temperature	Ø year: 7,0 °C	Stand management:	-1952: only weakly thinned
	Ø May-Sept.: 13,9 °c		1952-1994: moderately thinned
Geology:	Sandstone		1960s: underplanted with silver fir (Abies alba)
Soil:	Podzolic brown-earth		

Fertilizer Application

Fertilization started in 1953 with Ca, CaP, N, NCa, and NPCa, and was partly repeated in 1954, 1955 and 1966. See Table 2 for more information about the fertilizers applied.

Table 2: Overview about date, amount (t/ha), and compound of the fertilizers applied

Plot n°	Date 5/1953	7/1954	6/1955	3 u. 5/1966
1	2.0 Ca			1.0 P 1.0 N
2	2.0 Ca 0.4 N	0.4 N	0.4 N	0.5 N
3	Control plot			
4	0.4 N	0.4 N	0.4 N	
5	2.0 Ca 1.0 P 0.4 N	0.4 N	0.4 N	
6	2.0 Ca 1.0 P			

Ca: Calcium carbonate (36% Ca, 4% Mg)
N: Calcium ammonium nitrate (24% N, 15% Ca)
P: Basic slag (7% P [citr. sol.], 32% Ca)

Results

Growth Analysis

Data were available from 10 records since 1952. However, the use of these stand data is restricted due to irregular management of the plots (underplanting with silver fir *(Abies alba mill.)* in the 1960s; different thinning intensities), and to unequal site conditions.

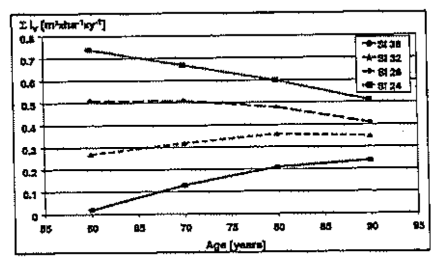


Figure 2: Estimated increase of volume increment per 100 kg nitrogen fertilization (acc. to Fiedler et al. 1978 & Nebe 1981)

Therefore, the analysis has been mainly based on tree ring and height growth measurements. From about 10 trees per plot[2] stem disks were taken in 1.3 m, 11.5 and 21.7 m tree height. Shoot lengths were measured from the top of the tree down to 21.7 m.

[2] From plot no 1, first intended to be omitted due to considerable site differences, tree ring and height growth analysis of only 5 trees were available. Therefore, the validity of the corresponding results is only limited.

Since there are no replications in this old experiment, restraints have to be admitted from the statistical point of view. However, results have been confirmed by other fertilization trials.

Variance analysis (t-test) was applied to check growth differences for significance[3]. Since the growth level of the fertilized plots turned out to be superior compared to the control plot even before the fertilization[4], the radial and height increments were adjusted before further processing by following procedures:

1. The annual radial and height increment were calculated as percentage of the mean before fertilization (1919–1950) for each plot.
2. The relative values of the fertilized plots were divided by those of the control plot, which allowed to eliminate weather impacts and aging trends to a great extent.
3. Absolute values, unbiased by site differences, were obtained by multiplying the relative values of the fertilized plots derived from step 2 by the increment of the control plot (Figure 3).

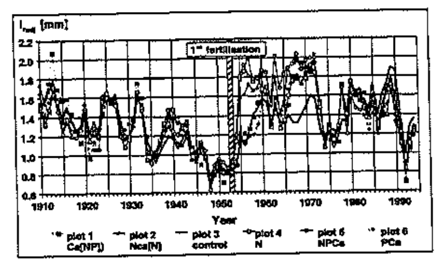


Figure 3: Annual radial increment (adjusted) years

The adjusted radial and height increments were used fo calculating the DBH, basal area, and volume developmen from 1952 until 1994. Mean DBH and mean height of th control plot were used as starting values for all fertilized plot (Table 3, plot 3, col. 4 and 5). A standard taper of 0.5 wa applied to calculate volume development.

[3] See fig. 1 showing the example of plot no 3 and 4
[4] Except for plot 2, the differences are statistically significant.

Table 3: Data of the analyzed trees (col. 2 u.3) and the stands (col. 4-6) in 1952 at the age of 67

plot	sample tree data		stand data			
	$d_{1.3}$ [1]	height	d_g [2]	h_g	h_{100}	site class
	[cm]	[m]	[cm]	[m]	[m]	[$m^3 ha^{-1} y^{-1}$]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	23.4	23.2	21.2	23.0	26.1	10.6
2	20.2	22.3	19.8	21.9	25.1	9.9
3	19.0	22.2	19.2	22.0	24.4	9.4
4	20.1	21.8	19.3	22.3	25.8	10.4
5	19.5	22.6	18.1	21.2	23.8	9.0
6	20.4	23.4	20.4	23.2	25.9	10.5

[1] without bark [2] with bark

Radial Increment

Figure. 4 illustrates the effects on the radial increment of the fertilized plots in relation to the control. Nitrogen, calcium, and phosphor fertilization (plot 5) resp. fertilization with nitrogen and calcium (plot 2) leads to an immediate and long lasting growth reaction. Pure N-fertilization (plot 4) also induces a sudden and considerable increment increase. In 1957, the radial increment of the three plots drops down rapidly, particularly in plot 4, fertilized with N only. In 1965, the increment of all the three plots increases again.

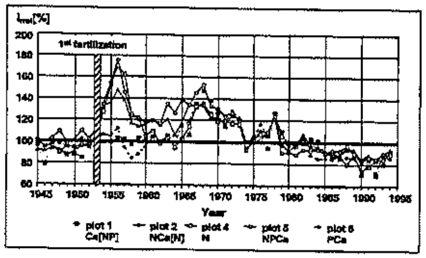


Figure 4: Adjusted radial increment in percent of the control plot

The increment of plot 1, fertilized in 1953 only with Ca and in 1966 subsequently with N and P, increases one year after N-fertilization, too, reaching the level of the likewise N, P and Ca fertilized plot 5. It is interesting that also the only Ca-fertilized plot 6 and the not additionally N fertilized plot 4 show an increment increase starting in the mid of the sixties. By analyzing the radial increment in 1.3 and 11.5 m tree height[5] it could be shown, that this is due to a silvicultural treatment, being different to the control. The fertilized plots were partly underplanted with silver fir and therefore thinned stronger in the mid of the 1960s.

Due to dry weather conditions, the radial increment of all fertilized plots decreases simultaneously in 1974. After a short recovery at the end of the 1970s, the increment of the fertilized plots drops below the level of the control.

Height Increment

Height increment has a much higher variation than radial increment, and the correlation to fertilization is less evident. Even when plots 2, 4 and 5 respond to the initial N-fertilization, and plots 1 and 2 also to the later N-fertilization in 1966, there are several increment peaks with no relation to fertilization.

Volume Growth

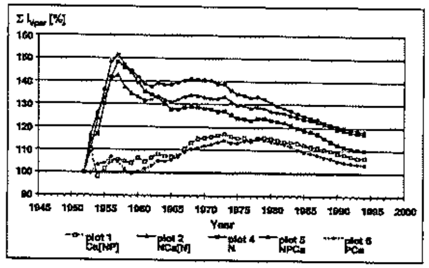


Figure 5: Total volume increment during the observation period (in percent of control)

After 42 years of observation, the plots with an *initial* N fertilization and combination with Ca resp. Ca and P have a surplus in total volume increment of 17 resp. 18% (Figure. 5). Pure N fertilization results in an additional volume growth of +10%. Plot 1, initially fertilized with Ca and later with N, reaches +7%, where the surplus is obviously due to the N application. Plot 6, fertilized with Ca and P, has the lowest surplus of +4%. The development of the total volume increment by time shows characteristic patterns according to the fertilizers applied and the site given:

- Liming in combination with phosphor induces long lasting, but restrained growth effects, being not significant in this experiment (plot 6).
- Pure N-fertilization leads to a sudden increment increase, wearing off after a rather short time (plot 4).
- Best results are obtained by combined N, Ca, and P fertilizers, with N inducing a sudden and strong increment increase and Ca and P having long-term effects (plots 2 and 5).
- The growth responses show a clear graduation according to the fertilizers applied in the order: PCa, N, NCa, NPCa.

The results correspond to the findings of other investigations with similar growth conditions and fertilizer application (see Table 1), but it becomes also evident, that the length of the observation period is very important for the assessment of fertilization effects. Observation periods of 20 years or less are too short for a final assessment.

Value Production

The software "timber harvest" of the Forest Research Station of Baden-Württemberg (Schöpfer et al.1997) was used for the calculation of the financial results. This software allows deriving assortment structure and net results from single tree height and diameter data, timber prices, and harvesting costs.

Calculation of the financial results has been performed for the total volume growth and the 200 dominant trees of the sample plots.

Volume growth of plot 5 being superior by 18%, a similar surplus of 17% is to be stated for the net value of the total volume growth (75.000 versus 64.000 DM/ha) (Figure 8). For the 200 dominant trees, the surplus is 13.000 DM/ha, resp. +46%, compared to the control due to a much more favourable assortment structure. The target of the experiment, to improve volume growth and value production of spruce stands on sites with poor nitrogen supply on a long term, has therefore been reached without any doubt.

Fertilization and thinning

The old experiment Norway spruce 337 does not include different thinning regimes, and if it would, these regimes were probably out of date from today's view. Under the market conditions in Central Europe, maximization of value production rather than volume production is the crucial point. In consequence, thinning regime has shifted by time from moderate thinnings from below to heavy selective thinning, aiming for an optimum growth of selected future crop trees (f.c.t), since these trees contribute 70-80% to the value production of the stand.

The growth of these trees can be optimized by crop tree growth norms, which describe the growth of a f.c.t. towards a specified production goal (Klädtke 1993, Klädtke 1999b).

Figure 6 shows the actual diameter growth of future crop trees from selectively thinned spruce sample plots and the diameter development of the growth norm (driven by the top height of the sample plots). The growth curves of the crop trees and the norm are very similar, and apparently the norms give a realistic idea of a goal-directed diameter growth of future crop trees. Those norms were applied to estimate the outcome of modern selective thinning, using the 200 dominant trees of the plots instead of f.c.t.

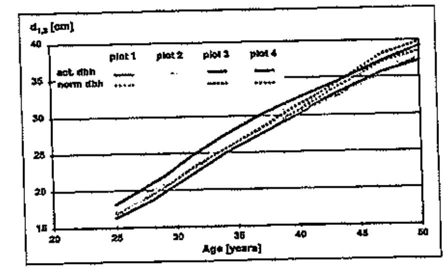


Figure 6: Diameter development of future crop trees in the thinning experiment Norway spruce 401 compared to the development of the crop tree growth norm for spruce

According to the growth norm, the target diameter at the age of 100 years for the top heights given should range somewhere between 54 and 57 cm (Figure 7, top). The actual diameter of the 200 dominant trees at the same age is between 37 and 41 cm only (Figure 7, bottom). Since the DBH of the 200 dominant is 12 cm below the growth norm already at the beginning of the experiment, low thinning intensity is probably the reason for the deviation. This follows also from the h/dbh-ratios of the dominant trees, ranging between 92 and 98 at 25 m top height. According to the growth norm, the target value is only 65.

The net values calculated for 200 selectively released trees exceed the results calculated from the actual diameter distribution of the 200 thickest trees by more than 200% (Figure 8). The net value of the total volume growth of plot 3 (control) and plot 5 (plot with the strongest fertilization effects) is still 20 resp. 13% below the comparative figures of 200 trees developed according to the f.c.t. growth norm. In this calculation, production risks due to extremely high h/dbh-ratios of the plots are not taken into account.

[5] As a reaction to thinning, the quotient of ir11.5 and ir1.3 decreases, as taper does, too. As a consequence of the stronger thinnings in the 1960s, the ir-ratios of the sample trees of the fertilized plots decreased significantly more than those of the control.

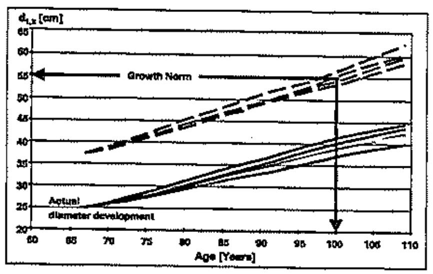


Figure 7: Actual diameter development of the 200 thickest trees of trial Noway spruce 337 Pfalzgrafenweiler compared to the f.c.t. growth norm

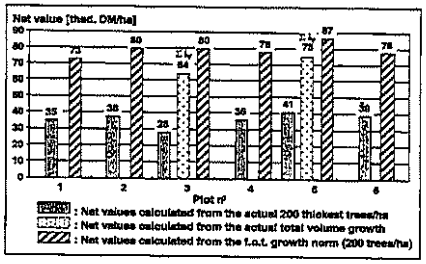


Figure 8: Real and attainable net values

Conclusions

Today, in Central Europe, fertilization as a means to increase volume growth has mostly lost its importance for the following reasons:

1. Many long-term growth studies reveal increasing growth rates especially for Norway spruce, silver fir, and beech due to improved silviculture, ending of litter raking from 1920 on, increased CO2, nitrogen imissions, etc. The results show for example for Norway spruce, that the actual volume increment of older stands on poorer soils is up to 20-40% higher than assumed so far (Kenk 1986, Spiecker et al 1996). Increment increases occur especially on poorer sites, making additional fertilization superfluous.
2. The sustainable harvest potential in Germany is higher than the actual logging volume by 30 to 40%, especially in the private forests, where only 6 out of 9 harvestable cubic meter per ha per year have been cut (Bösch 1996).
3. Under today's market conditions, total volume production has mostly lost its importance due to the low prices for industrial wood. For Norway spruce for example, about 30% of the total harvestable volume production does not cover the costs anymore.

All these facts lead to the conclusion that in Germany and probably Central Europe there is no need to increase volume production. The prime target of forest management today is rather to increase value production and to decrease production risks, and this can be reached much better by stand treatment than by fertilization. Fertilization in Germany therefore is carried out only to ameliorate forest soils by compensating acidification processes.

Summary

In the first part of the paper, an overview is given about the results of fertilization trials in Norway spruce stands, based on experiments of the Forest Research Station of Baden-Württemberg and from other parts of Germany. The results show that success of fertilization depends strongly on temperature and precipitation regime as well as on the nutrient status of humus and site. For Norway spruce in Central Europe, best fertilization results are obtained at medium altitudes with high precipitation and moderate temperatures. Moderate temperatures and sufficient precipitation provided, fertilization is most effective on poorer soils like sandstone and/or with poor humus layers like mor. On rich and on very poor sites, the efficiency of fertilization is low.

In the second part, the results of a fertilization trial in a 110-year-old Norway spruce stand are presented. The trial has been observed for 42 years and is located in the northern part of the Black Forest in Southwest Germany.

The best growth responses were found for a combined N, Ca and P fertilization, which increased the periodic volume increment by 18% and the net values by 13,000 DM/ha compared to the control plot.

Fertilization with nitrogen and liming induced a similar surplus in volume growth of +17%. Pure N-fertilization caused a surplus of +10%, with a sudden and strong, but only short-termed increment increase. Liming followed by a later N-fertilization resulted in an additional volume growth of +7%. The plot fertilized with P and Ca showed an insignificant superiority of 4%.

The growth responses observed are in accordance with results from other comparable fertilization experiments. Especially fertilization with nitrogen in combination with liming has long-termed positive effects on the growth of spruce stands on sites with low nitrogen supply.

Fertilization was compared to the effects of selective thinning, aiming at the optimization of value production. Growth norms, describing the optimum tree growth in view of this target, were applied to estimate the diameter development and value production selective thinning would have had. The DBH of the 200 dominant trees of the plots turned out to be 15-20 cm below the target. Selective thinning would have increased the net results by +52,000 DM/ha, which is 4 times more than the monetary effects fertilization has had (+13,000 DM/ha).

From today's view, in Central Europe fertilization as a means to increase volume growth has mostly lost its importance. Improved silviculture, ending of litter raking, improved CO_2 and nitrogen supply due to imissions and atmospheric deposition as well as higher temperatures have increased the growth rates considerably, especially for Norway spruce, silver fir, and beech stands considerably. Since this is true especially for poorer sites, additional fertilization is unnecessary. Furthermore, the sustainable harvest potential in Germany is 1/3 higher than the present logging volume, and finally, total volume production has mostly lost its importance due to low prices for industrial wood. Optimization of value production instead of volume production is therefore the principal target, and this can be reached much better by adequate thinning strategies than by fertilization.

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Fertilization Trials & Growth Implications

John Barker[1]

Summary

Fertilization trials and growth and yield implications

The benefits from early silvicultural treatments are difficult to evaluate since the value received is not realized until time of harvest, decades beyond the time at which responses are usually measured. Growth and yield models linking early stand treatments are generally deficient because of bad plot design, extended time periods and problems associated with continuity of effort. The following paper outlines silvicultural component trials designed to evaluate the effects of a range of treatments both singly and in combination and are structured to give stand based responses beyond the point of crown closure. These treatments involve fertilization, weed control, stock-type and species. Some also involved stand density.

Two site types are discussed. These are situated on northern Vancouver Island near Port McNeill and Holberg.

1. A rich alluvial site (Site Index (SI) ~35 m@ 50 yr bha)with heavy Rubus spectabilis competition. A factorial trial began in 1984 involving 3 stock-types (1-0 PSB 313, 1-0 PSB + 1 transplants and 1+2 transplanted bare root seedlings), a fertilizer treatment (125 gm Di-ammonium phosphate (DAP)/tree) applied at planting and 6 weed control regimes, (Roundup and Garlon (1 kg/ha ai) and Velpar liquid (2.5 kg/ha ai). Herbicide treatments were applied once in year 1 to one group of plots and yearly for the first 4 years to a second set. A control with no treatment was also established. Plots were planted at 1.8 m spacing and contained 25 trees plus a buffer row.

In 1990, a mechanical removal of alder was done to avoid loss of the control plots. Thus, controls can be viewed as a minimal treatment for survival.

Analysis shows

- a response to fertilization on a rich site occurs. The response is enhanced by weed control
- a large response to weed control, particularly repeated Velpar.
- a marked superiority of plug stock over bare root
- a percent response of over 400 % at age 3 has declined to less than 5% at 14 years and is projected using a stand growth model to be close to 1 or 2% at 45 years.

2. Poor sites (SI=15) with heavy ericaceous shrub competition (Gaultheria shallon). A factorial trial was established in 1988 following up results obtained from earlier trials begun in 1981.

The objective of the trials was to evaluate the possibility of converting poorly producing cedar/salal sites to closely related but much higher productivity, closely adjacent hemlock/amabilis fir sites. Lewis (1981) had suggested that a basis for the productivity differences lay in site disturbance frequency arising from blowdown.

Initial studies were directed at simulating blowdown disturbance by scarification which reduced salal cover, disturbed the forest floor and potentially increase growth by increasing mineralization rates. The plots showed little or no growth response to the treatment. As a result, the next round of experiments examined fertilizer application.

A sequence of trials beginning with miniplot screening trials plus foliar vector analysis, were established to determine nutritional deficiencies and optimal rates of application. It was found that N at 200 kg/ha and P at 75 kg/ha gave optimal responses for cedar and hemlock. These trials were followed up using area based, volume response trials and with species, cultivation (salal removal) and spacing trials. The salal removal and fertilization trial, established in 1984, showed that salal removal resulted in a growth response as did combined N and P applied either as AN or Urea. P alone resulted in poorer growth as the N deficiency was increased. Tree growth response with N+P continued for a long period and was still evident 10 years following application. Although foliar N levels declined, P levels in both soil and foliage remained sufficient indicating that re-fertilization did not require P. Crown closure has occurred on a number plots with the combined treatments of salal removal plus NP fertilization. Stand structure on these plots now strongly resembles the more fertile hemlock-amabilis variant while immediately adjacent control plots remain chlorotic and slow growing. This suggests that a long term change in productivity may be indicated. Work by Bradley et al. (2000) shows that fertilized plots had undergone a number of chemical, biochemical and microbial shifts indicative of a basic shift in site quality arising from fertilization.

The findings of these earlier trials were integrated into a large, comprehensive factorial trial directed at assessing the impacts of salal removal, fertilization, and stand density and both Cedar and hemlock growing on both site variants. The aim was to achieve crown closure at as early a date as possible, shade out salal and invoke a change in nutrient cycling to achieve continued nutrient supply.

This major trial, established in 1988, has been remeasured and results are encouraging that in fact, long-term increases in nutrient availability may be achievable by inducing changes in ecosystem function through fertilization. Some 10 years after establishment, estimated site index increases of as much as 15 m are indicated and a concomitant doubling of MAI. Of course, a much longer monitoring of the responses will be required before such conclusions can be ratified.

Further trials have been established on marginal cedar salal sites which although originally exhibiting hemlock-amabilis fir characteristics, reverted to nutrient deficient salal sites following harvest.

Research into the mechanisms behind the response is continuing with studies proposed on mycorrhizae, soil phenolics, soil microflora and microfauna as well as biomass components and photosynthetic efficiency.

The results of our trials, when added to results from Newfoundland on Kalmia sites and the United Kingdom on Calluna sites, suggest that gains from NP fertilization may be substantial and possibly long lasting on sites impacted by ericaceous plants.

A further trial has now been established on montane Vaccinium sites where hemlock and amabilis fir are exhibiting symptoms similar to those on the cedar salal sites on northern Vancouver Island.

The results of this work has led to the operational fertilization of over 10,000 ha of cedar salal forests to date.

The range of sites on which ericaceous vegetation occurs is large. It remains to see how far the results of the SCHIRP trials can be extrapolated.

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Rationale

- ◆ Re-establishment problems
  - ■ High site alluvial lands
    - Heavy brush competition smothered trees
    - Poor stocking, productivity far below potential
  - ■ Cedar/salal sites
    - Nutrient deficient
    - Stagnation, poor productivity

Spruce Trial

- ■ CWH vm1
  - Wet 2787 mm rain
  - Cool moist summers 757 mm rain in growing season (April-September)
  - Mean monthly temp >10° for 4 – 6 mo

Holberg

- ◆ General Description
  - Silty gravel soil, frequent flooding
  - ■ Old growth forest characterized by
    - Red Alder(Alnus rubra), Salmonberry(Rubus spectabilis)
    - Widely scattered Large Sitka spruce
- ◆ Logged 1977 – 1980
- ◆ Previous planting of Spruce failed
- ◆ Site was scarified in 1983 to remove dense salmonberry
- ◆ A factorial trial with 4 reps was established in 1984
  - ■ Three stock types 1-0 P, 1+1 P transplants and 1+2 bare root transplants 1,2 & 3 respectively
  - ■ 6 weed control treatments
    - Velpar, Garlon and Roundup once at planting and once a year for 4 years + a no weed control R1,G1,V1,C,R4, G4,V4
  - ■ Fertilization
    - 125 gm Di-ammonium phosphate DAP /tree (25gm N & 29 gm P) Control=1, Fert=2

Goal

- Quantify responses to different combinations of treatments
- Used 25 tree (7x7 trees @ 1.87 m) buffered plots to follow long term response
- Measured ht, Rcd, Dbh and weed cover
  - Yearly to 1988, 1990, 1995, 2000

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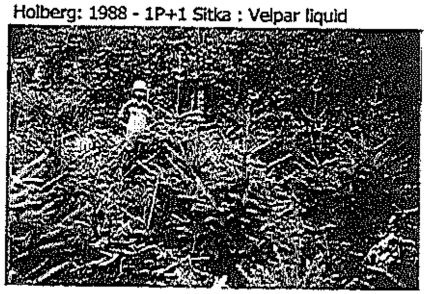
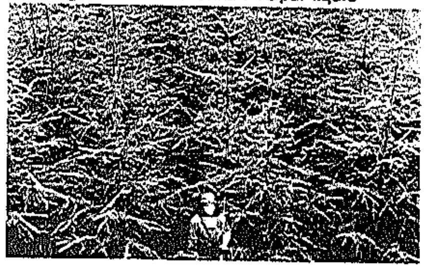
- Measured ht, Rcd, Dbh and weed cover
  - Yearly to 1988, 1990, 1995, 2000

Holberg Sitka spruce
After 1 growing season 1-0 plug 35 cm growth

Holberg: 1988 - 1P+1 Sitka : Velpar liquid



Holberg 1991 - 1P+1 Sitka : Velpar liquid

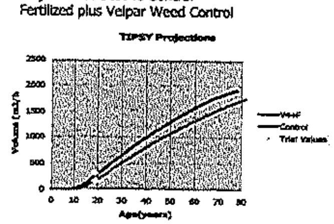


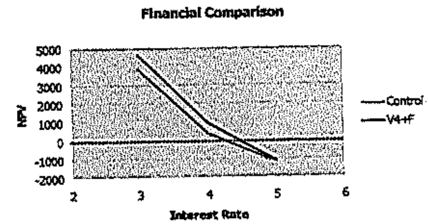
Holberg: Control 1991

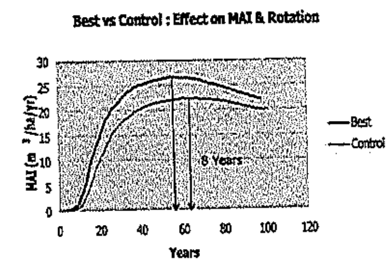
Results

- Fertilization, stock type & herbicide all had significant main effects
- Chemical efficacy varied. Roundup appeared to have most lasting effects
- Projection of gain to rotation showed gain from intensive treatments were better financially than minimal treatments at < 5% rate
- Time to maturity reduced by 8 years so forest level impacts (ACE) may result depending on age class structure of forest.

Projection of Best vs Control
Fertilized plus Velpar Weed Control



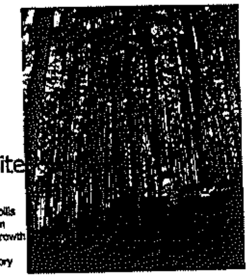




S1-HA Phase 1906 Blowdown Origin

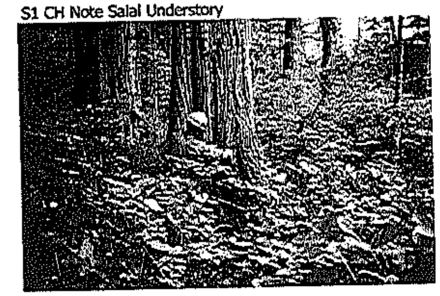
HA Site

% A. amabilis depends on advance growth & fire history



S1-CH Phase Salal dominates understory

S1 CH Note Salal Understory



The Problem

- Logged in early 1960's
- Slashburned & Planted Sitka spruce
- Grew well for ~6 yrs
- Salal recovered vigour
- Severe chlorosis
- Stagnating growth
- Lewis (1982) suggested CH is a degraded form of HA and that disturbance might rejuvenate productivity

Pt. McNeill S1-CH Sitka 15-20 years

Sitka on Calluna in Scotland

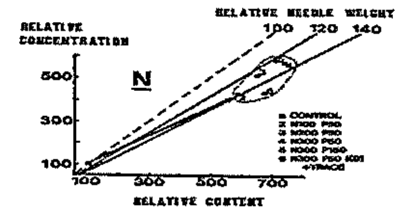
Early Attempts

- Low N applications in 1974 gave short lived responses.
- Scarification & burning were tried in 1981
- Cr, Hw and Ba were tested
- Burning gave temporary increase
- Scarification gave no response
- In 1983 undertook screening trials

Establishing Screening Trial

Foliar Analysis Results

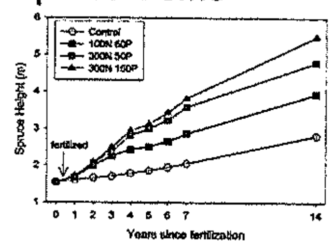
Results of Screening



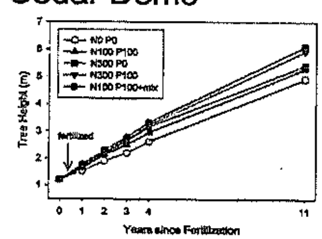
Demonstration Trials

- To apply screening results
- Obtain area-based responses
- Established for S, Cwr and Hw

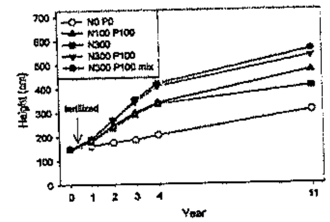
Spruce Demo



Cedar Demo



Hemlock Demo



Salal Eradication Trial

Installed 1984, Fertilized spring 1985

Factorial with 5 Reps

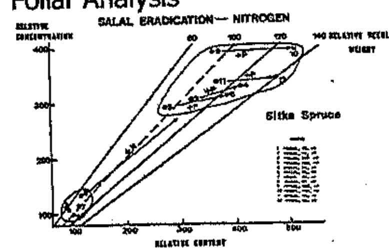
225 kg/ha N as Urea & as Ammonium nitrate

75 kg P

Salal removal

Spruce at start, much Hw & Cwr ingrowth

Foliar Analysis



Photos 1995
Control 1984 Trial

Salal Removed 1984
Fertilized spring 1985

SCHIRP

- In 1987 a multi agency group was formed to study the problem further
- Salal, Cedar, Hemlock Integrated Research Program
- Integrate earlier findings
- Assess long term responses by treatment and treatment combination
- Obtain crown closure shade out salal

Silvicultural Goal

- Obtain crown closure as quickly as possible
- Eliminate salal as a competitor
- Modify soil mineralization processes

Trial Design A

Replicates	4	
Ecosystems	2	CH,HA
Species	2	WRC, WH
Fertilizer	2	0, N+P
Spacing	3	500, 1500, 2500
Total Plots	96	

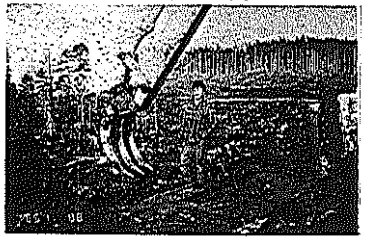
Trial Design B

Replicates	4	
Ecosystems	2	CH,HA
Species	2	WRC, WH
Fertilizer	2	0, N+P
Spacing	1	2500
Cultivation	2	0, root raked
Total Plots	64	

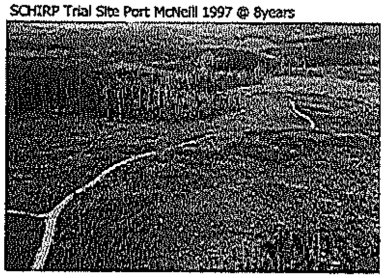
Analysis

- Analysed as two trials
- Designs A & B share the unscarified, 2500 tree plots.
- Plots were set up as 8x8 trees with a buffer

Backhoe scarification = Salal removal



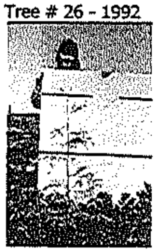
SCHIRP Trial Site Port McNeill 1997 @ 8years



S1 CH Contrast Fertilized vs Control Cedar

Cedar Fertilized
Tree # 13 - 1992

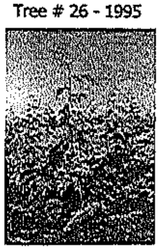
Cedar Control
Tree # 26 - 1992



S1 CH Contrast Fertilized vs Control Cedar

Cedar Fertilized
Tree # 13 - 1995

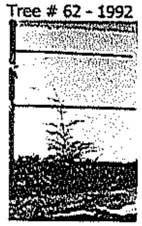
Cedar Control
Tree # 26 - 1995



S1 CH Contrast Fertilized vs Control Hemlock

Hemlock Fertilized
Tree # 46 - 1992

Hemlock Control
Tree # 62 - 1992



S1 CH Contrast Fertilized vs Control Hemlock

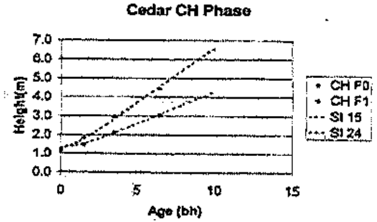
Hemlock Fertilized
Tree # 46 - 1995

Hemlock Control
Tree # 62 - 1995

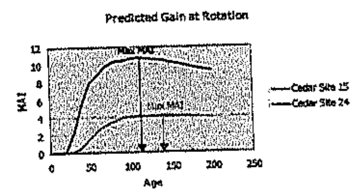
Growth Projections

- TIPSY Growth Model was used to project stand differences to rotation.
- Site Index differences were estimated by examining the lower ends of appropriate site index curves.

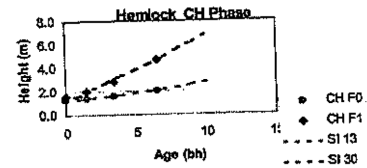
Estimated Site Index Impact



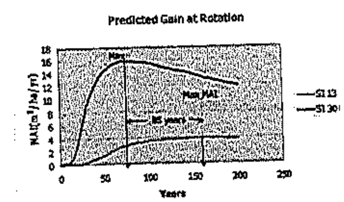
TIPSY PREDICTION Cedar



Estimated Site Index Impact

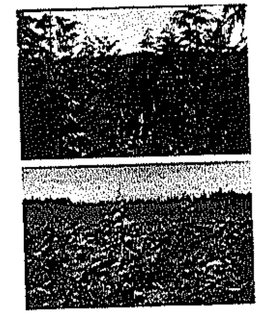


TIPSY PREDICTION Hemlock



Applications

- To date, >11,000 ha fertilized operationally
- Monitoring Plots are established
- Results need verification to see if response continues indicating rejuvenation of CH to HA condition



Cedar ~ 15 yrs old
Rupert 200
Operational Application
1986 & 1995

Photo Fall 95

Control Area
Unfertilized
Rupert 200

AAC Implications

- The increase in MAI indicated is as much as 10 m³/ha/yr .
- The potential increase in AAC assuming there is even a 50 % realization is therefore substantial.
- The question is "how long will the response last"?

Future Plans

- Monitoring will need to continue for at least 15 more years
- Ground vegetation will be assessed.
- Crown closure modeling will define rates of crown closure in relation to treatments ie spacing, fertilization and vegetation control(scarification)

Acknowledgements

- These findings are a result of the inputs and efforts of many people and institutions

- UBC
- Western Forest Products Limited
- Weyerhaeuser (nee MB)
- Timber West Ltd(nee Fletcher Challenge)

- Canadian Forest Service
- BC Ministry of Forests
- Forest Renewal BC
- NSERC
- BC Science Council

Using TIPSY to analyze the value of fertilized lodgepole pine stands

Mario Di Lucca[1]

Abstract

TIPSY is a growth and yield program that provides electronic access to managed stand yield tables generated by the Tree and Stand Simulator (TASS). In this paper, TIPSY 3.0b is used to compare the yield and value of fertilized and unfertilized lodgepole pine stands. Treatment costs, volume response and time of application are important variables. A sensitivity analysis addresses harvest cost and revenue, and discount rate. This paper emphasizes the process rather than the results. Results will vary with the assumptions used by forest resource managers.

Introduction

This paper illustrates a process for analyzing the yield and value of fertilized lodgepole pine stands using the Table Interpolation Program for Stand Yield (TIPSY 3.0b); Mitchell and Grout (1995), Di Lucca (1999), Mitchell et al. (2000). TIPSY is a growth and yield program that provides electronic access to managed stand yield tables generated by the Tree and Stand Simulator (TASS); Mitchell (1969), Mitchell (1975), Mitchell and Cameron (1985), and Di Lucca (1999). It retrieves and interpolates yield tables from its database, performs economic analyses, and displays summaries and graphics for a specific site, species and management regime. TIPSY now goes beyond interpolation since it models other treatments such as fertilization and genetic gain. Yield tables are available for various even-aged coniferous species of commercial importance growing on the coast and in the interior of British Columbia. For more information on TASS and TIPSY, please visit our web site at: *http://www.for.gov.bc.ca/research/gymodels/.*

Economic assessment in TIPSY

TIPSY includes an economic analysis module, known as the TIPSY Economist (Stone et al., 1996) that assesses silvicultural treatments simulated by TIPSY. This module determines the net value of the stand at each potential harvest age by discounting all costs and revenues incurred from stand establishment to harvest.

Examples of the use of TIPSY to assess the economics of pre-commercial thinning were prepared by Stone (1998), and in the Guidelines for Developing Stand Density Management Regimes by B.C. Ministry of Forests (1999).

What are the underlying fertilization assumptions in TASS and TIPSY?

In TASS, the action of fertilizer affects height growth and foliar efficiency—both of which affect bole volume. Figure 1 shows TASS simulations of coastal Douglas-fir fertilized at different site indices and stand heights. Greatest fertilizer response at harvest is achieved on sites 25 and 30 when applied to a 20 m tall stand.

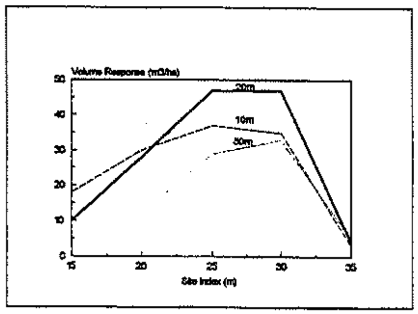


Figure 1. TASS simulations of fertilized coastal Douglas-fir stands

The current version of TIPSY does not reflect the biology of fertilizer response. In the interim, the user must provide the expected volume response in m³/ha or % ofer a 10 year period. TIPSY assumes that the volume response is constant and independent of the stand height and site index. Figure 2 shows the default response recommended for coastal Douglas-fir of 30 m³/ha for all sites. Work in progress will refine TIPSY's response properties.

[1] B. C. Ministry of Forests, Research Branch

TIPSY's default values for response to fertilization are expressed as total volume (i.e., the volume of all trees including stumps and tops). The response information for a particular species and site is derived from research plots in B. C. that were fertilized by hand to ensure uniform coverage. The response in the operational environment is expected to be lower because of irregularities associated with aerial application. When fertilizer is applied operationally, a reduction of 25 % is recommended (i.e., 20 m³/ha in research trials = 15 m³/ha when applied operationally). Stands can be fertilized only once in TIPSY. Repeated treatments are not available in TIPSY, although they can be accommodated in TASS. You can use fertilization with pure stands only.

For additional information on biological factors, application age, stand priority, operational factors, fertilizing method and application, monitoring and reporting please consult the Forest Fertilization Guidebook web site at: *http://www.for.gov.bc.ca./tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm.*

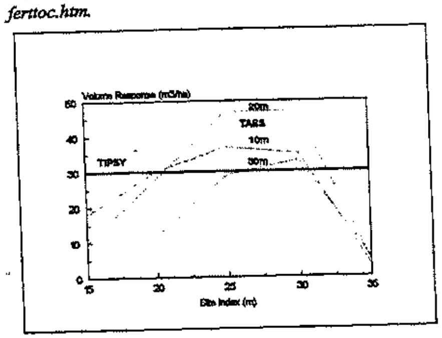


Figure 2. TIPSY simulations of fertilized coastal Douglas-fir stands.

What are the requirements for fertilization treatments in TIPSY?

To generate fertilization treatments in TIPSY, you need to specify:

a. The application age in terms of the number of years since planting, or germination in the case of naturally regenerated stands.
b. The expected increase in total volume increment expressed in either m³/ha or % of volume gain in a 10-year response period. You must rely on your own knowledge or the default response values provided by TIPSY. Figure 3 shows a plantation of coastal Douglas-fir with 1 200 trees/ha on site 28 that was fertilized at age 55. The lower dashed curve illustrates the response over time relative to an untreated stand when you specify a volume gain of 30 m³/ha. The upper bold curve shows the gain over time when you specify a volume response of 30 %. Note that the volume gain using either method increases from age 55 to 65, and levels off thereafter. Figure 4 shows the impact of fertilizer on cumulative stand volume compared to the unfertilized (i.e., control) regime.

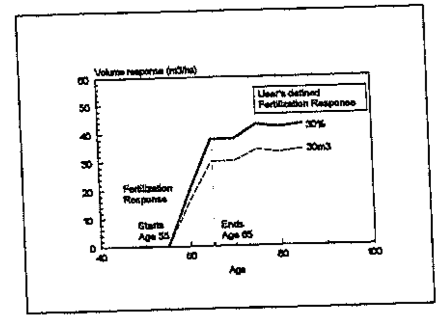


Figure 3. Fertilization responses of 30 m³/ha, and 30 % of periodic volume gain

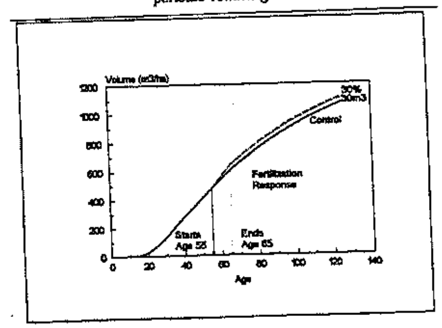


Figure 4. Cumulative volume response to fertilization

Figure 5 shows how the fertilization gain is distributed over the response period (i.e., from age 55 to 65). If you specify the response period of 30 m³/ha (Figure 5a), TIPSY will add 3 m³/ha per year for 10 years following application. At the end of the response period, the total volume will have increased by the specified amount of 30 m³/ha (i.e., 606 and 636 m³/ha for the control and fertilized regimes respectively at age 65).

If you ask for a gain of 30 % (Figure 5b), TIPSY calculates the volume gain in m³/ha by taking 30 % of the increase in total volumes of 479 and 606 m³/ha at ages 55 and 65, respectively. That is, volume gain = 0.30 x (606–479). This translates into 38.1 m³/ha, which equates to 3.81 m³/ha volume gain per year for 10 years following application (i.e., 606 and 644 m³/ha for the control and fertilized regimes respectively at age 65).

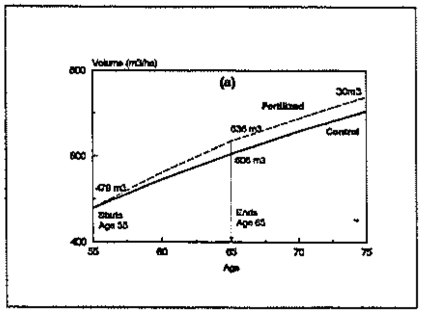


Figure 5a. Fertilization volume gain of 30 m³/ha

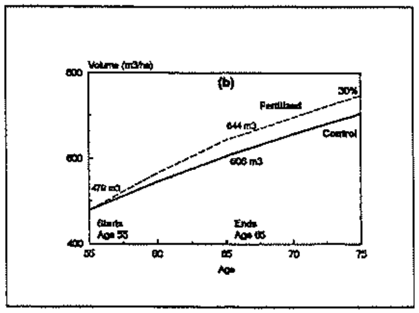


Figure 5b. Fertilization volume gain of 30 %

Using TIPSY to analyze fertilized stands

This section illustrates how TIPSY 3.0b is used to compare the yield and value of fertilized and unfertilized lodgepole pine stands. TIPSY provides a means of comparing costs and revenues that occur at different times. It converts future costs and revenues into present values using a selected discount rate. Thus, TIPSY discounts the expected flow of costs and revenues to determine the net present value and the site value from a stand management regime. Net present value is based on single rotation and cannot be compared with regimes having different harvest ages. Site value is more technically correct since it represents the maximum amount that someone would be willing to pay for bare land if the land is devoted to producing infinite rotations of identical growing regimes (Faustmann 1849). Site value is also referred to in the literature as soil rent, bare land value, and soil expectation value.

TIPSY output includes standing yield, lumber and economic information. Table 1 presents the stand specifications and management assumptions for an untreated stand of interior lodgepole pine. This table also includes information about harvesting, tree-to-truck, hauling, milling, development and overhead costs, and product prices. The fertilized regime uses the same information with the addition of the fertilization specifications in Table 2.

Table 1. TIPSY input values for the control lodgepole pine regime

Project title	Control (untreated)	*Harvest cost assumptions*[1]	
		Harvest system	Ground Skid.
Stand specifications			
Species	100 % Lodgepole pine	Tree-to-truck equation:	
Site index (m)	18	Constant	14.66
Regen. type	Natural	Slope/100	4.24
Density (sph)	10 000	Stems/1000	0.70
Regen delay (yrs)	2	Volume/stem	0.43
OAF's 1 & 2	1.0 & 1.0	Volume/1000	5.41
Thin to density (sph)	1 600	(Distance-50)/100	0.67
Table range and step	2/148/1	= $/m³ @ age 80	14.44
In relation to	Age		
Merch. limits (cm)	12.5+	Haul cost (interior):	
Forest District	Prince George	Cycle time (hr)	3
Biogeoclimatic zone	SBS	Off highway	no
Average slope (%)	10	Total haul cost ($/m³)	6.18
Distance to support (km)	100		
		Milling cost equation:	Expo.
Discount assumptions[1]		Sawmill cap. $/MBF	7.07
Discount rate (%)	4	Total milling cost	
Price increase (%)	0	$/MBF @ age 80	146
Cost increase (%)	0		
Increase duration (yrs)	25	Development cost ($/ha)	1 450
Analysis base year	0	Overhead cost ($/ha)	2 229
		Other harvest costs ($/ha)	0
Silviculture cost		Other treat. costs ($/ha)	0
assumptions[1]		Annual costs ($/ha)	0
Surveys ($/ha)	16		
Site preparation ($/ha)	434	*Lumber/chip prices*[1]	
PCT ($/ha)	620	2 x 4 ($/MBF)	387
PCT age (yr)	16	2 x 6 ($/MBF)	379
PCT stand height (m)	4	2 x 8 ($/MBF)	383
Trees removed (sph)	7 301	2 x 10 ($/MBF)	464
		Chips ($/BDU)	110

[1] Default costs and prices for Prince George Forest District. All costs and prices are in constant 1996 Canadian dollars.

Table 2. Treatment specifications for the fertilized lodgepole pine regime

Project title	Fertilized
Fertilization specs	
Total age (yr)	42
Stand height (m)	15
Response (m³/ha)	15
Cost ($/ha)	300

Table 3 focuses on the effects of fertilization on merchantable volume, mean diameter at breast height (DBH) for the 400 crop trees, lumber products, harvest revenue, site value, and physical and economic rotation ages.

Table 3. TIPSY results for the control and fertilized regimes

	Control	Fertilized
Yield comparison (12.5+)		
Age at comparison (yr)	80	80
Merch. volume (m³/ha)	367	384
400 crop trees mean DBH (cm)	27.8	28.2
Products comparison		
Lumber vol. (bd ft/ha): 2 x 4	61 807	64 099
2 x 6	17 999	19 433
2 x 8	1 014	1 287
2 x 10	1 884	2 404
total	82 709	87 223
Chips (BDU/ha)	66	69
Lumber recovery (bd ft/m³)	225.4	227.1
Harvest revenue ($/ha)	39 311	41 325
Physical rotation (12.5+)		
Age of culmination of MAI (yr)	82	76
MAI (=max) (m³/ha)	4.61	4.83
Site Value (<max) ($/ha)	-124	-37
Economic rotation (12.5+)		
Age of culmination of site value (yr)	65	65
MAI (<max) (m³/ha)	4.43	4.68
Site Value (=max) ($/ha)	78	119

Figure 6 shows how the merchantable volume from the fertilized regime starts to depart from the control at the application age of 42. At harvest age 80 (i.e., close to physical rotation) this regime has 17 m³/ha or 5% more volume than the control and it remains constant thereafter (Table 3). Total lumber output and harvest revenue for the fertilized regime were also 5% higher than the control at harvest age 80 (Table 3).

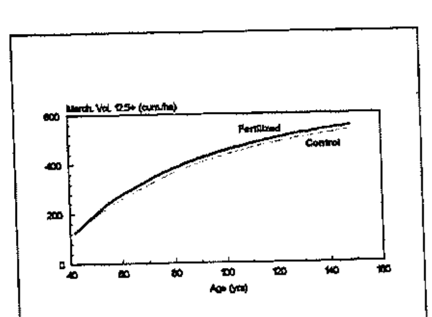


Figure 6. Merchantable volume (12.5+) over stand age for the control and fertilized regimes

From Figure 7 it is possible to determine the physical or biological rotation age, which is the age when mean annual increment (MAI) culminates. Harvesting at culmination of MAI maximizes volume production in perpetuity. The culmination of MAI occurs at ages 76 and 82 for the fertilized and control regimes respectively.

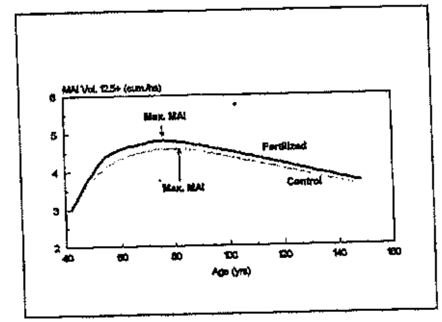


Figure 7. Mean annual increment (12.5+) over stand age for the control and fertilized regimes

Figure 8 shows the mean diameter at breast height (DBH) for the 400 crop trees over stand age for the control and fertilized regimes. The mean diameter for the fertilized regime starts to depart at age 42, and it is 0.4 cm larger than the control at harvest age 80 (Table 3).

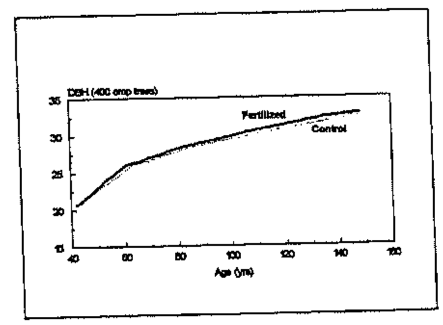


Figure 8. Mean crop tree diameter over stand age for the control and fertilized regimes

TIPSY calculates the site value by discounting all costs and revenues from the time they are incurred back to the default base age zero, using a discount rate of 4%. From Figure 9 we can determine the economic rotation age, which is the age of maximum value production or return from our investment. For both regimes the economic rotation age is 65 years. Note that the site value for the control is higher than for the fertilized regime in the early and late years, because the costs of the treatment surpass the benefits.

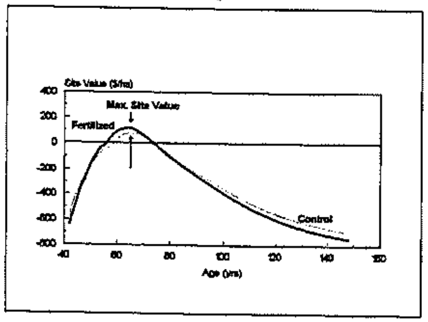


Figure 9. Site value over stand age for the control and fertilized regimes

From Table 3 and Figure 7 we conclude that if a forest estate is managed under a silvicultural system that requires harvesting at the physical rotation, the fertilized regime will produce 0.22 m³/ha more per year than the control (i.e., MAI gain = MAI fertilized – MAI control), or about 17 m³/ha of extra wood at harvest age 80.

The fertilized regime will reach the physical culmination of MAI six years earlier than the control regime. Fertilization allows us to harvest our stand earlier, which could be beneficial if we are facing a timber supply constraint.

If we manage for value (Table 3 and Figure 9), the fertilized regime will generate $41/ha more than the control (i.e., $119/ha and $78/ha respectively). Both regimes reached the maximum site value at age 65. This optimum economic rotation age occurred 11 and 17 years earlier than the physical rotations for the fertilized and control regimes respectively. If we harvest at the economic rotation, the economic return is maximized but we lose approximately 25% of volume production because we are harvesting before the culmination of MAI. However, the site values increase from $–124/ha to $78/ha for the control, and from $–37/ha to $119/ha for the fertilized regime, when comparing the optimum physical and economic rotation ages respectively.

The examples above assumed new stand regimes for which all costs and revenues were discounted from the time they occurr back to the base age of zero using an interest rate of 4%. If we want to evaluate the fertilization effects of an existing 42-year-old stand (i.e., with the same stand specifications as above), the future costs and revenues are discounted to the present (i.e., age 42) rather than to age zero. Figure 10 shows the site value for the control and fertilized regimes of an existing and a newly established stand. If we compare the site value difference between the fertilized and control presented in Table 4, the difference from a new stand is $41/ha and from an existing stand is $212/ha. Existing stands generate larger site values because all costs incurred before fertilization are treated as sunk costs, and therefore are not considered in the analysis.

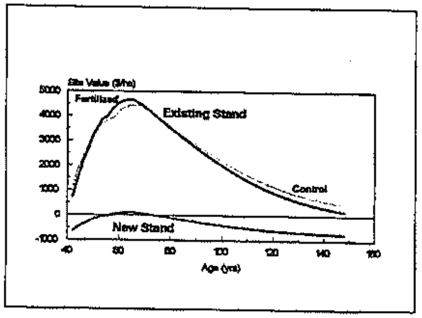


Figure 10. Site value over stand age for the control and fertilized regimes for an existing stand and a new stand

Table 4. Site value differences between the fertilized and control regimes for a new and an existing stand

Stand Type	Discount Age (yr)	Economic Rotation (yr)	Site Value ($/ha)		
			Fertilized	Control	Difference
New	0	65	119	78	41
Existing	42	65	4 665	4 453	212

Other considerations affecting site value

This section describes other factors that affect site value (e.g. fertilization costs, response and application age). In figure 11a, we elevate and lower fertilization cost from the base case by $200/ha (i.e., $300/ha + or – $200/ha) to evaluate its impact on the site value. The site value is higher when the cost of fertilization is reduced. Figure 11b shows the site values when we change the fertilization response by + or – 10 m³/ha from the base case of 15 m³/ha. Here the site value also increases with increasing fertilization response. Figure 11c shows the site value of three regimes fertilized at ages 30, 40 and 50 respectively. The later application at age 50 (in bold) has the largest site value because the fertilization costs are carried to final harvest for a shorter discounting time.

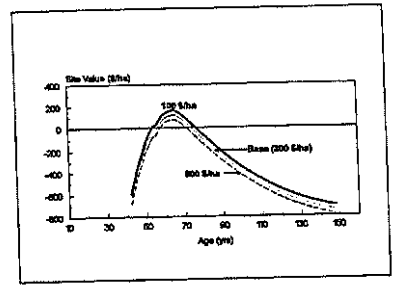


Figure 11a. Effect of fertilization cost on site value

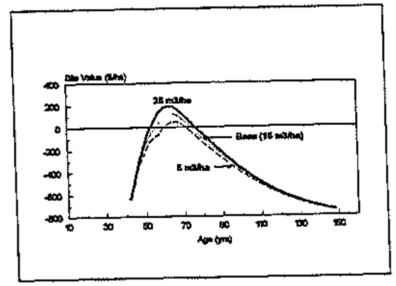


Figure 11b. Effect of fertilization response on site value

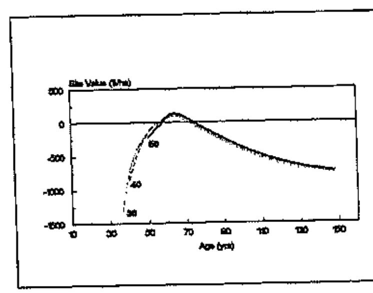


Figure 11c. Effect of fertilization application age on site value

Table 5 summarizes the maximum site values that can be achieved by changing fertilization costs, response and application age when compared with the base case. The change in fertilization response of + or – 10 m³/ha has the largest difference in site value when compared to the base case results (i.e., $73/ha for 25 m³/ha and $–72/ha for 5 m³/ha).

Table 5. Comparative analysis on site value

Factor	Maximum site value ($/ha)	Site value difference from base case ($/ha)
Base case	119	0
Response +10 (m³/ha)	192	73
Response - 10 (m³/ha)	47	-72
Cost + 200 ($/ha)	77	-42
Cost - 200 ($/ha)	161	42
Application age 30	89	-30
Application age 40	114	-5
Application age 50	133	14

Sensitivity analysis on site value

Sensitivity analysis on site value

Given the uncertainty of future economic conditions, it is important to assess the sensitivity of the assumptions used in the base case. Sensitivity analysis involves changing each major assumption used in the base case by some amount, say 10%. If the results do not change much, then the results are relatively robust with regard to that assumption. However, if a change in the assumption causes a major change in the site value, the analyst should review the validity of the assumption. The analyst should also report the sensitivity and the robustness of the results.

TIPSY contains an optional sensitivity analysis which tests changes in the discount rate, harvest revenues (i.e., obtained by the sale of logs or lumber, and chips), harvest costs (i.e., road development, tree-to-truck, hauling, and overhead costs), regeneration costs (i.e., surveys, and site preparation), fertilization cost, and pre-commercial thinning costs.

Figures 12a, 12b and 12c show how site value is affected by changing assumptions about harvest revenues, harvest costs and discount rate. Figure 12a shows that larger harvest revenues will generate larger site values. Figure 12b shows that lower harvesting costs can increase the site values. Finally, Figure 12c shows that site value always increases when discount rate is decreased.

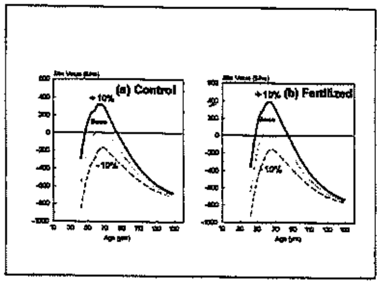


Figure 12a. Sensitivity analysis on site value when changing harvesting revenue by + or – 10 % for both the control and fertilized regimes

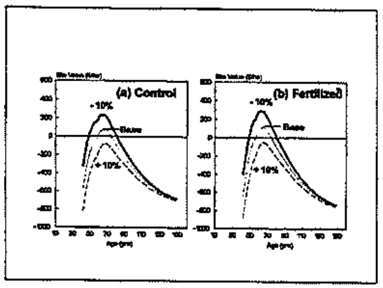


Figure 12b. Sensitivity analysis on site value when changing harvesting costs by – or + 10 % for both the control and fertilized regimes

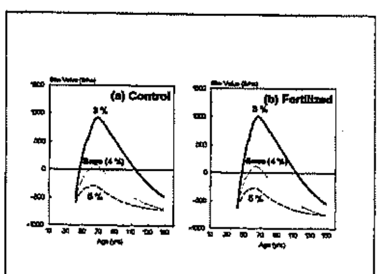


Figure 12c. Sensitivity analysis on site value when changing discount rate by – or + 1 % for both the control and fertilized regimes

Table 6 summarizes the maximum site values that can be achieved by changing the discount rate, harvest costs and harvest revenues for the fertilized and control regimes. In general, the site values from the fertilized regimes were always higher that those from the control regimes. A 1% change in the discount rate has the greatest effect on site value, ranging from $-265/ha to $1 005/ha, and from $-286/ha to $924/ha for the fertilized and control regimes respectively.

Table 6. Sensitivity analysis on site value

Factor	Site Value ($/ha)		
	Fertilized	Control	Difference
Base case	119	78	41
Discount rate + 1%	-265	-286	21
Discount rate - 1%	1 005	924	81
Harvest revenue + 10%	397	331	66
Harvest revenue - 10%	-152	-167	15
Harvest cost + 10%	-49	-75	26
Harvest cost - 10%	294	239	55

Conclusions

This paper demonstrates how TIPSY provides information about the volume and value of fertilized stands. Fertilization usually increases harvest volume and decreases physical rotation, and it can increase or decrease site value. We encourage you to use TIPSY to evaluate your particular fertilized regimes, since these results are only relevant to the assumptions selected for this example. If you want to try TIPSY, you are welcome to download a copy of the program from the TIPSY web site at: *http://www.for.gov.bc.ca/research/gymodels/TIPSY.*

In the next version of TIPSY we plan to improve the fertilization option with better responses to changes in site index and application time (i.e., age and height), different fertilizer application levels, and repeated fertilizer applications.

Acknowledgments

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Strategic silviculture planning initiatives in British Columbia

Ralph Winter[1]

Abstract

There has been a long-standing need to develop strategic plans for incremental silviculture investments in British Columbia (BC). A series of 3 different audits done during the 1990s have all clearly documented the need for strategic silviculture plans. With Forest Renewal BC (FRBC) funding the Ministry has developed the *Incremental Silviculture Strategy for British Columbia (interim)*. The strategy was developed in 1997, field tested in 1998 and released in 1999. The strategy is intended to provide broad general direction and encourage patterns of activities. The provincial strategy provides context for the development of management unit strategies, stand level analyses and FRBC required Resource Management Plans. It is expected that the strategy will be refined upon completion of management unit (Tree Farm License [TFL] or Timber Supply Area [TSA]) strategies.

In 1999 FRBC allocated $3 million over two years to develop management unit incremental silviculture strategies. A number of analytical and forest level modeling approaches are used to produce specific harvest level, timber quality and habitat supply objectives. The strategies contain silviculture regimes and silviculture programs aimed at achieving the desired management unit objectives. The strategies include explicit evaluation of the role of tree improvement, spacing, fertilization and partial cutting in the achievement of management objectives. The strategies are intended to help guide the allocation of available funding towards the timber supply, timber quality and habitat supply goals. The strategies will be used to guide prescription development and silviculture regime implementation. There are 68 management units, which have a silviculture strategy underway or complete. One of FRBC's key performance indicators is to have a silviculture strategy in place for every management unit in 2001.

For more information and copies of the Incremental Silviculture Strategy for British Columbia, the workplan for Forest Level Analysis for Silviculture Investments, completed management unit strategies, training and workshop materials see the Forest Practices Branch Web site http://www.for.gov.bc.ca/hfp/silstrat/index.htm

Presentation agenda

In BC basic silviculture is required by law on all lands that are denuded since October 1987. Basic silviculture can include activities such as site preparation, planting, use of improved seed, vegetation management, density management on over-dense stands and pruning for specific forest health or wood quality issues. Once these areas have met prescribed regeneration and stocking levels they are declared free growing. Incremental silviculture is defined as anything incremental to that which is required by law. Incremental silviculture largely applies to areas harvested or denuded prior to October 1987 and to new free growing areas. In this presentation incremental silviculture includes backlog reforestation of areas denuded prior to October 1987 and includes spacing, pruning and fertilization.

In this presentation I will overview some significant current progress in British Columbia to plan and rationalize incremental silviculture investments. I will present this in four key parts:

1. Incremental Silviculture Strategy for British Columbia—a cornerstone document which provides a planning framework and guiding direction for incremental silviculture investments in British Columbia.
2. development of management unit (Tree Farm Licence or Timber Supply Area specific) silviculture strategies for all 71 units in British Columbia
3. The development of a management planning and implementation system to guide the allocation of government or crown corporation funds such as Forest Renewal BC.
4. Future directions in the planning and implementation of silvicuture activities in British Columbia

Part 1—The need for a provincial strategy

There have been a number of past attempts by government at developing silviculture strategies in British Columbia. In the early 1990s a series of documents entitled: *Towards a Silviculture Strategy* laid some of the ground work. A number of world wide reviews on silviculture strategies and the current and future markets for forest products were carried out. While a significant number of documents were produced, they never were formalized into a provincial strategy for incremental silviculture. During the period 1980–1995, over 1 million ha of incremental silviculture treatments were applied to crown land.

Audits done during the 1985–90 and 1991–96 Federal-Provincial Forest Resource Development Agreements identified the need to have a strategy to guide the investments of public funds on crown land. Between 1996 and 1999, Forest Renewal BC (FRBC), a crown corporation, spent $80–130 million per year on incremental silviculture. The 1999 provincial auditor general's report of FRBC investments restated the need for an incremental silviculture strategy.

Purposes of the provincial strategy

About 95% of the 95 million hectares of BC are crown land, of which only about 23 million hectares contribute to the current Timber Harvesting Landbase. About 40% of the timber harvesting landbase is now second growth forest. The Ministry of Forests plays an important role in the stewardship of the crown land. Given that the majority of land is publicly owned it makes strategic planning and incremental silviculture investments a unique challenge compared to anywhere else in the world. The Ministry has needed an incremental silviculture strategy in order to:

- provide general guidance for incremental silv investments;
- provide context for TFL/TSA specific strategies;
- to help develop program plans and budgets (Resource Management Plans); and
- to give general guidance for stand level analyses and activities.

Development and release history

In September 1996 a group of headquarters Ministry of Forests (MoF) staff took on the challenge to develop a provincial incremental silviculture strategy for BC. Several draft ideas and concepts were developed which led to detailed background work being done in 1997 and 1998. Using funding assistance from FRBC and a contractor, a series of 6 detailed reports were produced including:

- Working Paper 1: Project Information, References
- Working Paper 2: Concepts of Strategy and Planning, Proposed Framework
- Working Paper 3: Government's Goals, Proposed Guiding Principles
- Working Paper 5: Proposed Financial and Socio-economic Analysis Framework
- Working Paper 4: Proposed Log Quality Framework, Timber Supply and Demand,
- Working Paper 6: Summary of TSA Basic Data

The 6 reports were based on 140 recent reports analyses, analyses and a review of both global supply and demand. The 6 contractor reports were used to develop the *Incremental Silviculture Strategy for British Columbia (interim)*. The strategy was reviewed with regional and district staff and was field tested in 1998 in the Vancouver Forest Region. After a series of reviews the document was released and implemented in 1999.

Strategy supports achievement of government's goals

Any strategy must have goals and principles in order to provide context for its contents. Over the past 20 years, successive provincial governments have articulated it goals for forest management in a wide variety of government documents and supporting rationale for incremental silviculture investment. The provincial strategy is based on 3 key goals that government has consistently held:

- Sustainable resource use
- Community stability
- A strong forest sector

Strategy is based on key guiding principles

BC's forests are developed by the one most diverse ecosystems in the northern Hemisphere. BC has 14 major biogeoclimatic zones and over 600 ecosystem associations. There are over 22 tree species being managed for and some of the most diverse habitat and wildlife conditions in North America. The inherent high diversity and values of BC's forests has resulted in the following principles being seen as key in guiding the strategy:

- BC's forests are important at all levels—from local to global;
- Because the land is crown land, stewardship and moral obligations to future generations must be met;
- Because future market demands and public values and desires cannot be forecast with certainty, the only

course of action that must be taken is one that manages risk and maintains options for future generations;

BC situation—current forecast

To give context to the incremental silviculture we also looked at the 1999 forecasts for future harvest levels. The recently completed Timber Supply Review number 1 indicated that without strategic intervention, future harvest levels would fall by 17%. This would translate into a potential 5% reduction in provincial Gross Domestic Product and the potential loss of 46 000 direct and indirect jobs. In addition, it was projected that without appropriate management, wood quality and habitat supply needs may not be met

BC situation—potential supply

Analyses of potential timber supply in BC were done in 1994 and then by background work for this strategy. The estimates suggested that future harvest levels could be increased to 75 million m^3. However the analysts making the projections recommended that this aggregate stand level projection would need to be confirmed on a management unit analysis for each of the 71 management units in BC.

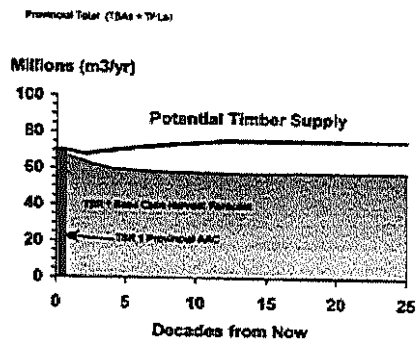

Figure 1. Provincial Total (TSAs + TFLs)

The incremental silviculture strategy suggested that long rotation management coupled with the strategic employment of incremental silviculture there would be an upwards affect on wood quality. The strategy also recognized that habitat supply needs and impacts would need to be more fully incorporated into future projections of timber supply and wood quality.

BC supply vs. global demand

The strategy examined the key demand for wood products for the future. It became quite clear in *Working Paper 4: Proposed Log Quality Framework, Timber Supply and Demand,* that externally to BC there were plentiful sources of cheap fibre. Currently in BC, about 95% of the pulp and paper mill furnish comes from sawmilling residues and not solid logs. The strategy suggests that BC will likely remain a sawlog economy and therefore should focus incremental silviculture investments in the production of sawlogs over fiber.

Working targets

To focus planning and silviculture investments the strategy contains a number of key working targets. These are targets which are intended to be refined over time and with more detailed analysis. The working targets are to:

- *Minimize* the anticipated interim reduction in timber supply so that it is not less than 65 million m3/yr
- *Increase* timber supply over the mid-term to a long-term level of 75 million m3 /yr
- *Maintain* the production of premium quality logs at or above 10% of total harvest volume

Premium quality logs are seen as those logs which command a higher than average price over sawlog and pulplogs. The current harvest profile suggests that about 15% of current logs are premium quality.

Major silvicultural strategies

To achieve the working targets a number of key strategies have been developed for both timber quantity and quality. The major silviculture strategy for timber quantity would include:

- An increased use of alternative silvicultural systems where suitable, particularly commercial thinning;
- Reducing green-up ages through appropriate regeneration practices;
- Increasing regenerated stand volumes by 20%;
- Elimination of the treatable backlog of not satisfactorily restocked land.

In addition a number of other non-silviculture strategies must also be implemented such as improving inventory and growth and yield information.

In order to achieve increases in regenerated stand volumes by 20% there would need to be

- A substantial increase of fertilization on suitable stands

- acceleration in the tree improvement program so that by 2007 new plantations will have 12% increased volume;
- Where environmentally suitable, institute a void management program to ensure stand voids do not exceed 10%
- Intensify forest health management to reduce losses to insects and disease.

To maintain or manage for wood quality the strategy suggests that the province

- Initiate long rotation quality management program for stands where harvesting must be delayed
- Initiate a timber value-added strategy (including combinations of spacing, pruning and fertilization)

Provincial strategy—concluding remarks part 1

The interim strategy is a ***first step***—and is intended to be refined over time. It has successfully provided much-needed guidance for management unit strategies and FRBC's Resource Management Program and investment planning. The strategy defines ***broad general direction*** and encourages ***general patterns*** of activities. It assumes in-depth mgmt unit analyses will be the basis for refined regional and provincial strategies

Part 2—FRBC's forest level analysis for silviculture investments initiative

The provincial strategy was released by the Ministry of Forests Chief Forester in April 1999. Shortly thereafter the Auditor General Report was released and it identified the need for FRBC to do more work on investment strategies. FRBC committed itself to funding the planning process outlined in the provincial strategy. FRBC provided $3.0 million over two years to support and fund the development of 71 management unit specific strategies. It is one of FRBC's key strategic performance measures—a strategy for every management unit by 2001. This initiative is one of the key FRBC success stories in response to the Auditor General report and public concern over incremental silviculture investments.

Purpose of management unit strategies

The purpose of management unit strategies is to prioritizes short, mid- and long-term silviculture options to address identified issues and objectives. The management unit strategy is intended to provide a forward-looking planning and priority setting context for Timber Supply Review base case assumptions. Many of the management units in BC have had as part of their base case assumptions on the completion of backlog NSR/impeded area programs, explicit fertilization programs, and explicit or implicit density control or pre-commercial thinning programs. The management unit strategy is intended to provide context and direction for stand level prescriptions and FRBC investments

Two types of strategies

Original estimates of cost for 71 management unit strategies were $7.1 million. However, only $3 million was available to fund the work. In order to put a strategy in place in all 71 management units within a period of 2 years, two main different types of strategies are being utilized.

Type 1—This approach uses existing TSR summary information to identify issues and opportunities for silviculture investments. It also uses stand level analyses and factoring estimates up to the forest level. This type of analysis produces interim management unit specific harvest level, timber quality and habitat objectives. Type 1 analyses provide plausible targets and strategies and silvicultural regimes which can be utilized as inputs in the more indepth type 2 analyses. These strategies are budgeted at $15,000 per management unit.

Type 2—uses readily available info plus in-depth forest level modelling to develop silv strategies and funding needs. The type 2 approach is also intended to produce specific harvest level, timber quality and habitat objectives. These strategies are budgeted at $75,000 per management unit.

Methodology

Strategies are developed by consultants under contract to MoF headquarters, regions or to Tree Farm Licence holders. The basic process is to identify issues and silvicultural opportunities and then develop prioritized cost-effective strategies that best address the issues. As part of the upfront development of a strategy a workshop is held. The usual workshop participants are licensees (40%), Ministry of Forests regional and district staff (50%) and others (10%) such as Ministry of Environment Lands and Parks (MELP) staff, FRBC staff consultants and First Nations participants. The workshop is used to identify issues, opportunities and silviculture regimes that are to be evaluated and examined by the consultants doing the in-depth analysis and strategy development.

For many of the participants, the workshop has been one of the first opportunities they have had to think beyond the normal silvicultural regulatory and administrative process and to

1. closely consider and examine where and how silviculture affects habitat, timber supply and quality issues for their individual mangement unit;
2. discuss mgmt unit specific issues and opportunities for silv regimes and investment; and to
3. jointly work together to clarifying or set objectives and design a silviculture program to achieve them.

The process involves reviewing the objectives for the management unit for timber supply, wood quality and habitat over time. It also involves reviewing the composition of the current timber supply review base case harvest projections.

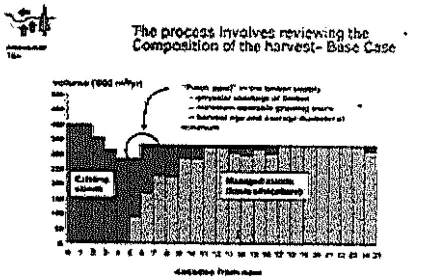

Figure 2. The process involves reviewing the Composition of the harvest – Base Case [Cortex Consultants Inc.]

The process then involves the design of a series of analysis scenarios with linked silviculture treatments and investments over time that are aimed at achieving the management unit objectives.

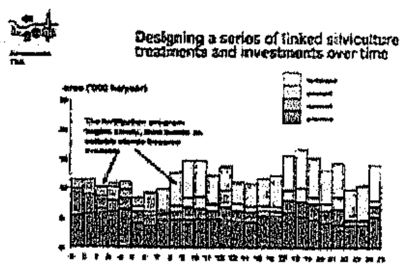

Figure 3. Designing a series of linked silviculture treatments and investments over time. [Cortex Consultants Inc.]

The process involves evaluating treatment impacts of a variety of silviculture investment and regime scenarios. It also involves evaluating how the incremental treatments would affect the achievement of management objectives (ie Stand level effects of fertilization – Base Case + incremental silviculture)

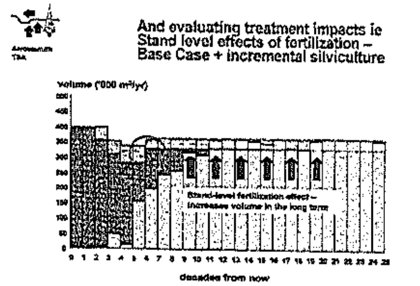

Figure 4. And evaluating treatment impacts i.e., Stand level effects of fertilization – Base Case + incremental silviculture. [Cortex Consultants Inc.]

The process also examines the Forest-level effects of the investments such as the forward substitution of yield increments

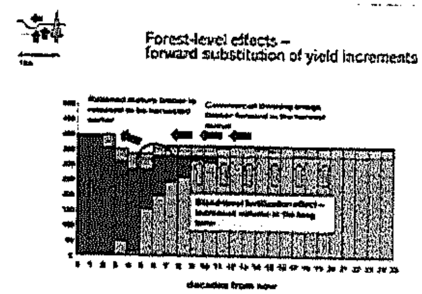

Figure 5. Forest-level effects – forward substitution of yield increments. [Cortex Consultants Inc.]

And finally the process involves Choosing an incremental investment scenario which best achieves the desired volume, value and habitat supply objectives over time for the management unit.

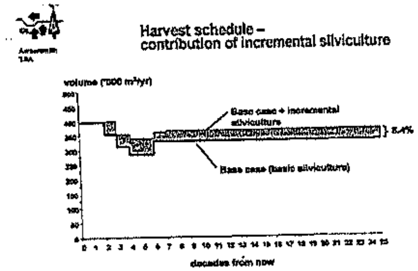

Figure 6. Harvest schedule – contribution of incremental silviculture. [Cortex Consultants Inc.]

Consultants take the direction and input of the workshop participants to complete analyses and develop the draft management unit strategy. The draft strategy is reviewed again by the participants either in another workshop or office review, revised and then edited to produce a final document. The following are some of the key contents that the consultants must include in a strategy:

1. Basic data

Show (in graphical form where appropriate) any readily available information regarding the timber harvesting land base that may be relevant to the strategy, such as: Land Area, AAC, Current Harvest Forecast, Site Class Profile, Age Class Profile, Tree Species Profile.

2. Issues

Identify the key issues affecting timber supply, from both a timber quantity, quality, health and habitat supply perspective. The timber supply review as well as the TFL management plan can be useful sources of information. If incremental silviculture has a role in the TFL in managing habitat supply, also include issues that are relevant to this.

3. Incremental silviculture history

Document recent incremental silviculture history. This should be classified according to whether or not it has been incorporated as part of the basis for the most recent AAC determination (and therefore a first priority for incremental funding). Recent program levels form a baseline comparison for the submitted strategy. A proposed program should not be unrealistic in comparison to historic levels.

4. Opportunities to increase timber supply

Document opportunities to increase timber supply and provide supporting rationale. These may come from actual analyses that have been recently conducted or from inferences from timber supply analysis sensitivity test results (for example, timber supply is sensitive to a reduction in green-up ages, therefore a program to reduce green-up ages will result in an increased future supply).

5. Potential treatments and treatable area information

Indicate which are the most favourable treatments and/or treatment regimes. *The description should be specific enough to guide and priorize the development of subsequent budget allocations, plans (Stand Management Prescriptions, Backlog Silviculture Prescriptions), multiyear agreements and standards agreements.* Where possible, provide any supporting research or growth and yield information that is directly relevant to the management unit.

6. Potential strategies by response time frame

Using the information from the preceding sections, develop, as appropriate, strategies which may be employed to increase future timber supply during each of the following three time frames (or other suitable breakdown):

- Short Term: 1–20 years;
- Mid Term: 21 years to the commencement of a steady long term harvest level (the transition period between the short and long terms); and
- Long Term: the period of a steady long term harvest level.

7. Opportunities to improve timber quality

Where possible, specify the desired product objectives at the log level. If product objectives do not already exist, a simple breakdown into fibre log, sawlog and premium log is recommended. Describe the characteristics of each of these. For example, a sawlog could be defined as any log with a top diameter inside bark ≥ 10 cm. Another way might be to characterize a sawlog stand. For example, any stand with a minimum DBH of 25 cm and/or a minimum volume/ha of 300 m3.

8. Potential treatments

Identify and discuss potential treatments that may achieve the desired product objectives. *The description should be specific enough to guide and priorize the development of* *subsequent budget allocations, plans (Stand Management Prescriptions, Backlog Silviculture Prescriptions), multiyear agreements and standards agreements.* Where possible, provide any supporting research or growth and yield information that is directly relevant to the management unit.

9. Potential strategies by response time frame

If strategies already exist, document these here. If strategies do not already exist, formulate potential strategies for maintaining or improving the quality of the timber supply. In the absence of any other target or strategy, consider what it may take to achieve a target of 15% premium logs. A specific target for sawlogs and fibre logs is may not be necessary where the standard silvicultural regimes and the AAC are based on sawlog quality second-growth stands.

10. Timber quality forecast scenarios

If available, include alternative forecasts of future timber quality profiles based on different silvicultural and investment regimes.

11. Habitat supply

If information is available, identify specific issues regarding habitat supply and biodiversity within the management unit. Identify opportunities for utilizing silviculture activities to mitigate habitat supply problems or opportunities to restore or maintain habitat quality. Identify general geographical areas where there are opportunities exist. List opportunities to restore or maintain habitat supply/biodiversity, based on existing strategies and guidelines (eg. Identified Wildlife Management Strategy, Biodiversity Guidebook, Landscape Unit Planning Guide, etc.). *The description of sites and opportunities should be specific enough to guide and prioritize the development of subsequent plans (Stand Management Prescriptions, Backlog Silviculture Prescriptions), multiyear agreements and standards agreements*

12. Working targets

In keeping with the above documentation, propose a set of working targets for timber quantity and quality. For example, a working target for timber supply might be to maintain the existing harvest level for the next 50 years, followed by a 10% increase of to a steady long term harvest level thereafter. A working target for timber quality might be to maintain the Year 2000 quality profile throughout the planning horizon. Develop and specify as appropriate, strategies to restore or maintain habitat supply/biodiversity indicating time frames for realizing the desired values. The Strathcona TSA contains an example of a regime table which should be attached to identify the treatment regimes and priority treatments that should be used to support the desired targets. The descriptions should be specific enough to guide and priorize the development of subsequent budget allocations, plans (Stand Management Prescriptions, Backlog Silviculture Prescriptions), multiyear agreements and standards agreements.

13. Incremental silviculture program

Propose a program by incremental silviculture activity, by year for 5 years, that will be necessary to achieve the targets and strategies. See Strathcona TSA table formats. The program should be within reasonable range of historic funding levels. If the necessary program is substantially above historic levels, split the proposed program into two components—the first being commensurate with historic levels and the second being incremental to the first. If relevant, indicate which parts of the program are necessary to achieve the assumptions regarding incremental silviculture in the current AAC determination.

14. Job outcomes

Identify the job outcomes of the proposed program, both the immediate outcome directly associated with carrying out the program activity and, where possible, the long term job outcome associated with increased timber quantity or quality.

15. References

This section is optional. List relevant reference material used in the development or documentation of the strategy.

16. Summary of information and research needs

This section is optional, but can be used to identify needs for further information and research that have become apparent during the development of the silviculture strategy. The outcomes of the work may have implications for an incremental silviculture strategy. This section can be used to identify priority information and research needs, which FRBC should consider for funding under FRBC's Sustainable Harvest, Strengthening Sustainable Forest Management or Science Council funding programs.

An example completed type 1 silviculture strategy which follows this format is the Strathcona TSA. A copy can be found at:

http://www.for.gov.bc.ca/hfp/silstrat/pdffiles/vancouver-tsa-strath-t1.pdf

Progress report

About 90% of the management units in BC now have a silviculture strategy completed or nearing completion. By the end of March 2002 all units will have a strategy in place. About 40 completed management unit strategies have been posted on the Ministry of Forests Web site. More will be added as they are completed. Completed management unit Silviculture Strategies can be found at the Forest Practice Branch Website at http://www.for.gov.bc.ca/hfp/silstrat/index.htm

Keys to success

Stand level growth and yield tools (such as TIPSY), forest level simulators (FSSIM, Woodstock, etc.) plus improved site productivity tools have only become widely available and used within the last 4 years. In addition, significant FRBC investments in training by the Silviculture Institute of BC and in other specialized courses provided by the Ministry of Forests have led to significantly increased knowledge of operational staff in the need for and methods for silviculture planning.

There have been few other initiatives in British Columbia that have been so widely deployed within such a short period of time without opposition. Operational staff have seen the need for strategic silviculture planning for years and have largely embraced this initiative. This FRBC initiative is a success because of:

- Keenly interested and generally supportive licensee, district and regional staff;
- Good collaboration at the strategy workshops;
- MOF, industry and MOELP taking leadership in setting objectives and development of strategies for timber supply, value and habitat; and
- local participants "owning" the strategies and desiring to rationilize and stratigically align their incremental silviculture treatments.

Other components—habitat supply

One of the clear objectives of the provincial strategy is to ensure that all management units include objectives and silviculture strategies for maintaining or enhancing habitat supply. Habitat supply objectives or constraints must be included in order to have a balanced forecast for future timber supply and quality projections. All the strategies incorporate existing Forest Practice(s) Code requirements contained in any existing higher level plans such as Land and Resource Management Plans and Landscape Unit Plans. They also incorporate or consider any known requirements for Old Growth Management Areas, Wildlife Habitat Areas, greenup, or known habitat management practices such as for elk, moose, deer, and spotted owl.

It was recognized at the outset that more work needed to be done on developing tools and techniques for incorporating and including long term projections for habitat into the type 1 and type 2 strategies. Part of the FRBC initiative funds the development of new tools, techniques and information extension for habitat. Current projects underway include:

- Reviewing and evaluating current data, models, techniques and tools for habitat supply modelling;
- Carrying out model evaluations to determine their suitability for use in habitat projections;
- Utilizing knowledge gained in the United States Columbia River Basin on wildlife habitat and management impacts and adapting it for use in South Eastern British Columbia;
- Carrying out extension efforts such as the recent habitat supply decision support workshop, which presented to 180 participants the current state of the art on non-timber projection tools and techniques.

Work on this component can also be found at the Silviculture Strategy Website.

Related activities

Another objective of this initiative is to provide more knowledge and understanding to planners and operational staff so that they could more meaningfully contribute to the development of the silviculture strategies and future timber supply reviews in their management unit.

FRBC has funded the development and delivery of a 4-day timber supply course, which includes basic concepts and hands on training in forest level analysis. The course has been extremely well received and very appreciated by all participants. Over the past 2.5 years 11 courses have trained over 250 students. The participants have included Ministry of Forests staff (50%), Licensee staff (25%), consultants (10%), Ministry of Environment Lands and Parks staff (10%), and Others (5%).

Current issue—site productivity and growth and yield estimates

During the development of the strategies, it has become clear that site productivity on many of the management units, especially on Timber Supply Areas (TSAs) was underestimated for second growth stands. Second growth site index was underestimated from 20 to 60% in some management units. This translated into significant underestimates in projected volumes at the stand and forest level. Site index is also important from a habitat supply projection perspective because stand structures and their availability for suitable habitat are dependant on site index. Site index is one of the 2 key variables in any stand and forest level financial or benefit analysis of incremental silviculture. If site index is underestimated in a unit it dramatically impacts on the perception of the financial worthiness of an investment and also impacts the choice of silviculture regimes that might be appropriate for a stand or the forest.

In some units as shown below, it is clear that if the current site productivity estimates were to be used, a volume oriented silviculture strategy might be designed. However, if the site productivity were to be higher as indicated with improved site index estimates, the silviculture strategy might focus on a value strategy. The Ministry of Forests along with the Ministry of Environment Lands and Parks has developed fundiing proposals to FRBC to help refine site productivity estimates throughout BC.

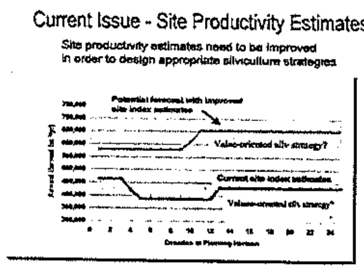

Figure 7. Current Issue—Site Productivity Estimates
Site productivity estimates need to be improved in order to design appropriate silvicultural estimates.

There are another series of growth and yield issues being identified during the silviculture strategy process. There is mainly one stand level growth and yield model used to model second growth stands. In some management units there is a need to improve the tool for projections of tree growth and yield for some species (i.e. Balsam and mixed species stands) and for some silviculture regimes such as:

- combination treatments of site preparation, planting, brushing;
- spacing and pruning; and
- complex regimes linking spacing, multiple fertilization entries and commercial thinning.

During the workshops some of the participants clearly articulated the need for more monitoring of growth and yield projections in the field. Some participants were concerned that stands that are projected to be operable according to model projections were not realistically operable when compared to field conditions. Currently there is little or no funding available to monitor and evaluate both the short and long-term growth and yield on stands. This is an important area, which will need more funding and work in the next few years.

Communication

This FRBC initiative has received considerable favourable interest and press coverage. The Auditor General's staff saw early work from this initiative and were generally impressed with the content of the strategies. The initiative has been:

- used in FRBC news releases;
- used by various ministry branch communications pointing to the forecasts in the strategies which can help address concerns about falldown, certification and international market issues;
- used by the tree improvement program to show the forest level implications and support for more tree improvement work and funding;
- presented to a wide variety of silviculture committees such as the Western Silviculture Contractors Association, and the Coastal Silviculture Committee meetings;
- included in studies such as the 1999 Forest Policy Review; and
- receiving keen interest and involvement by the forest industry and consulting community.

To conclude—part 2

We have a good start with this initiative. The province, regions and districts are defining strategic priorities and direction to guide incrementatl silviculture. There has been good support and buy-in for initiatives and excellent team work and hard work by regions, districts, industry and consultants to date. A first version of management unit and regional silviculture strategies for all areas will be completed this year. *We used to say this was the beginning of the beginning. Now, the end of the beginning is in sight. There is no turning back. BC will never again be without management unit silviculture strategies.*

Part 3—Management planning and implementation system

At the end of 2001 we will have a silviculture strategy in place for all 71 management units in British Columbia. There are 6 forest regions in British Columbia which receive incremental silviculture funds. Vancouver Region is one of them. Now that we have finished most of the strategies, the challenge becomes how to balance the proposed investment programs for 23 very different management units. How does a regional investment manager make decisions for allocating more or less funding to one management unit over another? How does he balance the silviculture funding needs for volume, value and habitat objectives across the 23 management units. What are the considerations for budget allocation and for development of associated performance measures or performance targets?

Government and FRBC need regional silviculture strategies to articulate how to balance priorities and funding and to develop realistic performance measures and targets for each management unit.

Initiatives are in place or under-construction for a complete management system for FRBC's Sustainable Harvest objective. These initiatives will provide a documented and transparent process for:

- articulating regional strategic priorities and direction;
- translating strategies into RMP plans and programs;
- determining budgets;
- fine tuning the FRBC performance measures or performance targets;
- carrying out activities, monitoring and reporting.

The silviculture strategies are an important component that helps guide the priorities, funding and performance measures for FRBC. The following diagram indicates the conceptual linkages of how the strategies link to the entire management system for FRBC's sustainable harvest objective:

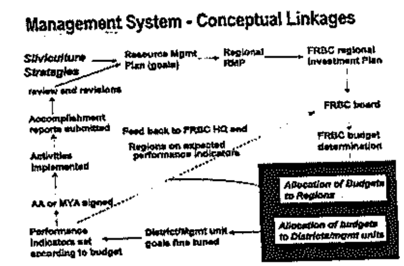

Figure 8. Managment System - Conceptual Linkages

Both the MoF and FRBC recognized the need for an allocation system as part of an overall management system. With the 1999 Auditor General's FRBC audit recommendations and the introduction of the *Budget Accountability and Transparency Act* in 2000 there was an increased need to ensure that public funds are strategically rationalized and have clear outputs and outcomes developed before funds are allocated.

The Ministry of Forests is working with FRBC staff to develop a comprehensive management system to meet these needs. The following diagram indicates a high summary of some key features of the management system that are under development.

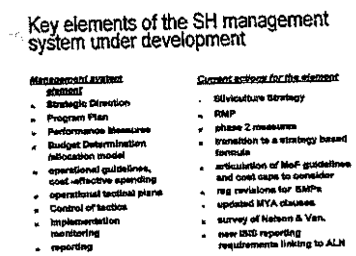

Figure 9. Key elements of the SH management system under development.

The management system is attempting to explicitly link the silviculture strategies:

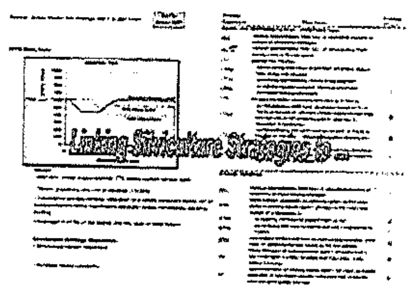

Figure 10.

to Management Unit specific Resource Management Plans describing the proposed budgets and (inputs), silviculture activities (outputs) and projected volume, value or habitat benefits (outcomes). The diagram below is a limited excerpt illustrating the concept:

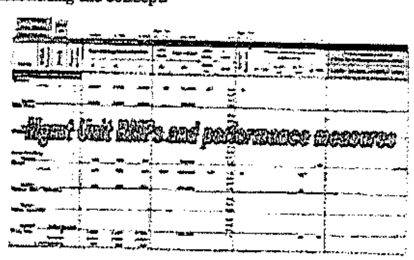

Figure 11.

The management unit Silviculture strategy priorities, the resource management program, budget requests, proposed performance outcomes are rolled up to a regional level to provide a comprehensive view of regional needs. Regional FRBC and Ministry staff can use the information to understand issues, opportunities and priorities for regional investment. The diagram is an excerpt illustrating the potential to understand management unit specific opportunities and outcomes:

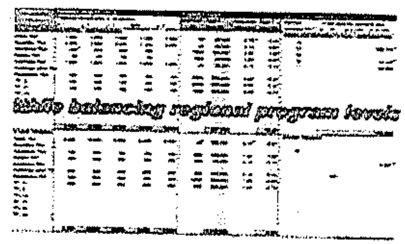

Figure 12.

Part 4—The plans for 2001-2002 and the future

In 2001-2002 FRBC will be investing another $750,000 in:

- the completion of ongoing type 2 strategies
- the development of new type 1 or type 2 strategies
- further extension of the timber supply course;
- implementing a new performance measure process
- carrying out strategy implementation monitoring

A further $300,000 will be invested in the developing a habitat supply modelling strategy, developing and testing new habitat supply modelling approaches, and extension.

About $100,000 will be used to develop 6 regional composite strategies using available mgmt unit strategies, and guided by the provincial strategy. These regional strategies will be developed with appropriate stakeholders and will clarify overall regional direction and priorities for silviculture investments to produce volume, value or habitat. A key challenge will be to determine how to equitably allocate funds, goals and performance measures to each management unit.

In 2002 the MoF and FRBC will either confirm or amend the provincial incremental silviculture strategy by taking into account new management unit and regional strategies. Again the purpose of the provincial strategy would be to give managers context on how to provincially emphasize and balance:

- volume;
- value;
- habitat supply;
- other objectives (First Nations involvement);
- revised performance measures; and
- budget determinations.

Making the strategies work!!

One of the key concerns since the inception of this program was that this initiative should not just become another planning exercise, that dies over time and is not utilised to guide and direct budgets and on the ground activities. There have been many previous examples of planning initiatives failing or not being fully incorporated into changed business practices.

Over the next year we will continue to ensure that there is a tight linkage between the strategies and the development of Resource Management Plans, budget proposals and performance measures or targets. We will continue to build the management system so that the strategies are clearly linked to budget determinations. FRBC will be looking at making amendments to the Multiyear funding agreements with licensees to ensure that they carry out silviculture treatments consistent with the priorities and directions given in the management unit specific silviculture strategies.

The Forest Practices Branch is currently working on some policy and regulatory proposals which would provide for silviculture strategies to clearly articulate the silviculture regimes and standards that apply for a management unit. If the strategies or a higher level plan contain sufficient detail, the policy work proposes that stand by stand officially required prescriptions can be eliminated or reduced. There are currently 1700 stand management prescriptions prepared each year at a cost between $3.5 and $4.5 million. If the essence of the silviculture regimes and associated standards can be incorporated into the silviculture strategy or an approved higher level plan, there is the potential for significant cost and administrative paperwork savings.

The future

The vision is that the Silviculture Strategies will become a key component or an appendix of a broader forest management plan for a TSA or TFL. The TFLs are likely to be the first to really see it work. A number of TFLs have completed comprehensive Type 2 strategies and are including the strategy in their TFL management plans. The Ministry is considering developing Sustainable Forest Management Plans for TSAs and it is anticipated that the silviculture strategies can be incorporated.

With the development of comprehensive management plans with explicit silviculture regimes and associated operating standards we can avoid the development of unnecessary or excessive stand level official prescriptions. We see the development of comprehensive forest management plans as the basis for one-plan approval including streamlined plan development, approval and revisions.

Within the next 3–5 years we will migrate to having more explicit comprehensive management plans for every TFL/TSA and the elimination or reduction in the need for stand level prescriptions except where a special variance is needed from the management plan

In the past there had been concerns that many of the silviculture treatments, regimes and standards were applied in a one-size fits all approach. With the advent of silviculture strategies and comprehensive management unit specific plans we will have silviculture investments tailored to each specific:

- forest estate condition
- growth and yield and inventory info
- forest harvest and management objectives

With the full involvement of industry, MoF, MELP and others we are developing a coherent silviculture strategy across all planning levels—province, region, management unit. We are only now nearing the end of the beginning…we see the need for ongoing refinement and improvement of this process.

With FRBC funding we have developed a comprehensive silviculture planning and management system for responsible and cost-effective stewardship of a precious heritage—BC's forests.

Rationalization of silviculture expenditures

Ben Holtman[1]

Summary

Determining the financial attractiveness of silviculture expenditures is a complex task. The planning horizon is long. The value to be received at the end is uncertain. Future legal conditions for operation are unknown. Successful execution of plans targeting particular products (e.g., high strength or appearance lumber) can require consistent commitment from silviculture expenditure to harvest. And the commitments required from associated converting and marketing businesses just begin at the onset of harvest and extend beyond.

Examples of Southeast USA industrial fee timber are presented illustrating the reduction of complexity through improved understanding of conditions where some choices are superior to others. Plantation management intensity and forest product choices are described. Implications are considered from single acre (or stand level) and total property (or total company) perspectives.

Introduction

A publicly owned forest products Company is managed for profitability and financial return to shareholder. Timberland silviculture expenditures must compete with other uses of Company resources. The unique long-term characteristics of these investments lead to questions such as:

- Is the up-front expenditure of forestry dollars justified financially?
- Do these investments depress the financial performance of the Company as a whole?
- Is the cost of growing wood increased, so that manufacturing divisions of the Company are burdened with higher cost raw material vs. timber purchase at current market value?
- Does the "law of diminishing returns" apply, so that the marginal production per unit of input is decreasing as silviculture treatments are added to a forest management program?
- Finally, is there sufficient robustness to the choice of management intensity, so it is reasonable to assume the program will be sustained over several decades of change in product prices, Company financial posture, etc.? If not, there is risk of fluctuations in management intensity over time, diminishing the returns expected when all treatments are performed for optimum synergy?

To facilitate decision-making about silviculture choices for raw material product targets and forest management regimes, it is helpful to describe those circumstances where one choice is preferred over another. The development of the relationships of preference requires precise definition of the decision criteria. However, this effort can be productive. Where it can be shown that one choice is always or almost always favored to offer results equal or superior to other choices, that decision can be made and attention focused on remaining uncertain aspects and in execution. In this paper, examples of loblolly pine plantations in the Southeast United States are discussed. We will consider choices about:

- Management intensity
- Pulpwood Vs. Sawtimber product targets

Management Intensity

The development of this example for a typical lower coastal plain Eastern North Carolina clear-cut setting was documented several years ago (1). The purpose was to examine increasing management intensity in loblolly plantation growing regimes. Four management options representative of four levels of management intensity are shown in Table 1. Each option differs only from the one immediately above in the table in the addition of a new silvicultural treatment or a more intensive method. Each increase in management intensity requires additional silvicultural investment. For example:

- The Thin + Hardwood Control includes a herbicide spray at age 4, but is otherwise the same as the Thin Only.
- The Thin + Intensive Site Prep regime achieves control of the hardwood and further enhances tree growth through a combination of pre-plant cultivation, bedding and correction of phosphorous deficiency through fertilization. The incremental cost @ year zero is several times greater than hardwood control alone.
- Finally, the Thin + Intensive Site Prep + Nitrogen Fertilization regime adds two treatments of urea fertilization later in the rotation.

[1] Weyerhaeuser Company

Table 1. Loblolly Pine Management Levels Evaluated/Cost and Yield Assumptions

Management Level	Description	Treatment Cost (U.S. $/ha)* Year 0	Year 4	Year 15	Year 23	Yields (m³/ha) Thinning Age	Pulpwood	Clearcut Age	Pulpwood	Sawtimber
Thin Only	Chop, Burn, Plant, Accept 25% Hardwood BA, Thin to 15 m²/ha at Age 16, Clearcut at 35. Achieve SI_{25} 17 m (@ 25 years)	304				16	26	35	22	85
Thin + Hardwood Control	Chop, Burn, Plant, Reduce Hardwood Competition to 5% BA at Age 4, Thin to 15 m²/ha at Age 16, Clearcut at 35. Achieve SI_{25} 17	304	90			16	43	35	22	181
Thin + Intensive Site Prep	Intensive Site Prep to Raise SI_{25} from 17 to 23. Includes Drain, Shear, Pile, Bed, Phosphorus Bed Fertilization, Plant, Thin at Age 14 to 17 m²/ha, Clearcut at 30.	643				14	67	30	25	223
Thin + Intensive Site Prep + N Fert.	Site Prep, Plant, and Thin as Above, Nitrogen Fertilization at Ages 15 and 23, Clearcut at 29	646		100	100	14	67	29	25	233

* Other costs included are period costs of $10/ha/year and land purchase at time of establishment of $500/ha. The land is resold at clearcut adding a positive cash flow.

Treatment timing and cost assumptions are shown in Table 1 and include an investment at plantation establishment for the bareland. Total investment over the rotation increases with management intensity (See Figure 1.) Timber harvest timing and yield assumptions are also displayed in Table 1. The increase in mean annual increment of timber production with management intensity is shown in Figure 2.

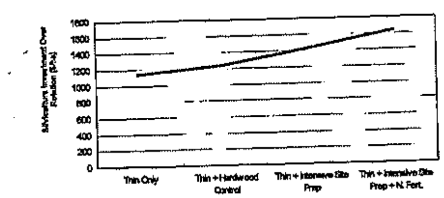

Figure 1. Silviculture Investment for Loblolly Pine Management Intensity Levels

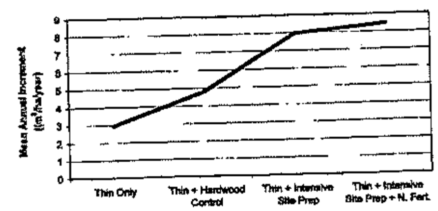

Figure 2. Mean Annual Increment of Timber Production for Loblolly Pine Management Intensity Levels

The **single acre based** financial criteria for forest management choices typically center on discounted cash flow analysis. These calculations require the specification of the time value of money or discount rate to be used. Net cash flows associated with the silviculture regime are discounted back to the time of establishment of the plantation. The discount rate used is a minimum hurdle for candidate investments. In the example, it was expressed in real terms (net of inflation) and on an after tax basis. Values of 4, 6, and 8% / year real after tax were used. In comparison, the average S&P 500 equity investment has produced an annual return of about 7% real after tax over the last 70 years. Timber growing can be rationalized to require a lower than average projected return for several reasons:

- From a pure **single acre financial perspective** timber growing is low risk and should not be required to match the performance of the average higher risk equity investment, e.g.,
  - There is flexibility in harvest timing while the timber continues to grow on the stump
  - Relative to other cyclical investments, timber has a negative beta coefficient. Included in an investment portfolio, the timber component tends to cancel some of the cyclical effect of the average equity on the total portfolio.
- Viewed for its contribution to **total property company goals**, long term silviculture investments are seen to enhance other components of the company's business, e.g.:
  - Timber growing can be an important component of a company's wood procurement strategy. The fee timber is captive supply to be blended with other sources for maximum return to the system.
  - Finally, silviculture investments usually produce increased wood growth in the long term. Even though the increased growth on the treated lands is not harvested for several years, there can be an immediate increase in harvest from other timberland managed by the company. There is potential for this near-term benefit in harvest when:
    - Mature timber availability above the harvest plan is present in the inventory.
    - Rate of harvest of that mature timber had been limited to assure sustained timber supply to meet customer and other stakeholder commitments through time. In some circumstances the additional future harvest from silviculture investments provides the opportunity to assure sustainability and allow higher harvest rates near term. The additional benefit attributed to the silviculture investment is called the allowable cut effect.

Table 2. Pine Stumpage Value Assumptions

	$/m³		
	Optimistic	Base	Pessimistic
Pulpwood	13	11	7
Sawtimber	56	39	22

The two most common single acre metrics used are Net Present Value (NPV) and Internal Rate of Return (IRR). The NPV is simply the sum of all costs and revenues, each discounted back to the time of plantation establishment. The IRR is that discount rate which produces NPV = zero. Both the NPV and IRR criteria require estimates of timber stumpage value for the time of future harvest. For the example a wide range of timber value assumptions were used (Table 2). While the NPV and IRR metrics most directly take all our projections about silviculture regimes to a familiar bottom line, break-even stumpage price also provides useful insight into the relative economics of alternative silviculture choices. The calculation of this metric does require the assumption of a discount rate, but avoids reliance on future timber value assumptions. Commonly referred to as wood growing cost, it is that revenue per unit of volume grown, which is required to achieve NPV = zero for a specified discount rate.

Wood growing cost results for the four levels of loblolly pine management intensity are shown in Figure 3 for three discount rates. The higher discount rates impose higher accumulations of capital costs on the long-term silviculture investments and produce significantly higher wood growing costs. In this example, we also see that the most intensive, highest investment, highest yield silviculture choice produces the lowest wood growing cost, regardless of the discount rate. We may not like the wood growing cost at the higher discount rate and the highest management intensity level, but we see even poorer results following the silviculture choices employing a lower level of management intensity.

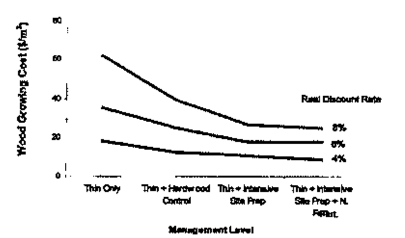

Figure 3. Wood Growing Cost vs. Management Intensity

In Figures 4, 5 and 6, NPV at the three discount rates and the three timber price levels is displayed for the four levels of management intensity. Of course, higher timber prices and lower discount rates produce higher NPV. For most timber price and discount rate combinations, NPV is highest for most intensive management choice. However, this is not true for the lowest timber price future evaluated at the 8% real discount rate. Here there is disadvantage to adoption of the more intensive siliviculture. In Figure 7, internal rate of return is shown for the three price levels. Here we see complete dominance of the more intensive silviculture. Returns are only a little above 4% real after tax for the low price future, but more intensive silviculture is still better than less intense, even though there is more cost early in the regime.

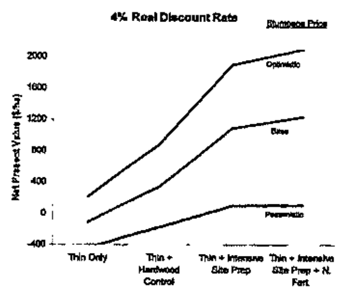

Figure 4. Net Present Value vs. Management Intensity

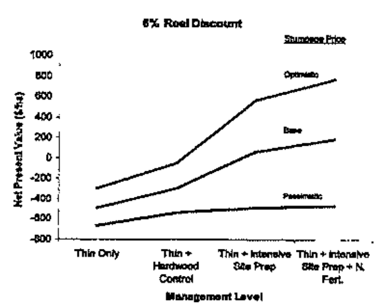

Figure 5. Net Present Value vs. Management Intensity

Different sets of tree-growing circumstances, different financial criteria and different assumptions about the future can produce different conclusions about management intensity. However, it is my experience that it is worthwhile to look for general conclusions about the dominance of some choices over others. Sometimes, what was previously controversial is actually a generally clear choice.

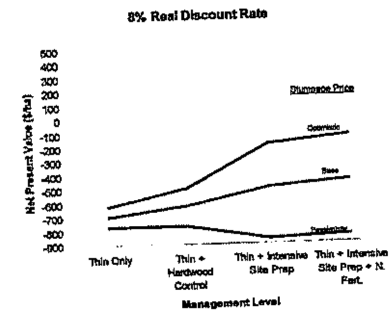

Figure 6. Net Present Value vs. Management Intensity

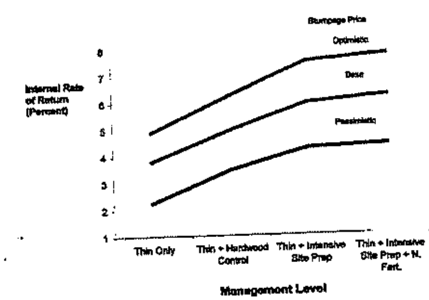

Figure 7. Internal Rate of Return vs. Management Intensity

Product Choice—Pulpwood vs. Sawtimber

Another forest management choice to be made in loblolly plantations is about target products. All the forest management intensity cases evaluated above included thinning and were carried to a final clear-cut age old enough to achieve tree size yielding mostly sawtimber at clear-cut. However, in the Southern United States, some pine plantations are managed without thinning and are clear-cut earlier. There may still be some small sawlog ("CNS") extraction, but most of the harvest will be pulpwood. While values for pulpwood have historically been substantially below sawtimber, the pulpwood prescription has some potentially significant financial advantages:

- Shorter rotation and therefore less carrying cost of the regeneration investment.
- Lower average harvest cost since commercial thinning is higher cost than clear-cut
- Commercially thinning in younger plantations has differential wood properties from the older clear-cut, which may pose marketing difficulties.

The plantation management intensity choice and even the commitment to ownership of the plantation will be dependent on the product targets, so there is need to gain clarity around that through illustration of the consequences resulting from the range of possible futures. We will contrast the most intensively managed sawtimber prescription in Table 1, to a pulpwood prescription with the same intensive site preparation, no thinning and clear-cut at age 20. The outcome of a **single acre** comparison will depend on whether the higher price received for the sawtimber provides sufficient benefit to overcome the other pulpwood advantages.

The comparison is illustrated in Figure 8. Lines of constant internal rate of return to pulpwood and sawtimber management are drawn for a broad range of possibilities of pulpwood and sawtimber stumpage price. Consider the simpler pulpwood regime first. Here we assume that only pulpwood is harvested, i.e., no CNS sawlogs are pulled. The financial return to pulpwood growing is therefore not dependent on the sawtimber price, only the pulpwood. The lines of constant return will be vertical and returns increase with higher pulpwood prices. Each of the pulpwood prices is in effect a Wood Growing Cost. In contrast the sawtimber management regime produces a mix of sawtimber and pulpwood (see Table 1), so financial return will vary with both stumpage values. Therefore the lines of constant return to sawtimber slopes downward as pulpwood price increases. For example, consider the 8% IRR Sawtimber management line. The downward sloping line states that the sawtimber stumpage value required to make 8% will decrease as the pulpwood stumpage value increases. Points in the chart where the sawtimber and pulpwood lines cross for identical IRR are those stumpage prices for sawtimber and pulpwood where we are indifferent between the product choices. The line connecting these points describes all combinations of indifference. Above this line sawtimber management is best and below, pulpwood is preferred. The location of these lines (or the axis scales) will depend on a host of assumptions about site productivity, silviculture and harvest costs, and market expectations for the local area. However, it is my experience that it is useful to prepare the chart and compare the lines with price expectations over future price cycles. It is possible that one product choice will be completely or mostly dominant from a **single acre** perspective.

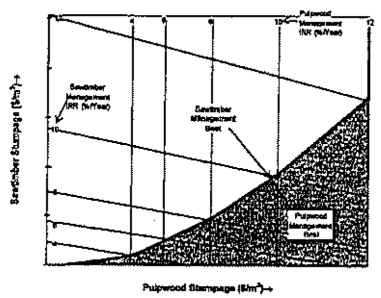

Figure 8. Plantation Product Choice—Pulpwood vs. Sawtimber

Evaluations of product choice from a **total property** perspective will also influence the decision. For example:

- The shorter harvest rotation associated with the pulpwood choice could facilitate an allowable cut effect, when the inventory contains a significant proportion of mature timber.
- Alternatively, there may other motivating factors in lieu of the tree-growing profit rationale employed throughout the preceding part of this paper. For example, here is one different chain of thought:
  - Suppose that the Company's investment hurdle rate exceeds expected tree-growing returns regardless of whether a pulpwood or a sawtimber regime is to be used. I.e., the Company does not believe that shareholder value will be increased if expected timber market values are received for the harvest, whether it is pulpwood or sawtimber.
  - However, the Company does want a minority proportion of their supply for pulp and paper manufacturing facilities to be provided from fee ownership. It is used to leverage cost of purchased wood supply.
  - In this case the Company may rationalize that the lowest cost means to provide the supply security is through the pulpwood management regime.

Conclusions

- While long term tree-growing choices about forest management intensity and plantation products initially appear complex and overwhelming, at least some of the choices are simplified when analysis reveals that one choice is superior to others regardless of what the uncertain future holds about product values.
- Key single acre analysis metrics will include discounted cash flow (NPV and IRR) and break-even wood growing costs.
- Total property considerations such as allowable cut effect and other implications for the rest of the system such as outside purchased wood supply will also play a role.
- Specifics vary, however, it is common to see that fertilization added to forest management regimes produces higher incremental financial returns to tree-growing and lower break-even wood growing costs than the base regime with less or no fertilization.

Reference

Holtman, J.B., *1987 Forest Management Intensity / Wood Growing Costs / Financial Returns* in Proceedings at IUFRO Forest Growth Modeling and Prediction Conference, Minneapolis, MN.

Will companies really have incentives to practice enhanced forest management?

M.K. (Marty) Luckert[1]

Overview

- Levels of Analysis for the Economics of EFM
- Stand Level Problems (Rodriquez et al. 1998)
- Forest Level Problems (Hegan and Luckert, 2000)
- Administrative Level Problems (Luckert and Haley, 1995)
- Conclusions

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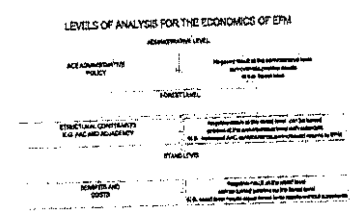

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Stand Level Problems:

- Assumptions
  - Conifer dominated mixed wood
  - Clearcutting, Medium Sites
  - \$5/m3 aspen; \$15/m3 spruce, i=2%
  - Harvest at stand age of 100 years
  - No investment vs. extensive [aerial seeding (yr 0), glyphosate (yr 8)] vs. intensive [site prep and plant (yr 0), glyphosate (yr 8)]

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Stand Level Problems: Results

	No Investment	Extensive	Intensive
Regen. Lag	28 years	9 years	2 years
PV Costs	\$0/ha	\$339/ha	\$1082/ha
PV Benefits	\$271/ha	\$376/ha	\$550/ha
NPV	\$271/ha	\$37/ha	-\$531/ha

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Forest Level Problems

- Model: WOODSTOCK and C-WHIZ
- Assumptions: Same as before, except....
  - 200 year planning horizon
  - Harvest at stand age which maximizes NPV
  - Three runs: LFN, all candidate stands treated with Extensive, Intensive
  - Two standing inventories ("mature", "juvenile")
  - Four AAC scenarios (No Flex., Present Flex., Double Flex., Total Flex.)
  - Two AAC compositions (Spruce AAC, Aspen Incidental; Spruce and Aspen combined AAC)
  - With and Without Green-Up Constraint

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Forest Level Problems: Results

- Volumes
  - Juvenile starting inventory, little or no ACE
  - Green-up constraints reduced ACEs
  - Spruce AAC increases (vs. no investment); 24% for extensive, 41% for intensive
  - Combined AAC (approx. 50% higher than spruce AAC) decreases 8% for extensive, increases 4%for intensive.
  - But increased volumes are a necessary but not sufficient condition for ACE incentives..... Values????

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Forest Level Problems: Results – Values

- Changes in values not much different among AAC stringencies, but big difference compared to no AAC constraint:
  - Spruce AAC, 100% increase in value
  - Combined AAC, 50% increase in value
- Combined AAC generally worth more than Spruce AAC

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Forest Level Problems: Results - Values

	% Change in NPV compared to no investment	
	Extensive	Intensive
Spruce AAC	16%	9%
Combined AAC	-9%	-16%
No AAC	-6%	-23%

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Administrative Level Problems

- Survey in 1992 of 10 provinces (for period 1985-86 and 1990-91) showed:
  - 7 provinces had ACE policies
  - 3 provinces had zero stumpage on ACE increases
  - 4 provinces granted ACE increases based on potential, 2 based on actual increases
  - 6 provinces policies were under review
  - Only Newfoundland had any ACE investment activity (shared public and private expenditures) Why????

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Administrative Level Problems

- AAC already high
- Rent Collection
- Non-binding AACs
  - Abundance of mature public timber
  - Thin log markets
  - Flexible AACs
- Costs of approval
- Uncertainty of benefit stream

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Conclusions : For the Three Levels...

- Stand Level Economics Look Bad:
  - increases in timber values could help
  - long way to go in Alberta
- Forest Level Economics Are Mixed:
  - driven by mature inventories of timber;
  - increases in timber values could help
  - increases in AAC constraints could help
- Administrative Level Problems Look Bad:
  - diminishing availability of unallocated mature timber could help;
  - careful design of policy could help

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Conclusions: But......

- Are we trying to push a string?
  - has anybody succeeded in doing this?
  - is it possible in given our ecosystems and institutional structures?
- Should we try to push it, even if we can?
  - "Short term" solution depending on mature inventories
  - Sustained Yield vs. Sustainable Forest Management
  - Sustained Yield, ACE and "revenue neutral" forestry

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Financial analyses of intensive silviculture: To invest or not to invest? That is the question.

Ian S. Moss[1]

Introduction

The question of whether or not to invest in silviculture has been asked many times before. Why do we keep asking this question? Has our view of the world changed? Is it that we expect an increase in demand for structural or decorative wood or paper products, making investments attractive where they weren't before? Is there a looming shortage of world wide wood supply? In the main the answer to these latter questions is that even if demands are increasing there is no pending shortage of supply to fill that demand, particularly as there is an increasing supply of plantation grown fibre becoming available to the market-place (for a brief overview see van Kooten and Bulte, 2000., Pp 371 to 375).

In the following discussion I hope to give you a sense of why we are unable to make much progress in understanding the decision to invest in silviculture. To put it simply, the tools for analyzing this problem have evolved but we haven't evolved with them. This problem is not just with practitioners like you and I, it's also with executives in both government and industry and with the way we have structured our organizations. Roger Hayter (2000) views the problem, in part, as being one of foreign direct investment; according to Hayter we (in British Columbia) have become a branch plant that fuels innovation at the home (foreign) base. We produce. Others learn to produce more and more efficiently using our resources. My view is more one of a local practitioner or employee devoted to increasing the value of our forests from both a timber production and an environmental protection perspective. I find that one of our greatest weaknesses is in our understanding of how to apply economics and so have made a concerted effort to better educate myself in this regard. Some references are provided at the end of the paper so that you can travel down the same trail if you so choose. This paper is a result of what I have concluded while endeavouring to apply what I have learned to both private and public forest and stand management. So why do we keep asking the question of whether or not we should invest in intensive silviculture? Is it because we keep giving the same answer and that the answer is neither convincing nor realistic?

Have we learned about responses to treatments such that our previously conceived notions woefully underestimate the potential benefits of investments therein?

There has been some new knowledge about *potential* responses to treatment, particularly through optimum fertilization trials but these are mostly of biological significance, being well beyond anything that would be considered of economic value. We have also gained further knowledge from thinning and fertilization trials, particularly as it applies to lodgepole pine, but in the main, the results are within the range of those that might be expected (e.g., see Bowen and Nambiar, 1984.) so that they really confirm previous economic analyses of the costs and benefits of these kinds of treatments. The real problem is that there are only a few trials to represent a wide variety of site and stand conditions. We remain uncertain about how to go about applying what we have learned so far. We just don't have enough experience with applying different kinds of treatments across a wide variety of site and stand conditions accompanied by systematic observations (measures) of the outcomes (responses). It is not that we can't estimate the costs and benefits of applying silviculture treatments; it is simply that we're unsure about the reality of those estimates.

Have tenure arrangements changed radically in the last 20 years?

The insurance industry and private investors have taken an increased interest in private land forestry, as a means of compensating for increased exposure to risk in their other investments. We are seeing somewhat of a trend away from the integrated forest companies and toward the management of private woodlands that market logs instead of lumber and chips (for a general overview on

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timberland investments see Zinkhan et. al. 1992.). This shift in perspective has the potential to increase demands for silviculture investments, where before emphasis was placed on investments further along the supply chain, but the degree to which owners of these woodlands understand the potential for improving their assets still varies widely. In both private and public land forestry, the technology available to support better asset management is impeded by a lack of knowledge of, and in some cases interest in, how to go about using that technology to good effect. There has been a long standing focus in the industry on the harvesting and processing of wood products because of the short term impacts these have on ones profitability; and a corresponding neglect of how to manage the forest asset base to improve financial prospects over the longer term. The irony of this situation is that when it comes time to valuing forest based manufacturing assets, by far the largest component is captured under the availability and security of wood supplies. However, most investors lack the sophistication to understand the difference in sources of income when it comes to liquidating woodland assets versus increasing asset value and the potential for sustainable cash flow over the longer term. In the short term Executives have the option to increase share prices and their performance bonus by increasing the rate at which assets are liquidated. Instead maintaining or enhancing forest assest values could be used to meet the demands of long-term investors who are looking for lower risk, more stable investments to balance their portfolios. It takes work to cultivate this kind of investor; the trick seems to be that the rewards for doing so must come from the investors themselves and their Board of Directors. The problem is that the investors may be in it for the short term only, but even if they are not, they may not have a sufficient understanding of the business of forest management to produce a method for rewarding Executives that is truly in their best interests.

When the facts described above are combined with public land tenures, investments that can improve the land base must be weighed up against hospitals and schools from the owners perspective, and weighed up against uncertainty in the regulatory environment in the other. Tenure holders must first take that the attitude that they want to increase the security of wood supply through improved tenure arrangements, and that the way to obtain this is to demonstrate improved planning and management practices in areas in which they operate and wish to increasingly control, making it possible for politicians to slowly abandon the need to have a tightly controlled regulatory framework, and making it possible for them to demand lower stumpage from the forested land base. The problem with this gambit is that you must "pay before you play." The transition is made more palatable by redirecting funds from stumpage back into the forest industry at the beginning, but it still requires a high level of cooperation between the owner and the tenure holder, and a high degree of integrity and skill in terms of the delivery of the product by the latter. In addition, the benefits from this transition may take a considerable period of time before they are realized. Owners of forest company X operating on public lands must ask themselves this question: "Why would they do business on Public Lands if they were not intent on obtaining increased control over the assets that are necessary to make their business profitable?" The alternative is to watch the Government run your business for you; you can be the book- keeper.

To these thoughts we could add further considerations for Aboriginal peoples on our business practices. This is a longer discussion than I have time for. What needs to be said is this: that the attitudes toward silviculture investments, the reasons we haven't practiced what we've preached, are profoundly tied up with these issues of attitude and ownership. For many businesses the path toward better forest management is not very clear, so the answer is to follow what is being demanded of them, through certification for example, rather than lead in the direction they think they must go, of which certification is a by-product for example. For those that can't see the path clearly, investments in silviculture will only be needed as something to be traded in return for a tenure agreement or needed simply because the one thing that is commonly understood to be true is that we should plant trees.

Has economic theory advanced to the point that what we once thought to be true is no longer true?

On an historical note: Johann Heinrich von Thunen's (1783–1850) manuscript on: "The Principles for the Determination of the Rent of Land, the Optimum Period of Rotation, and the Value of Timber of Different Ages of Firs" was published by Schumacher in 1863 (Schumpeter, 1954). He was a farmer as well as an economist. He considered rent as a function of location, not fertility or climate, since land quality in the "isolated state" is uniform, and thus rent differentials arise from differences in transportation costs (van Kooten and Bulte, 2000).

To return to the original question, most of the recent expansion of forest economic theory has been directed toward issues of conservation and "sustainability" through consideration of non-market, and non-timber goods and services provided by forests and forest management (see for example, Bowes and Krutilla 1989. and van Kooten and Bulte 2000). Silviculture investment analyses has not advanced very far in the last 20 years although our ability to use this techniques has been enhanced by the availability of computers.

Substantial advances have been made in the understanding of (financial) risk and there has been a large expansion in the kinds of financial instruments available for managing risk and the associated potential for reward and regret (for a good general reference see Bernstein, 1995). There is a substantial opportunity for taking these same concepts and applying them to forest management, particularly to the key decision of how to maintain a proper balance between holding assets in reserve versus cashing them in. "You've got to know when to hold them, know when to fold them, know when to walk away, know when to run." Actuarial methods used to account for risk have direct application to the management of forests. In my view many governments and many in the forest industry have not even woken up to these advances as they apply to forest-land management. It is no wonder then that we can't find the appropriate context in which to evaluate silviculture investments. We don't even speak the same language as those who might invest.

To sum it up...

To summarize the discussion, we have known for some time that fertilization can increase wood production, but the question then becomes one of knowing where and when these benefits will be accrued, and how often given our operating conditions. We also have questions as to: who should pay, who will benefit and what are the forms of investment? The remarkable fact is that many, perhaps most forest companies, do a credible job of managing forest operations, but have only the vaguest idea of what it means to do a better job of forest asset management. If we stop to think about it in these terms, we will realize why fertilization, along with many other kinds of treatments are contemplated by many and applied by only a few. We need a better forest asset management and investment framework to guide us in decision-making. Many institutions involved in forest management don't have such a framework. This results in both needless expenditures in some areas (particularly associated with poorly developed forest management policies, rules and "guidelines") and lack of expenditures in others (particularly where more knowledge would lead to increased efficiencies in the allocation of expenditures). Investment in fertilization is an option well understood in general, but in many jurisdictions, poorly understood in practice.

Organizing ourselves for better silviculture practice

We must try to bring increased certainty in terms of the options available to us through the harvest schedule.

At the heart of good forest asset management one must strike an appropriate balance of producing a high level or cash flow against the option of producing a higher, more secure level of cash flow in the future. The most important decision is the one that determines where and when one harvests, and how much is cut. To capitalize on any silviculture investment one must be vigilant in managing the trade-offs between protecting existing growth potential, enhancing future growth potential, preventing losses due to unforeseen (catastrophic) events, and producing an acceptable return to capital. If we cannot garner a higher degree of certainty in the harvest schedule, then in the long run, investments in silviculture will be wasted. A major operational barrier to effective silviculture investments is knowledge of the inventory and the rate at which it is growing and being depleted by natural agents. The best investment one can make is to discern those stands that are notto be harvested because they either rapidly accruing in value, or have considerable potential to do so. It is also to discern those stands that should be harvested because they do not have any such potential and they increase the exposire of the surrounding forest to the threat of destruction by natural agents. The point is that you really have to want to increase forest asset value before you can become a good investor. You have to work at it. To begin with it is a matter of doing better with the information and resources you already have.

The forest manager must learn to adequately anticipate the needs for values other than timber, to avoid the end result that the chickens are counted before they hatch.

Most managers are focussed on short-term gains, with the result that by the time you've recognized a problem with the state of the forest, it is frequently too late to do anything about it; someone else will do it for you (and/or perhaps to you). We must change our attitude if we want to avoid these kinds of problems in the future. The example closest to home is the enactment of the forest practices code in British Columbia, the end result of which is the loss of discretion over how, when and where stands are harvested. It means that the opportunities for realizing returns on investments in silviculture are reduced, and yet paradoxically, they may be seemingly increased insofar as they can be used to navigate between overlapping, policy driven constraints. The problem is that this artificial investment climate may not translate into an improvement in competitiveness and may in fact further compromise ones position in the market. The investment climate is manufactured and controlled from the outside, presumably more than it needed be if the (environmental) issues had been acknowledged and acted upon earlier in the process. Forest managers must look for win-win scenarios in the distant time horizon when it comes to protecting environmental values, while at the same time retaining a high degree of flexibility in terms of how, when, and where timber is produced.

We must commit to paying "up front" to learn about the kinds of responses that can be realistically expected from different kinds of treatments and treatment combinations.

It doesn't matter whether you are measuring response in terms of wood production or habitat use; you have to pay before you play. This game requires long-term commitment because you must first learn (the pay) about something that ultimately may take many years before you have any real understanding. In the case of fertilization you can do some short term, cheaper investigations using single tree trials across a wide range of site and stand conditions for a given species, but eventually you will want to know what you are actually buying in terms of increased stand level yields over time. The problem gets worse because while you can work out some basic relationships using well controlled experimental plots, in the final analyses you will need some monitoring plots to see if you are actually obtaining the benefits expected based on experiments. There is no substitute for good information.

To obtain realistic estimates of gains (or losses) the company must be well organized in how one goes about doing monitoring—particularly when dealing with anything other than very uniform site and stand characteristics.

This is perhaps why we see fertilizers used most commonly in the context of tree farming and agriculture. You are dealing with very simple, somewhat homogenized (ecological) systems that reduce some of the uncertainty around the outcome. There may be a place for fertilization in the world of ecosystem management, but if it is to be found, it is amongst the collection of natural disturbance patterns and habitat types, with wood production taking on more of a role as a secondary-product. It takes a higher degree of sophistication to monitor and reliably predict outcomes associated with increased variability in site and stand characteristics. The design and implementation of a good monitoring system is not a trivial task.

Keep it simple, take the art of the long view.

We may have complex forests, we may even want to retain much of the complexity, but we can only do a few things really well. This means that as forest managers (are there any here who are such beasts?) we must be very clear about what it is we are trying to produce so that the people that do that work can succeed in producing it. "What are the desirable and reasonably possible forest level outcomes?" as Dr. Baskerville has asked so many times. When trying to produce these outcomes one must draw upon the art of the long-view and that takes practice; you don't become an Olympic swimmer without a lot of practice in the pool.

Promote institutional learning.

The best way to protect institutional learning is inside co-operatives, particularly when it comes to Public land management. In my view co-operatives are a realistic way to organize information gathering exercises since when we measure competition we tend to see it more on a regional basis rather than a corporate basis. BC is a high cost producer, and yes there is some variation around this theme, but the variation is small when compared with the differences between ourselves, the Southeast US, Chile and New Zealand for example. Furthermore, our products, SPF lumber for example, draw little distinction amongst suppliers; price is everything. Large multi-national companies simply internalize regional differences and allocate resources accordingly, ultimately re-organizing, shutting down or selling those assets that are poor performers. The final point about co-operatives is that they distribute the effort of gathering and organization of information more widely, but it is up to each individual to make an efforts toward putting that information to good use. A major problem faced by forest companies is how to produce and process data in support of more effective decision-making. The view from the ground is that people go about their daily business without really understanding how to better connect their end of the business with the demands made by the Executive. The view from above is that there are significant demands being made on every aspect of the business. Those demands are passed down the chain of command without any real idea as to how they will be met. The result is a discontinuity between the demands that are made and the

results that are produced. Companies need to work harder at understanding both ends of the business if they are to succeed in producing timely and effective information necessary to make progressive decisions.

Pay as much attention to forest management as you do to forest operations management.

More could be said along these lines, but I think you get the point. To begin with a forest company must pay as much attention to forest management as one does to forest operations management. You can't get to a consideration of alternative silviculture investments if you don't go there first.

Lastly, I'd like to look into the question of some alternative approaches to silviculture investment analyses. In general terms these thoughts apply to both public and private land management, the key difference being that as the owner of the resource you get to keep the rent.

Silviculture investment analyses

Lets start with the basics. On one hand, from a straight discounted forest cash flow perspective, we might be better off just cashing in the inventory, taking the money and investing it elsewhere in higher yielding investments—cut and run. On the other hand, if we want to stay in business and protect our existing assets, then we should spend some dollars on silviculture, even at a low rate of return, to slowly build the asset value of the forest resource, and thereby maintain or enhance the future potential cash flows, and option value of the forest (i.e. build in more flexibility in terms of when, where and how harvesting is done). In the latter case one must be prepared to accept a lower return on silviculture investments in order to build a higher level of steady state cash flow over the intermediate to long terms. The value to a company in the short-term is not so much in the forest resource, as it is in the ability to organize people and information to deliver long term sustained growth through better information management systems and forest management practices. This knowledge is exportable, enabling a forest company to operate anywhere in the world because one is ultimately able to reap larger (sustainable) gains from the same starting set of assets when compared with competitors. From the perspective of operating in foreign countries these credentials may in some cases be critical to becoming eligible for gaining long-term access to harvest timber. At the two extremes one is either in the business of building long term asset value with stable or increasing returns, or in the business of liquidating assets for investments elsewhere. Investments in silviculture can be used to build the asset side of the business.

What does this say about the traditional investment analyses methods as applied to silviculture? It says that a moderate level of investment at low discount rates is most likely warranted where the products are a combination of:

- reduced uncertainty in forest management decisions,
- an improved ability to organize the gathering, analyses and utilization of information to meet strategic goals (this takes practice),
- a steadily increasing number of options for improving the balance of forest level cash flows, profit margins, and assets, and options for reducing the potential risks of losses (practice makes perfect, i.e. continuous improvement).

The analyses must be done with consideration of the following options: At the forest level there are gains to be had by logging more wood with less equipment, fewer roads, and smaller cut-blocks—a slower throughput, higher profit margin and annual cash-flow operation, but the decision to take this strategy is constrained by the potential for losses due to insects, disease and other damaging agents. This is in contrast to managing a woodlands by logging the same amount of wood with more equipment, roads and larger cut blocks—a higher throughput, and lower annual operating margins following the tradition of plantation management; the decision to take this latter strategy is constrained by the potential for risk that you may go out of business because you were not amongst the lowest cost producers during times of poor market demands. So the choices are low risk, low discount rate investment strategies following along the lines of the first point, or high risk, high discount rate investment strategies following along the lines of the second point. In fact risk comes in terms to two forms: from the potential for damage from biotic and abiotic agents that increases with increasing rotation ages, and from the potential for going out of business altogether that increases with decreasing rotation ages. Failing to adequately protect environmental values can also increase the risk of loosing market options. The lowest risk option(s) are associated with the lowest discount rates when it comes to investment analyses. If you are thinking about investment in fertilization, think about it in these forest level terms, not in isolation as some kind of a stand level investment (although this can be helpful when getting down to where best to apply the treatment).

Conclusion

Silviculture investment analyses must be done within the context of a forest level strategic management framework. The appropriate discount rates used in the investment analyses require careful consideration of the potential for reward and regret. In order to obtain the rewards and avoid the regrets, it is necessary to organize the collection and processing of data into information, and the reporting of the information for decision support, such that it is directed toward meeting the strategic goals of the company. This, in turn, requires careful attention to the business along the entire chain of command. Strategic goals must be translated into operational outcomes and operational outcomes must fulfill strategic goals. Silviculture investments are best made with a view to either: (1) maintaining longer-term forest assets that pose a low risk, steady income option for the outside investor, or (2) maintaining a high throughput, lower marginal rate of return at the time of harvesting. The first strategy can be accompanied by applying lower discount rates to silviculture investments, because it is more than compensated by high annual marginal rates of return to the forest at the time of harvesting. The second strategy requires that higher discount rates are applied because there are low annual marginal rates of return to the forest at the time of harvesting. To determine whether or not investment in forest fertilization is a good thing, one must have first set an appropriate strategic forest asset management goal. With this goal in mind, one can organize the operations for successful implementation by developing an appropriate invest framework and then organize data collection and information processing, and by ensuring that employees know how to use this information across the entire chain of command. The management system must then be used and improved or modified to work efficiently and effectively with time.

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Economic comparison of different silviculture intensities

Jeremy Williams

Summary

The economic benefits of intensive forestry were initially analyzed using a framework that applied to a single hectare or individual stand in isolation from all others, which is inappropriate for use when a forest management unit is being considered. The appropriate financial analysis is done at the forest level using a forest projection/wood supply model and makes use of the allowable cut effect to provide immediate financial benefits, so long as the silvicultural capacity of the unit has not been saturated. However, there a number of disincentives to intensive forest management built into the tenure system, and that also affect behaviour on private land. As a result, despite incentives for intensive forest management, relatively little has been undertaken to date in Ontario. The Ontario Forest Accord of 1999 has recognized this issue and has proposed to create incentives for intensive forest management in order to offset the effect of an expansion of the protected areas system on wood supply.

What everyone wants to know is:

Does intensive silviculture pay?

What is intensive silviculture?

- No standard answer
- Perhaps simplest to give relative definitions:
  - Activities that increase the m.a.i. above norm for that forest unit.
  - Increasing the silvicultural cost per hectare above norm.

Faustmann analysis - 1

- Assumes you plant bare land and harvest at maturity
- Where a forest exists, this separates harvest decision from planting decision

Faustmann analysis - 2

Activity	Extensive	Medium	Intensive
Scarify & Plant	0	650	740
Release @ 15 & 25 yr	0	65	65
Release @ 35 yr	0	0	32.5
Fertilize @ 20 yrs	0	0	170

Example from Benson (1988). Species not specified (black spruce in Ontario)

Faustmann analysis - 3

	Yield (m3/ha)	Harvest Age	NPV ($/ha)
Extensive	170	100	-41
Medium	204	80	-689
Intensive	238	70	792

Timber value = $10/m3; Discount rate = 6%

Faustmann analysis - 4

- What happened?
- Long delay to harvest killed economic return
- Treatment had no impact on rest of forest
- Appropriate for small separate tracts of land
- Inappropriate for sustained yield forests - wrong model for the situation

Capturing ACE

- ACE = Allowable Cut Effect
- Immediate increase in annual harvest in anticipation of future yield gains from more intensive management
- Extent of ACE depends on age class dist'n and relative yield gain - tapers off as overall management intensity reaches high levels

ACE Example - 1

- 38,000 ha black spruce forest on Site Class 1A (yield 250 m3/ha @ 90 years)
- Relatively large area of mature and regenerating stands
- Max SY with no silviculture: 97,000 m3/yr

ACE Example - 2

Regime	First Operable	Vol when First Op	Discount Cost/ha	Area Planted/yr	Ann Disc Cost MS	Disc Cost/m3
1.8 m	55	268	1174	325	382	29.38
2.0 m	50	231	1066	225	240	18.46
2.5 m	40	162	939	225	211	16.23
3.0 m	40	149	870	250	218	16.77
Seed/ PCT	45	162	454	350	159	12.23

Where is all the intensive silviculture in Ontario ??

Lack of Intensive Silviculture

- Reduced stumpage clause in FMAs never activated
- Renewal charge levels declining
- Tenure deemed insufficient
- MNR will allocate "surplus"

Ontario Forest Accord - 1

- Agreement between Forest Industry, the Ministry of Natural Resources, and the Partnership for Public Lands (coalition of the World Wildlife Fund, Federation of Ontario Naturalists and Wildlands League)
- Application of the "Triad" - Exchanges intensive forest management for parks

Ontario Forest Accord - 2

- Raised protected areas to 12% of area of commercial forest management.
- There would be no net increase in the cost of wood delivered to the mill and there would be no long-term reduction in the supply of fibre necessary for processing on both a planning area and regional basis.

Measures to Enable EFM - 1

- Develop an Ontario forest science partnership in order to:
  - develop and test a range of intensive forest management practices;
  - assess the impacts of intensive forest management on increased forest growth and yield;
  - assess the environmental impacts of intensive forest management;
- direct science activities in support of Ontario's forest management planning requirements under the Timber Class Environmental Assessment and Crown Forest Sustainability Act.

Measures to Enable EFM - 2

- Implement measures directed at improving the utilization of Crown timber and increasing the volume /or quality of Crown timber over the long term. These measures will include:
  - semi-commercial thinnings
  - improvement cuts in degraded hardwood forests
- salvage cuts in low volume or quality stands that are not currently harvested.

Measures to Enable EFM - 3

- Establish incentives in relation to extraordinary expenditures on intensive forest management to grow Crown timber.

- Participate in the designation of intensive forest management areas (special supply areas) in forest management plans. In the initial phase of intensive forest management areas designation and implementation, these areas will be limited to a mutually acceptable portion of the landscape.

Measures to Enable EFM - 4

- MNR will make best efforts, together with the forest industry and the environmental groups to obtain appropriate modifications to the Timber Class E.A. and the Crown Forest Sustainability Act and its regulations, in order to permit intensive forest management practices (pending more precise definition of specific requirements) and the lengthening of the term of forest management plans.

Carbon Credits

- Kyoto Agreement will allow RAD activities to contribute to net emissions reduction
- Definitions of terms - afforestation
- Project versus base case - demonstrate additionality
- Some existing forestry projects
- Potential to generate additional value

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Fertilizer grade

Fertilizers and Soil Chemical Analyses. FEST 306

Prof Weetman

Both 'Single Element' and 'Composite' fertilizers are rated in the percentages of *elemental* Nitrogen (N), Phosphorus Pentoxide (P_2O_5) and Potassium Oxide (K_2O) equivalent to the amount of elemental N, P and K they contain. The following ratios and percentages for Phosphorus and Potassium fertilizers are useful in working out the relationship between P and P_2O_5 and K and K_2O in fertilizers.

$$\frac{N - P - K}{N - P_2O_5 - K_2O}$$

1) Phosphorus : Phosphorus Pentoxide

	P_2		O_5		P_2O_5	
	61.95	+	80.00	=	141.95	by weight
or	1	:	1.2914	:	2.2914	in ratio
or	43.64%	+	56.36%	=	100.00%	in per cent

2) Potassium : Potassium Oxide

	K_2	+	O		K_2O	
	78.20	+	16.00	=	94.20	by weight
or	1	:	0.2046	:	1.2046	in ratio
or	83.01%	+	16.99%	=	100.00	in per cent

The atomic weights of the principal elements in fertilizers are:

N = 14.01	Ca = 40.08	C = 12.01
P = 30.98	Mg = 24.32	O = 16.00
K = 39.10	S = 32.07	Cl = 35.40
	Na = 23.00	H = 1.01

1) Ammonium Nitrate [NH_4NO_3 or $NH_4^+ NO_3^-$]

N	X	2	=	28.02	= 0.3499 N, or 35% N (elem)
H	X	4	=	4.04	
O	X	3	=	48.00	
				80.06	

Thus $\frac{N - P_2O_5 - K_2O}{35 - 0 - 0}$ (pure salt)

33 - 0 - 0 (technical grade)

2) Urea [$CO(NH_2)_2$, non-ionic]

C	X	1	=	12.01	
O	X	1	=	16.00	
N	X	2	=	28.02	= 0.04665 N, or 46.7% N (elem)
H	X	4	=	4.04	
				60.07	

2) Triple Superphosphate

This fertilizer varies in chemical composition (Figure 2). Triple Superphosphate is usually from 40-50% P_2O_5 or from 17.5 to 21.8% P (elem.).

(Note: 40% ÷ 2.2914 = 17.5%, 50% ÷ 2.2914 = 21.8% P elem.)

Thus $\frac{N - P_2O_5 - K_2O}{0 - 40\text{ to }50 - 0}$ (technical grade)

1) Potassium Chloride [K Cl, or $K^+ Cl^-$]

K	X	1	=	39.10	= 0.5244 K or 52.4% K (elem)
Cl	X	1	=	35.46	
				74.55	

(Note: 52.44% K X 1.2046 = 63.17% K_2O)

Table 2. Single and double element fertilizer compounds and conversions (fertilizer ...

To convert elemental amounts to fertilizer amounts multiply by	NITROGEN AND NITROGEN-CALCIUM, POTASSIUM AND PHOSPHORUS FERTILIZERS				To convert fertilizer amounts to elemental amounts multiply by
1) 2.86 3.03	Ammonium Nitrate [NH_4NO_3]	(X)	35 - 0 - 0 33 - 0 - 0	(pure salt) (technical)	0.350 0.330
2) 2.14 2.17	Urea [$CO(NH_2)_2$]	(X)	46.7 - 0 - 0 46 - 0 - 0	(pure) (technical)	0.467 0.460
1) 12.66 11.49	Super Phosphate or Mono Phosphate	(P_2O_5)	0 - 18 to 20 - 0	(technical)	0.079 0.087
[illegible]	Potassium Chloride		[illegible]		[illegible]

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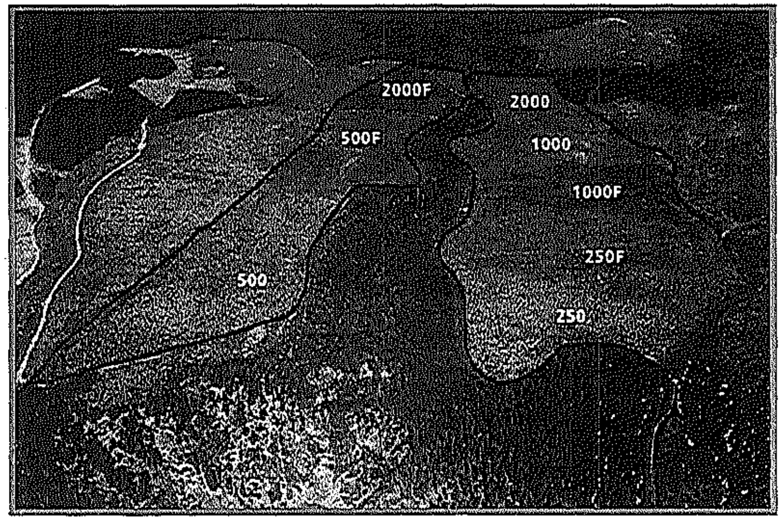
Handout:

Prof Weetman Oct/01 Forest nutrition lecture



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