RESPONSE OF INTERIOR SPRUCE TO FERTILIZATION IN THE INTERIOR OF BRITISH COLUMBIA

By

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ABSTRACT

In 1987, a research project, conducted in the interior of British Columbia, was undertaken in order to obtain preliminary fertilization response data for three interior species. In 1988, as part of this contract, 12 screening trials were established in young interior spruce stands in the north-central interior of B. C. using factorial combinations of nitrogen and "complete" mix fertilizer. Initial assessment of the unfertilized foliage obtained from the 12 installations indicated that all stands exibited low nitrogen and potentially low sulphur levels. After fertilization, the effects of the treatments were measured by needle weight response, nutrient concentration, and subsequent nutrient content response. In all 12 installations the largest needle weight response occured when the nitrogen and the "complete" mix fertilizers were combined.. In the treatments where nitrogen was applied alone, no significant change in needle size was recorded. Nutritionally, nitrogen fertilization resulted in large increases in nitrogen concentration, indicating this element was limiting. As well, nitrogen fertilization also produced large decreases in K, S, and S04-S concentrations. Nitrogen-only fertilization also caused large elevations in the N/S ratios to occur. This elevation in N/S ratios and the subsequent decreases in S and S04-S concentrations seem to indicate that nitrogen-only fertilization has a negative impact on the sulphur nutrition of interior spruce. The addition of the "complete" mix fertilizer was, in most cases, successful in returning the decreased nutrient concentration levels of K, S, and S04 and the elevated N/S ratios back to their original unfertilized status. From these results it appears that nitrogen fertilization of interior spruce should only be considered if it is accompanied by a mixture of other nutrients; the most important component being sulphur.

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INTRODUCTION

The focus of forest fertilization research in British Columbia has focused almost entirely on lodgepole pine (Pinus contorta Dougl. var latifolia Engelm.) (Brockley 1989). For other commercial interior species, the little information that has been collected has indicated that severe to very severe nitrogen deficiencies are common (Ballard 1982b). This information of a N deficiency may indicate that growth of these species could be improved by the addition of nitrogen. In the absense of fertilization growth response data, however, this prediction cannot be verified.

In 1987, Dr. G. F. Weetman (Faculty of Forestry, UBC) was contracted by the B.C. Ministry of Forests to undertake a research project with the objective to obtain preliminary fertilization response data for three Interior species - western larch (Larix occidentalis Nutt.), interior Douglas-fir (Pseudotsuga menziesii var. glauca [Beissn] Franco) and interior spruce (white spruce (Picea glauca [Moench] Voss) and Engelmann spruce (P. engelmanni Parry) or the naturally occuring hybrids of these species). Since so little was known about the nutrition or fertilization response potential of these species, a "screening" approach to the problem was selected. A similar "screening" approach was used successfully to gather preliminary response information for lodgepole pine (Weetman and Fournier 1982). For the 1987 project, a factorial design, using combinations of nitrogen and a "complete" mix fertilizer, was developed to obtain the appropriate information. The "complete" mix fertilizer was used to test whether nutrient deficiencies other than nitrogen affected the growth of these species. If the "complete" mix was found to be successful in stimulating tree growth above that achieved with nitrogen alone, then future studies would be designed to isolate the specific nutrient(s) responsible.

During the first year of the study, 10 fertilizer trials (4 interior Douglas-fir; 4 western larch; 2 interior spruce) were established in the southern interior of British Columbia. In 1988, a further 17 trials (12 interior spruce; 5 interior Douglas-fir) were established in the north-central interior of British Columbia. This thesis will evaluate the nutrient status and the fertilization response potential of the 12 interior spruce trials that were established during the second year of the project.

OBJECTIVES

The objectives of this study were to:

1. estimate the relative responsiveness of interior spruce to factorial combinations of nitrogen and a "complete" mix fertilizer by measuring the weight of needles formed during the first growing season following treatment;
2. document specific nutrients affecting the growth and fertilization response potential of young interior spruce by examining first-year foliar nutrient data in combination with vector analysis;
3. identify specific nutrients to be included in future conventional, fixed-area plot trials.

REVIEW OF WORK DONE TO DATE

Intensive forest fertilization research in the interior of British Columbia did not really begin until 1980, when a fertilization workshop was held in Kamloops, B.C. (Brockley 1991). Participants noted that silvicultural practices such as reforestation of backlog areas and proper species selection would have the greatest positive impact on forest yields in the B.C. interior over the long term. However, they also recognized that fertilization is one of the few techniques capable of producing gains in harvestable wood volumes from existing stands. Participants rejected the possibility of a large-scale operational fertilization program until the nutritional and environmental factors affecting the growth of interior tree species were better understood. They also recommended the development of a research program to determine the responsiveness of interior species to fertilizer application.

Forest tree and stand growth responses following nutrient additions have been well documented in the temperate and boreal forests of Scandinavia and North America (Krause et. al., 1982; Moller 1983a, Miller et. al., 1986). In some regions, large-scale operational fertilization is often considered to be an attractive silvicultural investment. In the interior of British Columbia, however, virtually nothing was known about the nutrition of interior forests until the late 1970's. At that time, Dr. T. M. Ballard (Dept. Soil Science, University of B.C.) began to gather foliar baseline data from various conifer species in the B.C. interior as part of his contract research for the Ministry of Forests, Research Branch (Ballard 1979, 1980, 1981, 1982a). His review of the data (Ballard 1982b) indicated that:

"Severe or very severe N deficiency is common. (Foliar N concentrations near or below 1 % are frequently found.) Slightly to moderate P and K deficiencies are diagnosed occasionally, but are probably seldom significant unless N deficiency is relieved. Low (possibly slightly deficient) Ca is encountered on very few sites. Although foliar S concentration is often low, S deficiency is rarely diagnosed, because the tree's demand is commonly limited by N deficiency. Hence, it is often suspected that N fertilization could induce S deficiency in some parts of the interior. Low (but probably not deficient) Mg is encountered sometimes. Fe deficiency is diagnosed surprisingly often, and not only on well drained soils of high pH. Low (presumably deficient) Zn seems fairly common in western hemlock east of Prince George... Foliar Cu is often low and may well be deficient. Foliar B data in the interior have not yet indicated a clear and present deficiency... Mn is sometimes near deficiency levels on well drained, calcareous soils, but has not yet been found at low enough levels to indicate a definite problem for plant growth. So far, we lack the data to evaluate Mo status in interior forests."

However, in the absence of fertilization growth response data, these deficiencies and predictions could not be verified.

Lodgepole pine has been the subject of most of the forest fertilization research undertaken to date in the B. C. interior. Research studies elsewhere have shown this species to respond well to fertilization (Weetman et. al., 1985; Weetman 1988; Yang 1985a, 1985b; Cochran et. al., 1981) The bulk of the B.C. research has been directed towards young (ie., 15 to 30 years of age), thinned stands (Brockley 1991). Fertilization of older, semi-mature stands is generally regarded to be more economically attractive since earlier harvest reduces carrying charges on the investment. However, due to the very high densities of natural regeneration following "disturbance" (either natural or artificial) and its slow rate of self-thin, the older, previously unmanaged high-density stands tend to exibit high rates of mortality and low crown ratios and thus provide a lower potential for fertilization response (Brockley 1991).

Emphasis is placed on thinned lodgepole pine stands because the growth stimulation due to the application of fertilizer in thinned stands is not constrained by crown growing space and fertilizer is not wasted on trees that will die. This growth stimulation accelerates mortality, resulting in a reduction in net treatment response (Brockley 1991). Also, when a stand is fertilized with nitrogen, the effect tends to be an increase in both foliage mass and photosynthetic efficiency (Miller and Miller 1976, Brix 1983). Thus, the thinned stand, with its improved light conditions and room for crown expansion, tends to respond to fertilization more favourably than unthinned stands.

A two-pronged approach was adopted in the planning and implementation of fertilization research in the B. C. interior. The first phase of this program was to establish a network of fertilizer screening trials. These fertilizer screening trials use a number of replicated "single tree" or "micro" research plots which, when sampled for needle weight and foliar nutrient responses, provide rapid identification of nutrient deficiencies and the fertilization response potential of the stand. Many studies have documented a positive relationship between first-season increases in needle weight and subsequent stemwood response (Weetman and Algar 1974, Camire and Bernier 1981, Timmer and Morrow 1984, Weetman et al 1988, Brockley 1989).

Efficient screening trials are inexpensive to establish and require less site and stand uniformity than other types of trials. Therefore, a large number of forest stands can be tested over a short period of time. Because so little nutritional information was available for interior forests, this technique was generally acknowledged as the most appropriate method of beginning fertilization research in the B. C. interior (Brockley 1991). By testing a variety of nutrient regimes, these screening trials can be used to identify appropriate fertilizer treatments. These treatments can then be included in the more expensive second phase of the operation - conventional growth and yield research using permanent sample plot installations (Brockley 1991).

In 1980, Dr. G. F. Weetman (Faculty of Forestry, University of B. C.) established 25 of these screening trials - 17 in lodgepole pine, seven in interior Douglas-fir and one in white spruce - on a variety of sites in juvenile- spaced stands ranging in age from nine to 40 years. The trials were established to: 1) test the responsiveness of the stands to nitrogen, phosphorus, and potassium singly and in combination, and 2) explain the reasons for the response, or lack of it, by means of foliar diagnosis (Weetman and Fournier 1982). The selection of these three elements, in particular N, was due to the results of numerous fertilization trials in Scandinavia and North America. These studies clearly indicate that nitrogen is the nutrient which most extensively limits the growth of northern temperate and boreal forests growing on mineral soil within the glaciated region.

The results obtained from these screening trials indicated the variable responsiveness to N additions. For example, eight of the 17 lodgepole pine stands were moderately to very responsive to nitrogen additions: the remainder were weakly responsive or unresponsive. Lodgepole pine was generally unresponsive to P and/or K additions. The Douglas-fir and white spruce stands were generally unresponsive to fertilization despite severe nitrogen deficiencies. Weetman and Fournier (1981) suggested that this lack of response could possibly be due to moisture limitations and/or vegetation competition. Weetman et. al. (1988) subsequently reported that the 4-year basal area response of the lodgepole pine trials generally agreed with the predictions based on first-season needle weight response.

With the availability of the short-term nutrient response information obtained from the screening trials, the second phase of the Interior Forest Fertilization program was implemented. This phase involved the establishment of conventional trials. Conventional trials are permanent plots established and measured at the start of an investigation and remeasured at regular intervals over subsequent years, providing an estimate of total stand area response (ie., $m^3 \cdot ha^{-1}$ of extra wood produced) (Brockley 1991). This information is required to support and rank forest fertilization investments in the interior of B. C.. Conventional trials also provide the means by which techniques such as foliar analysis, screening trials, etc., can be be calibrated in order to improve the predictive and interpretative value of these techniques. Unfortunately, conventional trials are expensive to establish and remeasure. It is also often difficult to find uniform stands and sites that are large enough to accomodate sufficient treatment replication (Brockley 1991).

Between the years 1981 and 1983, 11 such conventional field trials were established in young, juvenile spaced, lodgepole pine stands throughout the southern and central portion of the B.C. Interior. The treatments tested involved three different levels of nitrogen - 0, 100 and 200 $kg \cdot ha^{-1}$ applied as urea (46-0-0). Three-year results from this study indicated that, on average, lodgepole pine tree and stand increment were increased substantially by nitrogen fertilization (Brockley 1989). The results also confirmed the tentative nitrogen deficiency diagnosis for lodgepole pine that had been previously indicated by foliar analysis and screening trials. However, the fertilization response was quite variable, and foliar anlaysis data showed that reserves of nutrients other than nitrogen, although generally adequate to balance native supplies of N, may sometimes be inadequate to sustain or enhance growth following N fertilization. Of these other nutrients, sulphur and boron deficiencies, either induced or aggravated by nitrogen fertilization, appeared to be the most common and widespread (Brockley 1989). With this information, an additional four trials were established to test the effect of N with and without the addition of sulphur, as well as with or without the addition of boron - on the growth of lodgepole pine. The accumulated evidence indicating nitrogen-induced sulphur and boron deficiencies was summarized by Brockley 1990a.

In 1982, Dr. G. F. Weetman established a lodgepole pine "optimum nutrition" research trial near Okanagan Falls, B.C.. The trial was established in a naturally regenerated, 9-year-old, recently thinned lodgepole pine stand. The objectives of the study were to : 1) determine the potential productivity of lodgepole pine growing under optimum nutrient regimes, and 2) identify specific foliar nutrient concentrations associated with maximum stand growth. The plots are fertilized periodically to maintain desired foliar nutrient concentrations. The five-year basal area response indicated that plots fertilized repeatedly with relatively large amounts of nitrogen and a "complete mix" fertilizer responded extremely well. Those that received N without the "complete mix" responded poorly (Estlin 1988). Foliar analysis conducted seven years after initial treatment showed extremely high N/S ratios in the N - only treatments indicating that N additions may have induced a sulphur deficiency on this site (Brockley 1990a).

Until recently, research into the nutrient status and fertilization growth response potential of species other than lodgepole pine in the B. C. interior has been limited. As mentioned previously, screening trials in seven young interior Douglas-fir and one white spruce stand generally responded poorly to fertilizer applications (Weetman and Fournier 1981). However, fertilization research undertaken in the Intermountain region of the United States indicates that Douglas-fir is generally responsive to nitrogen fertilization (Scanlin and Loewenstein 1981, Moore 1988, Shafii et. al., 1989). As well, Ballard and Majid (1985) found a significant response to foliar-applied iron and nitrogen in Douglas-fir on a calcareous site near Kamloops, B. C. On the coast of British Columbia, coastal Douglas-fir has responded well to the application of nitrogen as well as to the combination of thinning and fertilization (Barclay et. al., 1982, Lee and Barclay 1985).

Results from a small number of fertilization research trials in Alaska, Alberta, and eastern Canada indicate that white spruce exibits considerable variability in its response to nutrient additions (Van Cleve and Zasada 1976, Krause et. al.. 1982, Weetman et. al.. 1987). In eastern Canada, the Interprovincial white spruce trials generally produced no response when stands were treated with N, P, and K, nor with combinations of the three. External factors, such as Budworm infestation in New Brunswick and very high site productivity in Nova Scotia, were considered to be the contributing factor to this lack of response (Krause et. al.,. 1982). Of the Interprovincial trials, only in Alberta were growth responses to fertilization significant. These Alberta stands responded well to nitrogen additions, with the highest application of nitrogen increasing total volume by an average of 35 percent over a five-year period. When nitrogen was applied at a low rate, and in combination with phosphorus and potassium, growth response was not significantly different from that of the control.

In Quebec, white spruce installations at Grand ' Mere have shown significant growth response to potassium fertilization (Gagnon et. al., 1976; Truong Dinh Phu and Gagnon 1975). The greatest response was obtained when potassium was combined with nitrogen, suggesting that nitrogen did have some effect on growth. The response to potassium in this Quebec installation verified nutrient deficiencies diagnosed by Lafond (1958) as well as those researchers who documented potassium deficiencies on sandy, outwash plains in Quebec (Linteau1962; Paine 1960; Swan 1962) and New York State (Heiberg et al. 1959, 1964; Heiberg and Leaf 1961; Leaf 1968; Stone and Leaf 1967).

In northern Ontario, Morrison and Foster (1979) found that mixed stands of white spruce, black spruce, and balsam fir generally had a poor response to fertilization. They found that when nitrogen and phosphorus were applied alone, both had a depressing effect on growth, the amount of growth reduction being directly related to the application rate. When these two nutrients were combined, however, the reverse situation occurred. The lack of statistically significant growth response and apparent depressing effects of some treatments on growth, may have been partially due to the large variability in species composition within and between treatments since responses were largely attributed to balsam fir and not to white spruce (Morrison and Foster 1979).

In Alaska, combined thinning and fertilization treatments of white spruce resulted in a greater mean basal area increment per tree compared to the control (Van Cleve and Zasada 1976). However, while individual trees in the thinned and fertilized treatments responded well, absolute growth response measured on a per hectare basis would probably be less than that obtained in a control due to the lower stocking levels in thinned stands..

In Great Britain, fertilization has been successful in improving the growth of Sitka spruce (Picea sitchensis [Bong.] Carr). On moorland and heathland soils, nitrogen deficiency restricts tree growth. Until the 1970's this N deficiency was thought to result from competition from heather. However, increased planting of Sitka spruce on very nutrient-poor soils revealed that, even after removal of heather by herbicide treatment, growth was still limited by low availability of nitrogen. The possible causes of this low availability of N were limited soil nitrogen capital and/or slow rate of nitrogen mineralization. It was found that applications of nitrogen fertilizer could overcome this deficiency, although it was suggested that several applications may be required to achieve full canopy closure when nutrient demands are reduced (Taylor and Tabbush 1990).

In Scandinavia, it has been found that nitrogen tends to be the only nutrient that gives a significant positive growth response to Norway spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.) forest stands (Moller 1982). Pettersson (1984) found, after establishing nitrogen trials in young stands of Scots pine and Norway spruce, that in young stands it is probably the biomass of roots and needles that is the determining factor for how much nitrogen can be taken up and utilized by the trees. This means that the capacity of a young stand to take up nitrogen gradually increases at the same time as there is an increase in the needle and root biomass with the maximum capacity being reached at canopy closure. However, there could be other factors such as restricted availability of specific nutrients, eg. S and B, that could also be limiting growth. For example, it has been found that Scots pine and Norway spruce forests established on peatlands commonly suffer from boron deficiencies (Braekke 1979, 1983a; Veijalainen et. al., 1984). It has also been found that on mineral soils, boron deficiencies may be induced or aggravated by nitrogen fertilization (Aronsson 1983; Braekke 1983b; Moller 1983b). Research into this aggravation of the boron problem has demonstrated that growth disturbances can generally be alleviated by boron application. It is thus recommended that, in Sweden, boron be mixed with nitrogen when fertilizers are applied north of 60 degrees lattitude (Moller 1983b).

Although the fertilization response potential of interior spruce in the B.C. interior has not been well documented, foliar nutrient concentration data indicate that nutrient deficiencies may be common in interior spruce plantations (Ballard 1986, Ballard and Hawkes 1989). Several nutritional problems (notably N, Fe, and Cu) appear to be more prevalent on sites where burning or mechanical site preparation have been undertaken (Ballard and Hawkes 1989). In many cases, foliar data indicate that S may become growth-limiting following nitrogen fertilization.

Prescribed burning and mechanical site preparation are commonly used in the B. C. interior to facilitate planting and to enhance survival and early growth of interior spruce plantations. Reduced vegetation competition, warming of exposed mineral soil and an increase in nutrient availability may create a favourable environment for newly established seedlings (Feller 1982; McMinn 1982; Ballard and Hawkes 1989). Unfortunately, site preparation may be detrimental to tree nutrition. Scalping or burning of the nutrient-rich surface organic layer may result in significant loss of many nutrients, especially nitrogen and sulphur (DeBell and Ralston 1970; Tiedemann and Anderson 1980; Morris et. al., 1983). Also, the solubility of Fe and Cu may be reduced due to higher soil pH after burning (Tarrant 1954; Mortvedt et. al., 1972). Although short-term benefits may be achieved by a particular treatment, a reduction in soil nutrient capital and tree nutrition may have a negative impact on the long-term productivity of some sites.

Whether the beneficial effects of site preparation on seedling survival and growth outweigh the negative impacts on tree nutrition will depend on the severity of the treatment, the nature of the surface organic layers and underlying mineral soil and the soil temperature (determined by elevation). Ballard and Hawkes (1989) reported that although nutrition tended to be poorer, height growth tended to be better where burning had been done. However, their data implied that growth would be further enhanced if the nitrogen deficiencies were relieved. This possibility must be tested by establishing a series of fertilizer trials in interior spruce plantations throughout the B. C. interior.

METHODS AND MATERIALS

Study area

The study area is in the central interior of British Columbia. Included is the northern portion of the Interior Plateau physiographic region (i.e., Fraser Basin and Nechako Plateau) and the southwest portion of the Central Plateau and Mountain physiograhpic region (i.e., Nass Basin) (Holland 1964). Within this large geographic region, 12 young (less than 20 years of age) stands of white spruce , or its naturally occuring hybrids - Engelmann spruce x white spruce and Sitka spruce x white spruce, - were selected for experimental fertilization. These stands were selected according to the following criteria:

1. The stand had been planted or thinned;
2. Homogeneous site and stand conditions;
3. Stand area was a minimum of 6 ha `in size.

The 12 experimental stands are in two Biogeoclimatic Zones; the Interior Cedar-Hemlock (ICH) and the Sub Boreal Spruce (SBS). Moisture and vegetation differences occur between these stands due to the large geographic area.

The four study sites established in the ICH are located just east of the Coast Mountains within the Hazelton variant of the Northwestern Transitional Subzone (ICH mc) (Haeussler et. al., 1985). A coastal influence, created by warm, moist air from the Pacific Ocean flowing up the valley of the Skeena River, tends to moderate the predominantly continental climate of this region. The Hazelton variant itself is characterized by relatively dry, cold winters with light, dry snowpack and a short frost - free period. The summers tends to be warm and relatively dry with significant summer drought (Haeussler et. al., 1985). The spruce stands growing under these conditions are characterized by forests comprising a white spruce x Sitka spruce hybridization.

The remaining eight study sites are located further to the east in the SBS Biogeoclimatic Zone. The climate of this zone is continental. It is characterized by seasonal extremes of temperature, has severe, snowy winters, relatively warm and short summers, and relatively low annual precipitation (Meidinger and Pojar 1983). Of these eight SBS sites, three lie within the Babine Lake variant of the moist, cool Central SBS subzone (SBSmc), two lie within the dry warm Southern SBS subzone (SBSdw), and three lie within the wet cool Central SBS subzone (SBSwc).

Detailed site and stand descriptions of the 12 study sites, as well as approximate locations, are given in Tables 1 and 2, and on the map of locations presented in Figure 1.

Experimental Design and Field Procedures

The micro-plot screening trial technique was used in each of the candidate stands. This technique includes a number of stages. The initial stage, occurring in the spring, involves the rapid establishment and fertilization of a number of small-radius plots. The plot size should be large enough to ensure adequate coverage of the rooting system by the applied chemical. The second stage, occuring in the fall, involves the collection of current years foliage. In the final stage, the foliage is weighed and analyzed. From this analysis, the nutritional status of the stand can be diagnosed by evaluating shifts in nutrient concentration, content, and needle weight (Weetman and Fournier 1982).

Each of the screening trials was designed as a 3X2 factorial experiment using three levels of nitrogen (0, 100 and 200 $kg{\cdot}ha^{-1}$ as ammonium nitrate) and two levels of granulated "complete" fertilizer mix (0 and 1170 $kg.ha^{-1}$). The "complete" fertilizer mix was designed to deliver ($kg{\cdot}ha^{-1}$): P-99, K-102, Ca-129, Mg-51, S-50, Fe-9, Zn-3.5, Mn-3.7, Cu-1.5, B-1.5 and Mo-1.0. Each of the six treatments was applied to ten 6-m radius micro-plots (Figure 2) arranged in a completely randomized design. The plots were located along a number of transect lines established on a bearing parallel to the slope of the terrain and or perpendicular to the forest access road (Figure 3).

Normally, the first plot on each transect line was at least 10 m from the access road and the subsequent plots placed about every 20 m thereafter. A representative-sized dominant tree was selected at the centre of each plot. Trees with visible defects (i.e., multiple tops, scars, weevil damage, etc.), large openings, skid trails and stream areas were avoided during the selection process.

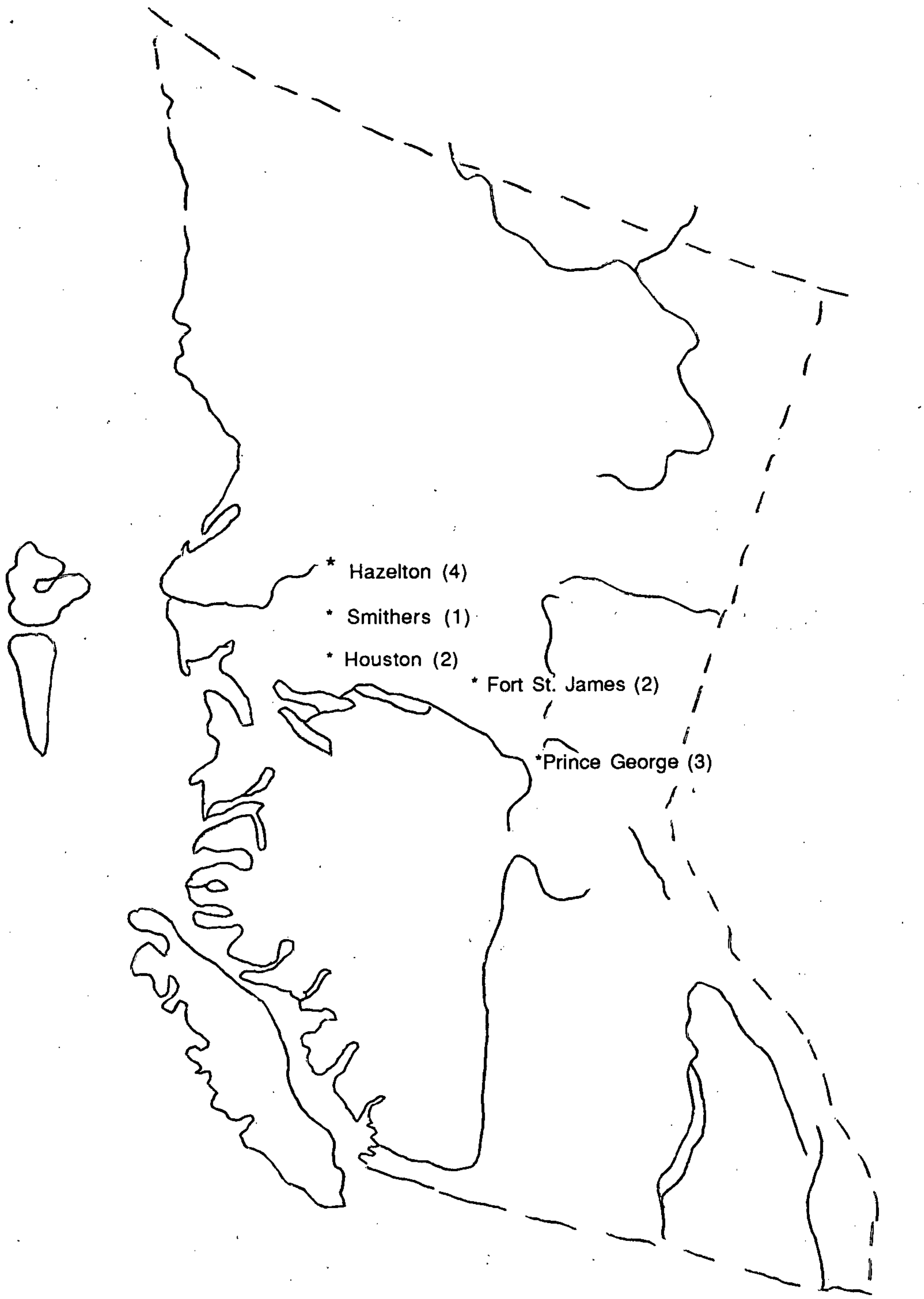


Figure 1. General location of the 12 experimental interior spruce installations.

Table 1: Location, biogeoclimatic classification and stand characteristics of experimental spruce stands

Installation No	Location	Forest District	Biogeo-climatic Subzone	Ecosystem Association	Average age (years)	Average diameter (cm)	Average height (m)
1	Kitsequecla	Kispiox	ICHg3	01.1(a)	19	7.37	4.94
2	Robinson Lake	Kispiox	ICHg3	0.8	17	5.09	3.65
3	Muldoe Creek	Kispiox	ICHg3	01.1(a)	20	6.20	4.33
4	Date Creek	Kispiox	ICHg3	O1	20	8.52	5.83
5	Betty Lake	Morice	SBSel	O1	17	3.56	2.99
6	Chapman Lake	Bulkley	SBSel	O1	15	6.56	4.60
7	Camp Lake	Fort St. James	SBSk3	O4	16	3.17	2.87
8	Jumping Lake	Fort St. James	SBSk3	O6	15	3.44	3.00
9	Andrew Bay	Morice	SBSel	O4(a)	14	3.49	2.92
10	Bowron km 36	Prince George	SBSj1	O7	18	4.91	3.67
11	Bowron km 42	Prince George	SBSj1	O7	15	7.10	4.59
12	Hwy 16	Prince George	SBSj1	O1	20	5.21	3.71

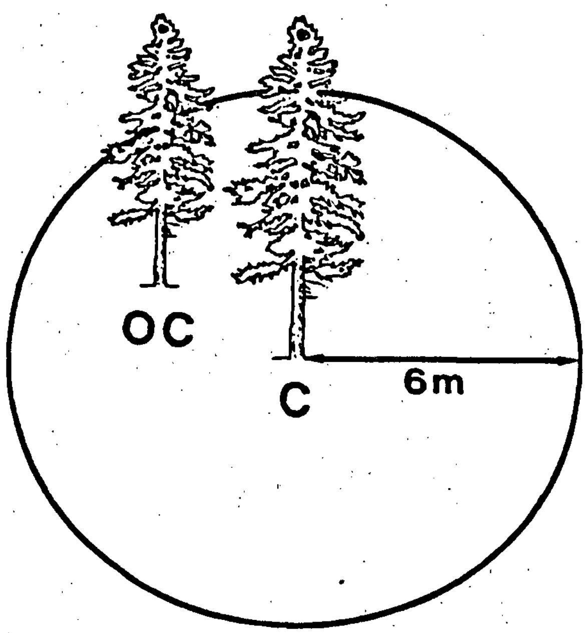
Table 2: Soil classificatiion and information for the 12 interior spruce experimental stands.

Installation No	Location	Soil Classif. *	Landform *	Drainage	Soil Texture	Rooting depth (cm)	Restricting layer depth (cm)
1	Kitsequecla	E.DYB	Mb	Mod. well	vfSL/Sil	30	40
2	Robinson Lake	E.DYB	CxMb	Rapid	LS	40+	Nil
3	Muldoe Creek	E.DYB	sMb	Well	SL	40	35
4	Date Creek	O.HFP	gMb	Well	SL	35	Nil
5	Betty Lake	E.DYB	Mb	Well-Mod.well	SL/L	30	Nil
6	Chapman Lake	O.HFP	gFgb	Rapid	LS	50+	Nil
7	Camp Lake	O.R	sgMb	Well	SL	30	Nil
8	Jumping Lake	O.DYB	FxMb	Well	SL	25	Nil
9	Andrew Bay	O.HFP	gMb	Rapid	SL/LS	50+	Nil
10	Bowron km 36	GLBR.GL	cMb	Mod. Well	CL/C	35	Nil
11	Bowron km 42	GL.HFP	sLb	Mod. Well	S	40	Nil
12	Hwy 16	GL.GL	cMb	Mod. Well-imperf	CL/C	20	28

* CSSC 1987

The fertilizer was hand - applied in the spring, before bud flush, using small 1.66-kg plastic bags of ammonium nitrate and 1.86-kg bags of the "complete" mix. These bags of were premeasured and packaged before going into the field. Two 1.66-kg bags of ammonium nitrate represented 100 kg N·ha^{-1} of and seven 1.89-kg bags of chemical represented 1170 kg·ha^{-1} of "complete" mix.

Upon completion of the fertilization, an off-centre tree was selected in each plot approximately 3 m away from the "centre" tree. Since these plots were to be permanently located, the centre and off centre tree were tagged and painted at DBH, with height and DBH measurements recorded. In all cases, the exact location of each plot was recorded on a map using prominent tie points.



C - Centre
OC - Off-centre
Figure 2. Diagrammatic representation of a micro-plot with a 6 metre radius.

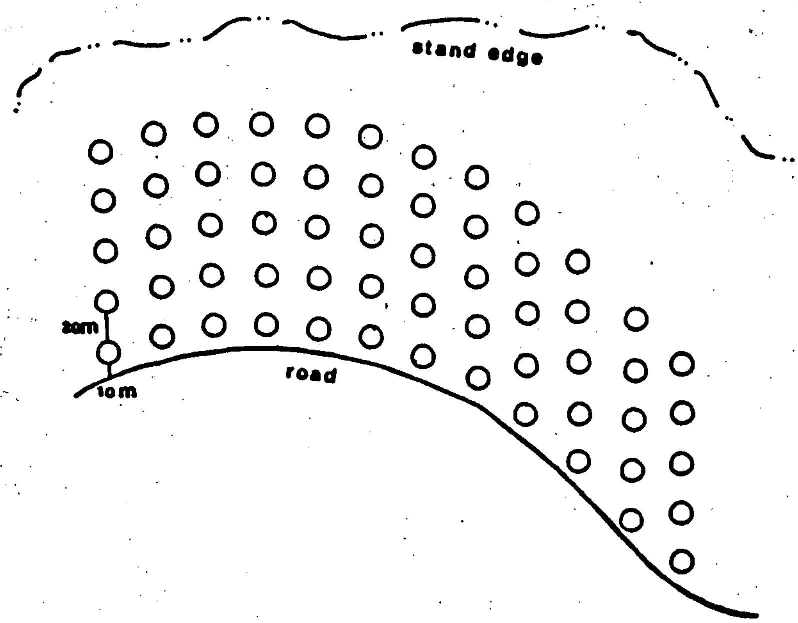


Figure 3. Typical layout of experimental plots in a plantation.

Foliar Sampling

The fertilization response was determined by analyzing fall collected (September) foliage samples obtained from each of the centre and off-centre trees for all the plots. The samples were taken from 1/4 to 1/3 of the distance from the top of the tree, collecting only the current year's foliage from two branch ends per tree (Ballard and Carter 1986).

The foliage collected from the centre and off-centre trees of each plot were bulked together to produce 60 foliage samples per installation. The composite samples were frozen (-20 ^{0}C) and subsequently oven-dried at 70 ^{0}C for 24 hours. The dry mass of 500 randomly-selected needles was measured and recorded for each composite sample.

Analysis of Foliage

The 10 composite samples for each treatment were randomly divided into two groups to produce two composite samples per treatment for chemical analysis. Each composite sample consisted of equal amounts of foliage from each of the individual samples. The 12 composite samples per installation were ground and then sent to MacMillan Bloedel's Environmental

Laboratory in Nanaimo B. C, where they were analyzed for N, P, K, Ca, Mg, total S, Sulphate-S, Mn, Cu, Zn, B, total Fe and active Fe. The N, P, K, Ca, Mg, Fe, Cu, Zn, and Mn analyses were done by digesting the ground foliage using a variation of the sulphuric acid-hydrogen peroxide procedure described by Parkinson and Allen (1975). The digests were analyzed colorimetrically for N using the Berthelot (phenol-hypochlorite) reaction (Weatherburn 1967) in a Technicon Autoanalyzer II. A spectrophotometer was used for the determination of P, using a procedure based on the reduction of the ammonium molybdiphosphate complex by ascorbic acid (Watanabe and Olson 1965). Total Ca, Mg, K, Fe, Cu, Zn and Mn were measured by atomic absorption spectrophotometry (Price 1978). After dry ashing, boron (B) was determined by the azomethine H colorimetric method described by Gaines and Mitchell (1979). Sulphur was determined with a Fisher Sulphur Analyzer, using the procedures of Guthrie and Lowe (1984). Sulphate-sulphur was extracted with 0.1 N HCL followed by colorimetric determination using the procedure of Johnson and Nishita (1952). Active Fe was determined by a modification of the method of Oserkowsky (1933) using HCL extraction and atomic absorption spectrophotometry. Active Fe is considered to be a more reliable indicator of a tree's Fe status than total Fe (Zech 1970).

Statistical Analysis

For each installation, the effect of the factorial combinations of nitrogen (three levels) and complete mix (two levels) on needle mass and nutrient concentration were examined by means of a two-way analysis of variance conducted on the University of British Columbia main frame computer using the Genlin Statictical package.

The two-way analysis of variance conducted on the needle mass used the recorded mass for all 60 plots per stand. This produced an ANOVA table with the following components:

Source of Variation	Degrees of Freedom	
Treatment	5	
Nitrogen		2
Complete Mix		1
N X C		2
Error		54
Total	59	

The individual nutrient concentration data was obtained from only 12 composite samples per installation. Therefore, the appropriate ANOVA table is as follows:

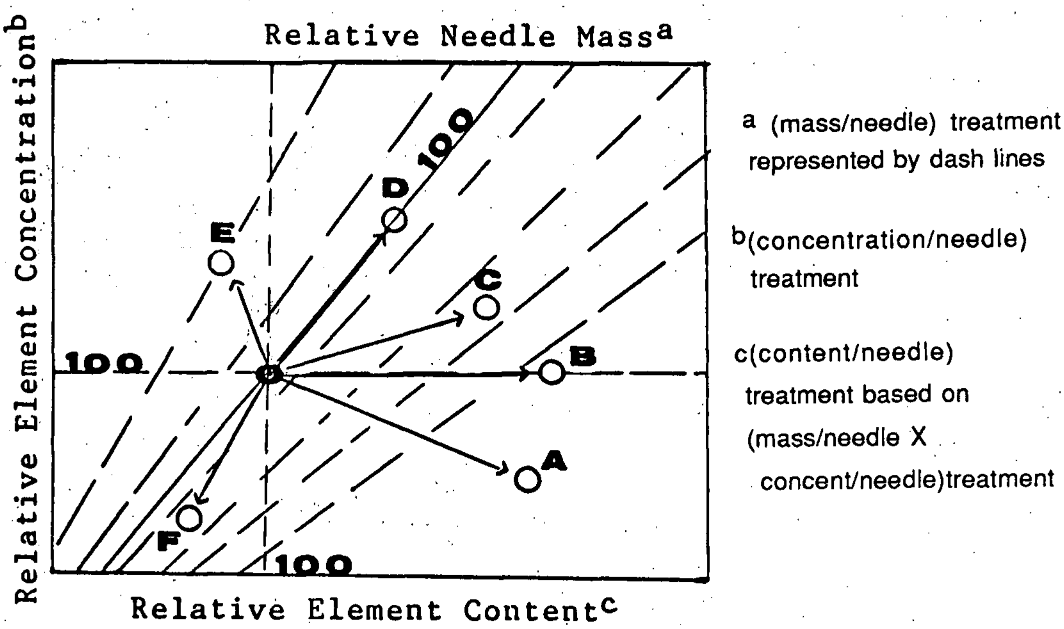
Source of Variation	Degrees of Freedom	
Treatment	5	
Nitrogen		2
Complete Mix		1
NXC		2
Error	6	
Total	11	

Comparison of individual treatment means were made using the technique of Least Significant Difference (Steel and Torrie 1980). Differences in needle weight response between specific treatments or combination of treatments were tested by selecting, a priori, a number of single degree-of-freedom contrasts. A probability threshold of $p = 0.05$ is used throughout the text for inferring statistical significance.

Fertilizer Response Prediction

The foliar graphical diagnosis technique was used to interpret needle weight, nutrient concentration, and nutrient content data obtained from the graph for a specific element by the technique first employed by Krause (1965, 67) and further refined by Timmer and Stone (1978) and Weetman and Fournier (1982). Since then, this technique has been successfully used to evaluate the nutritional status of different forest stands (Carter and Brockley 1990) as well as the nutritional status of seedlings (Timmer and Armstrong 1987; Timmer and Teng 1990) This foliar graphical diagnostic technique is based on two assumptions: (1) the dry weight of individual needles is closely correlated with fertilizer growth response and (2) that needle number is fixed in the first season following fertilization (Timmer 1979). The graphs are constructed by plotting relative foliar concentration of a given element on the y-axis, the relative content per needle on the x-axis and a series of diagonal lines from the origin representing relative unit needle weight (Figure 4). The use of relative values enables multiple stand or multiple nutrient comparisons to be made. The basis for interpretation revolves around the position of the treated plots in relation to the control (O symbol at point 100,100 in Figure 4). For example, any points falling in the sectors above or below the control needle weight line (100 line) would indicate a loss or gain, respectively, in relative needle dry weight in comparison to the control. The direction and magnitude of the resulting changes in all three parameters can be described by a single arrow (Figure 4) which forms the basis of the diagnosis system (Timmer 1979). The interpretation may apply either to the different nutrients added as treatments or to any others.

The shifts presented in Figure 4 , according to Timmer (1979), represent the following. The shift towards A (arrow in Figure 4) signifies decreasing concentration but increasing needle weight and content, hence, the supply of the nutrient has been diluted by additional growth (false antagonism). This suggests that the specific nutrient under question is not the major limiting nutrient, unless associated with the "Steenbjerg effect" (Steenbjerg 1954). The outward horizontal shift towards B represents the boundary case whereby weight and content increase without change in concentration - this could be the result of nutrient transport into the foliage being just sufficient to keep pace with the expansion of the shoots or needles or redistribution within the plant. The shift towards C signifies an increase in both nutrient concentration and needle weight. If this element was added, it could imply that the initial level of this element was limiting, for non-added elements, it would illustrate a synergistic effect on the ion applied (Smith 1962). The shift towards D results from the increased accumulation of the element without any gain in needle weight, perhaps indicating luxury consumption. The shift towards E results from the increase in concentration in combination with a reduction in needle weight, thus indicating toxic accumulation, unless associated with some other growth constraint. Finally, the shift towards F results from the depression of nutrient concentration and content in the presence of an increase or decrease in needle dry weight. This is a deficiency induced by the treatment, thus indicating a true antagonism.



Direction of shift	Response in: Needle weight	Response in: Nutrient Conc.	Response in: Nutrient Content	Nutrient status	Possible diagnosis
A	+	-	+	Dilution	Non-limiting
B	+	0	+	Unchanged	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic
E	-	++	+ -	Excess	Toxic
F	+ -	-	-	Excess	Antagonistic

Figure 4. Interpretation of directional relationships between foliar concentration, nutrient content and dry weight of needles following fertilization (after Timmer and Morrow 1984).

3

RESULTS AND DISCUSSION

Response data from this study are presented sequentially, starting with an examination of the nutrient composition of foliage observed in the control or unfertilized trees. These data are followed by an assessment of foliar responses of the fertilizer treatments. Since all of the nutrients were applied as a combined fertilizer (with the exception of N) and not applied singly, their effect on the growth of interior spruce is speculative. This section will, however, indicate specific nutrients which appear to have the most significant impact on the growth of interior spruce.

Nutritional Status of the Unfertilized Stands

The unfertilized foliar concentration levels for all 12 interior spruce installations are summarized in Table 3. The foliar standards for white spruce that were suggested by Stone (1968), Timmer (1979), Ballard and Carter (1986), Allen (1987), Brand and Janas (1988), and Taylor and Tabbush (1990) indicate some nutritional concerns. The primary element of concern is nitrogen. According to the above mentioned authors, the adequate range for nitrogen lies between 1.50 and 2.37 (percent dry mass). The range of N determined for the 12 interior spruce installations was 0.99 to 1.26 (percent dry mass) (average being 1.08) (Table 3), suggesting that foliar concentration levels of nitrogen are severely deficient.

Despite favourable growth performance, Ballard and Hawkes (1989) reported that interior spruce plantations that had been established on broadcast burned sites also exhibit severe nitrogen deficiencies. However, David et. al. (UBC faculty of Forestry unpublished1987) suggested that while N levels were low on burned sites at higher elevations, environmental factors, such as soil temperature and moisture regime, were the primary cause. Since all 12 spruce installations were established on sites that had been burned, a nitrogen deficiency was not unexpected.

While the sulphur levels appear to be adequate to balance the amount of nitrogen present in the stand, an application of nitrogen may induce a deficiency (Ballard and Carter 1986).

Table 3. Initial interior spruce mean foliar nutrient concentration prior to fertilization.

				%							ppm			
Installation	N	P	K	Ca	Mg	S	Mn	Fe	A-Fe	Cu	B	Zn	SO4-S	N/S
Kitsequecla	1.20	0.22	1.00	0.55	0.12	0.096	868	32	23	1.5	20	32	206	13
Robinson L.	1.04	0.21	0.99	0.45	0.10	0.097	563	106	18	3	19	43	237	11
Muldoe	0.99	0.19	0.79	0.51	0.12	0.087	877	31	16	2	19	45	230	11
Date Creek	1.11	0.21	0.98	0.51	0.10	0.097	697	25	19	0.5	15	47	268	11
Betty Lake	0.86	0.20	0.72	0.43	0.09	0.076	216	35	17	1.5	16	41	170	11
Chapman Lake	1.09	0.19	0.72	0.53	0.10	0.087	371	71	21	2	14	41	127	13
Camp Lake	0.93	0.20	0.68	0.63	0.10	0.082	352	20	16	2	19	50	182	11
Jumping Lake	1.16	0.20	0.74	0.53	0.09	0.086	524	17	21	3	16	59	133	13
Andrew Bay	0.96	0.20	0.76	0.36	0.10	0.075	273	95	16	3.5	11	34	117	13
Bowron km 36	1.26	0.23	0.81	0.52	0.10	0.095	578	35	22	2	17	60	106	13
Bowron km 42	1.25	0.24	0.65	0.46	0.10	0.103	566	70	38	0.5	17	50	82	12
Hwy 16	1.05	0.19	0.72	0.56	0.11	0.088	514	22	15	2	18	59	118	12
Mean	1.08	0.21	0.80	0.50	0.10	0.089	533	47	20	2	17	47	165	12

The remaining two nutrients which appear to have levels low enough to cause concern are copper and active iron. The critical foliar Cu levels suggested by Brand and Janas (1988) for white spruce (ie., 2.9 to 3.3 ppm) indicate that the majority of the 12 spruce installation are low in this nutrient. These low values may not be due to an actual copper deficiency in the soil, however, but rather may be due to a problem with the sensitivity limits of the analysis conducted on the foliage sample. The only information available for adequate levels of active iron is found in Ballard and Carter (1986), where it suggests that levels below 30 ppm indicate a possible deficiency. It is important to note that although the active Fe levels appear to be low, there is very little fertilization response information available to verify the tentative levels presented for this nutrient.

The remaining macronutrients (ie., P, K and Ca) and micronutrients (Fe, B, Mn, Zn, etc.) appear to be adequate. For the nutrient K, the levels found in the 12 installations are higher than the levels presented in Ballard and Carter (1986) (ie., levels this high are not even recorded) and are classified as optimum by Czapowskyj et. al.,(1986). The high levels recorded for Ca are also not presented in Ballard and Carter (1986), although, according to Brand and Janas (1988), the levels of Ca found in the 12 installations are adequate (ie., fall within the adequate level range of 0.49 to 0.58 percent dry mass).

Response to Fertilization

Needle Weight

In all 12 installations, fertilization had a highly significant effect on the weight of needles formed during the first growing season after treatment (Table 4) (Figure 5). When applied singly, nitrogen and the "complete" mix fertilizer had little effect on needle weight. In the case of the N200 treatment, comparisons using LSD show that this treatment resulted in no response in needle weight whatsoever. The statistics, presented in Table 5, indicate that in all 12 installations the main effects of "nitrogen" and "complete mix" were significant. From this it can be concluded that differences in needle weights occured when different levels of nitrogen and different levels of "complete mix" fertilizer were added.

Table 4 : Summary of needle weights (g/1000 needles) and their corresponding relative values (Relative to control=100)for the 12 interior spruce experimental stands

Installation No	Location	Control	N0+C	N100	N100+C	N200	N200+C	LSD
		Treatments						
1	Kitsequecla	6.70 (100)	6.24 (93)	7.52 (112)	8.48 (127)	6.32 (94)*	8.10 (121)	1.15
2	Robinson Lake	5.87 (100)	7.40 (126)	7.50 (133)	7.79 (133)	6.92 (118)	7.97 (136)	1.16
3	Muldoe Creek	5.82 (100)	5.25 (90)	6.31 (108)	7.60 (131)	5.98 (103)*	7.71 (132)	0.92
4	Date Creek	5.59 (100)	5.63 (101)	6.40 (114)	7.40 (132)	5.87 (105)*	7.75 (139)	1.02
5	Betty Lake	4.82 (100)	4.98 (101)	5.68 (118)	6.64 (129)	5.18 (107)*	7.44 (154)	0.78
6	Chapman Lake	6.11 (100)	6.24 (102)	6.91 (113)	7.52 (123)	6.56 (107)	7.08 (131)	1.05
7	Camp Lake	4.40 (100)	4.83 (110)	5.81 (132)	6.51 (148)	5.01 (114)	7.20 (164)	0.96
8	Jumping Lake	4.73 (100)	4.80 (101)	5.62 (119)	6.51 (138)	4.53 (96)*	6.73 (142)	0.83
9	Andrew Bay	5.00 (100)	5.00 (100)	5.78 (115)	6.76 (135)	5.06 (101)*	7.02 (140)	1.18
10	Bowron km 36	4.75 (100)	5.13 (108)	5.58 (117)	6.29 (132)	5.28 (111)	6.14 (129)	0.70
11	Bowron km 42	5.49 (100)	5.88 (107)	6.20 (113)	6.57 (120)	5.83 (106)	6.74 (123)	0.67
12	Hwy 16	4.51 (100)	4.64 (103)	5.12 (114)	5.99 (132)	5.39 (120)	5.46 (121)	0.68
	MEAN	5.32 (100)	5.50 (103)	6.22 (117)	7.01 (132)	5.66 (106)	7.11 (134)	
	STD ERROR	0.21	0.23	0.22	0.21	0.20	0.22	

* = installations where N X C interaction is significant at p = 0.05

Table 5 : Analysis of variance and contrasts conducted on foliar dry weight of the 12 spruce sites sampled in 1988.

	Installation Number											
Source of Variation	1		2		3		4		5		6	
Factorial Partitions	F	P	F	P	F	P	F	P	F	P	F	P
Nitrogen (N)	5.597	0.006	3.396	0.041	11.933	0.000	7.790	0.001	13.504	0.000	5.502	0.007
Complete Mix (C)	5.101	0.028	8.126	0.006	9.460	0.003	10.634	0.002	18.232	0.000	5.479	0.023
N X C	5.230	0.008	1.042	0.360	7.023	0.002	3.536	0.036	7.248	0.002	1.576	0.216
Contrasts												
N vs N + C	11.421	0.002	2.709	0.105	21.634	0.000	16.041	0.000	26.353	0.000	7.650	0.007
N 100 vs N 200	4.400	0.044	1.010	0.185	0.513	0.208	1.069	0.182	1.609	0.156	0.433	0.212
N 100+C vs N 200+C	0.444	0.967	0.095	0.187	0.058	0.229	0.464	0.210	9.536	0.003	0.786	0.195

Table 5 continued.

	Installation Number											
Source of Variation	7		8		9		10		11		12	
Factorial Partitions	F	P	F	P	F	P	F	P	F	P	F	P
Nitrogen (N)	13.226	0.000	9.502	0.000	10.518	0.000	4.961	0.011	8.792	0.000	10.008	0.000
Complete Mix (C)	15.476	0.000	18.731	0.000	16.744	0.000	8.060	0.006	10.378	0.002	3.579	0.064
N X C	3.033	0.056	7.485	0.001	5.461	0.006	1.189	0.313	0.509	0.604	1.211	0.306
Contrasts												
N vs N + C	18.018	0.000	27.638	0.000	24.197	0.000	7.429	0.008	9.941	0.002	3.875	0.058
N 100 vs N 200	2.763	0.102	6.915	0.012	2.864	0.099	1.264	0.173	0.729	0.198	0.592	0.204
N 100+C vs N 200+C	2.055	0.135	0.268	0.219	0.360	0.215	0.269	0.219	0.188	0.223	2.502	0.114

F = F-ratio from ANOVA
P = Probability of a larger F

In 6 of these 12 installations, however, the significance of the main effects of "N" and "C" are of less consequence than the significance of the interaction effect (ie., N X C) (Table 5). The interaction of N X C is significant when the value (in needle weight) is greater that the sum of the individual effects concluding that nitrogen is more effective when the "complete mix" fertilizer is added. In the case of the six installations (installations 1, 3, 4, 5, 8 and 9) where the interaction is significant, the greatest increase in needle weight occurs when nitrogen and the "complete" mix fertilizer is combined. It is also important to note that this interaction is usually significant in the same installations where the needle weights for the N 200 + C treatments are larger than the needle weights for the N 100 + C treatments (Table 4). This difference is clearly illustrated in Figure 6 and 7 where Betty Lake represents a significant interaction (and where the needle weight of the N200+C > N100+C) and Chapman Lake represents a nonsignificant one (where the needle weight of the N200+C < N100+C). In the cases where the needle weight for the N 200 + C treatment is less that the needle weight for the N 100 + C treatment, although the differences are not significant (contrast 3 in Table 5), the extra 100 kg·ha^{-1} of nitrogen added may be too high, causing possible nutritional problems.

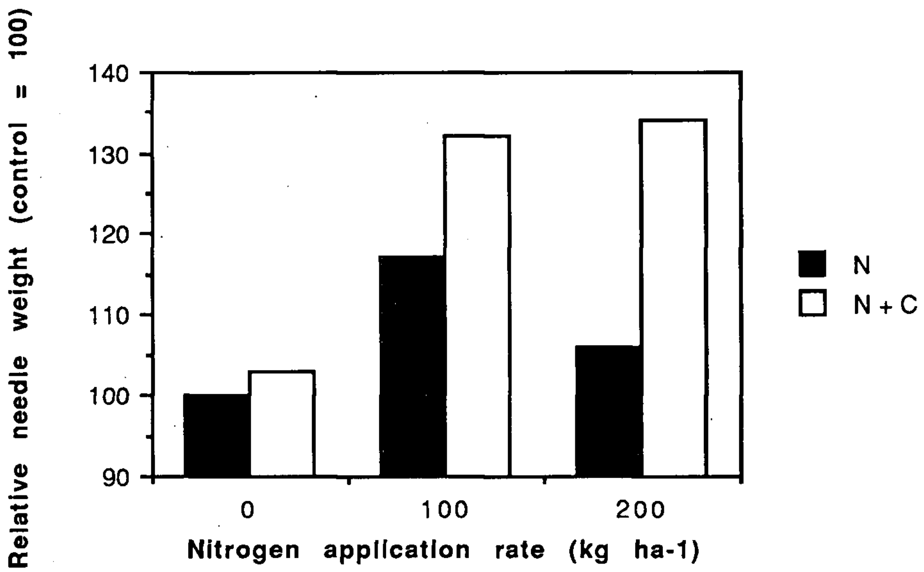


Figure 5. The effect of individual and combined applications of nitrogen and "complete" mix fertilizer on the mean dry weight of needles (g/1000 needles) produced in the first growing season after fertilization (relative to control = 100). Treatment values represent the mean of all trials (n=12).

The remaining contrasts in Table 5 indicate that in all experimental stands, with the exception of installation 12, there is a significant difference between the needle weights of the nitrogen only treatments and the treatments where nitrogen and the "complete mix" fertilizer are combined. The contrasts also show that, in all but two cases, there are no

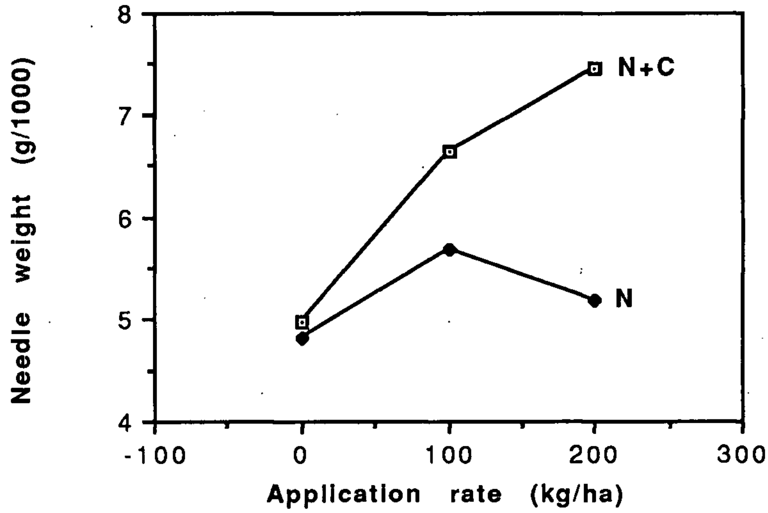


Figure 6. The significant interaction effect of individual and combined application of nitrogen and "complete mix" fertilizer on the mean dry weight of Betty Lake needles (g/1000 needles) produced in the first growing season after fertilization.

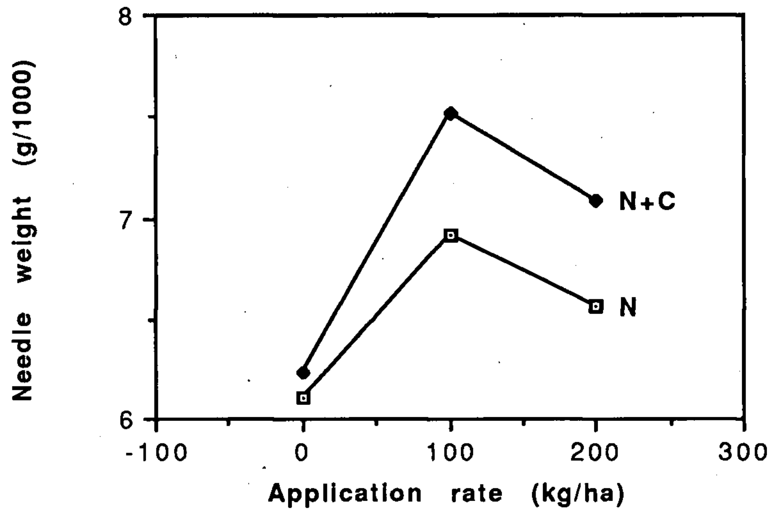


Figure 7. A nonsignificant interaction effect of individual and combined application of nitrogen and "complete mix" fertilizer on the mean dry weight of Chapman Lake needles (g/1000 needles) produced in the first growing season after fertilization.

significant differences between the two applied nitrogen treatments (i.e., N 100 vs. N 200), although N 200 needle weights were consistently lower than the N100 treatments. This same trend existed (i.e., no significant difference in all but one case) between the N 200 + C and the N 100 + C treatments.

These results suggest that although the limited amount of nitrogen already present in the stand will undoubtedly hinder growth of interior spruce, application of nitrogen alone will also result in a poor response unless other nutrients are added in conjunction with N. In other words, although supplies of certain non-added nutrients may be adequate to balance native supplies of N, they may be inadequate to sustain or enhance growth following N fertilization.

Foliar Nutrient Concentrations 1988

Due to the nature of the "complete" mix fertilizer and the limited information from which interpretations can be derived, the exact nutrients responsible for changes in needle weight response cannot be specifically identified. However, examination of the nutrient concentrations, following one growing season after treatment indicate a few important trends (Table 6).

Nitrogen fertilization resulted in large increases in foliar N concentration. These increases were directly related to the amount of nitrogen applied, i.e., the higher the N application dosage, the higher the foliar N concentration level. Even the "complete" mix fertilizer without N treatment (N 0 + C) had a modest improvement on nitrogen nutrition (ie., increased concentration and content). Using the interpretations provided by the graphical analysis, this increase in foliar N concentration and subsequent increase in content in the presence of needle weight response, illustrates the "C" shift (Timmer 1979) and implies that initial levels of nitrogen were limiting (Figure 8).

This interpretation confirms the original diagnosis that nitrogen levels were deficient. However, Figure 8 also illustrates that this "C" shift only occurs when the application of nitrogen is accompanied by other elements. Although nitrogen concentration and content may increase with the application of N alone (indicating increased uptake), there is no change in

Table 6. 1988 mean foliar interior spruce nutrient concentrations for all installations by treatment after one growing season (n=12).

	%						ppm							
Treatments	N	P	K	Ca	Mg	S	Mn	Fe	A-Fe	Cu	B	Zn	S04-S	N/S
Control	1.08	0.21	0.80	0.50	0.10	0.089	533	47	20	2	17	47	165	12
N 0 + C	1.17	0.27	0.86	0.53	0.11	0.111	611	55	23	2	32	48	27	11
N 100	1.95	0.22	0.67	0.50	0.10	0.087	556	45	25	2	17	50	30	22
N 100 + "C"	1.90	0.24	0.76	0.52	0.10	0.118	650	61	27	2	25	46	93	16
N 200	2.65	0.24	0.56	0.50	0.10	0.081	565	50	27	3	18	50	16	33
N 200 + "C"	2.42	0.25	0.65	0.49	0.10	0.132	577	65	33	3	24	40	103	18
Least significance difference (p = 0.05)	0.305	0.025	0.119	0.074	0.014	0.015	301.5	44.0	10.0	1.3	6.9	10.8	66.8	3.8

needle size. This lack of needle weight response illustrates "luxury consumption"; nitrogen is taken up by the spruce but due to some other limiting factor, it is not used to stimulate needle growth (Figure 8).

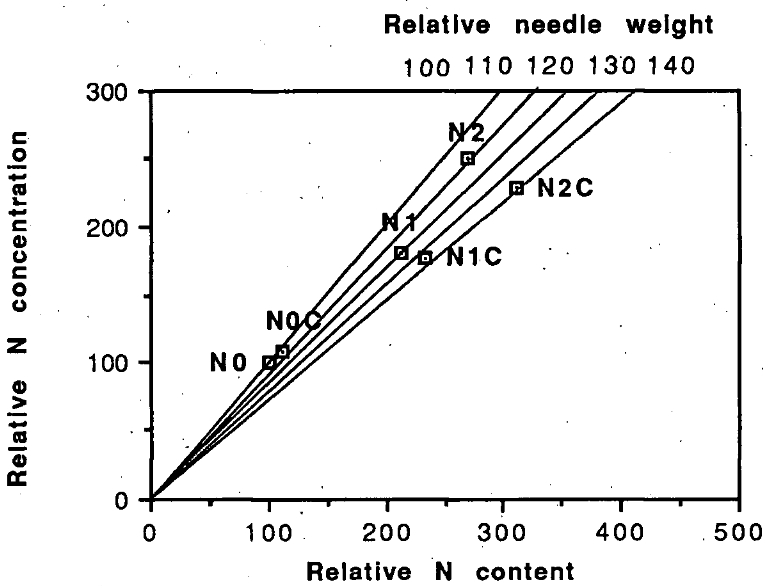


Figure 8. The effect of individual and combined applications of nitrogen and "complete" mix fertilizer on interior spruce needle dry mass and foliar N nutrient status (relative to control = 100) one growing season after fertilization. Plotted values are means of all installations (n=12).

In order to help determine which element could be causing this increased needle weight response, or lack of response in the case of the N only treatments, the remainder of this discussion will focus on foliar nutrient data from the N 200 and the N 200 + C treatments. These two treatments clearly illustrate the extremes in foliage response to the various fertilizer treatments.

Figure 9 illustrates the effect of the N 200 treatment on the elements P, B, Active Fe, Ca, Mg, S, and K. By looking at the graphical positions, combined with their actual nutritional values (Table 6), it appears that the application of N had either no effect or produces an enrichment response (Timmer <u>et</u>. <u>al</u>., 1990) on P, B, Ca, Mg, B, and AFe. Therefore, it appears that N does not induce a problem with these elements. The same trend exists for the elements Fe, Mn, and Zn (Table 6).

The graphical analysis illustrated in Figure 9 also indicates that applications of nitrogen alone appear to have an antagonistic effect on the uptake of K and S. This negative impact of nitrogen applications is partially alleviated when the "complete mix" fertilizer is added (Figure 10).

The shift indicated in Figure 10, makes it apparent that the sulphur component of the "complete mix" fertilizer is successful in increasing the foliar S concentration levels above those found in the nitrogen only treatments and above those found in the unfertilized trees (Table 6). For potassium, the K component of the "complete mix" fertilizer was only partially successful in replacing the amount of K that was lost in the nitrogen-only treatments. With regards to S, the increase in sulphur levels when S is added is only one indication that sulphur may be one of the causes for the lack of needle weight response when nitrogen is applied alone.

Sulphur is required by plants for a number of functions. It is required for the synthesis of many amino acids which are essential components of protein and which contain approximately 90% of the organic S found in plants. Sulphur is also needed for the formation of chlorophyll: for the activation of certain

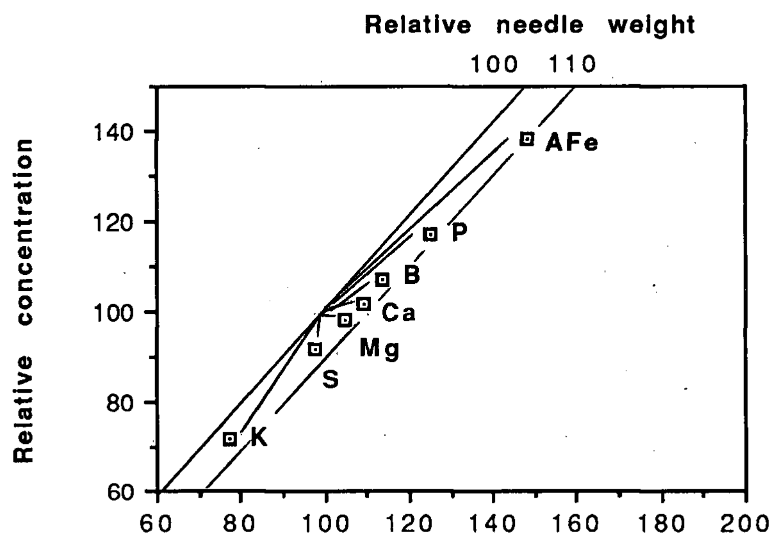


Figure 9. The effect of the treatment N 200 on interior spruce needle dry mass and foliar Afe, P, B, Ca, Mg, S and K nutrient status (relative to control = 100) one growing season after fertilization. Plotted values are means of all installations (n=12).

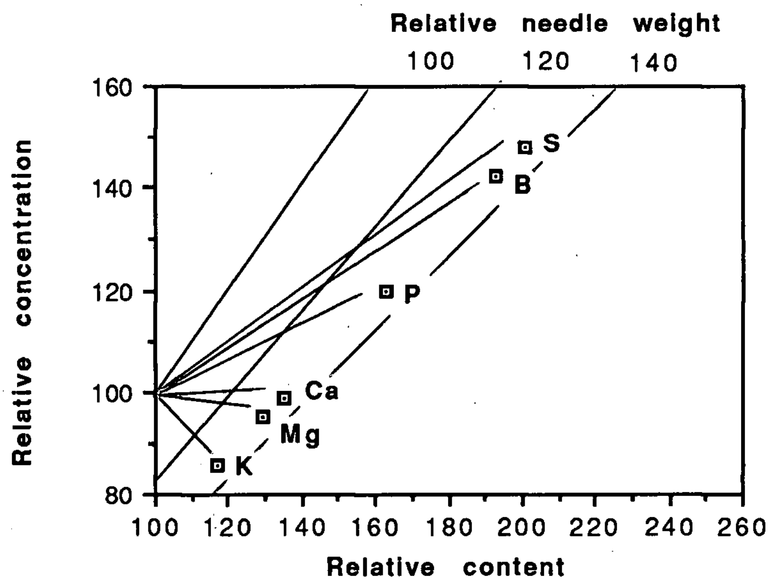


Figure 10. The effect of treatment N 200 + C on interior spruce needle dry mass and foliar S, B, P, Ca, Mg, and K nutrient status (relative to control = 100) one growing season after fertilization. Plotted values are means of all installations (n=12).

enzymes and the synthesis of certain vitamins: for the formation of proteins that functions as an electron carrier in photosynthetic processes: and for the formation of compounds involved in the fixation of nitrogen (Turner 1979).

There are three major natural sources from which plants can be supplied with available sulphur: (a) soil minerals, (b) sulphur gasses in the atmosphere, and (c) organically bound sulphur (Brady 1984). In humid regions the principal reservoir of sulphur in soils is the sulphur contained in the soil humus (or organically bound sulphur). As the humus becomes oxidized, nitrates and suplhates are set free (Russell 1973, Tisdale et. al., 1985). These released sulphate ions are the primary source in which plants obtain adequate sulphur supplies.

Research has indicated that nitrogen is utilized only at a rate at which sulphur is available and, therefore, protein formation is limited by this availability (Turner 1979). Under conditions of sulphur deficiency, inhibition of protein synthesis is correlated with an accumulation of soluble organic nitrogen and nitrate (Marschner 1986). This finding may indicate the reason for the accumulation of large levels of nitrogen by the N 200 treatment without any increase in foliage size.

Research has also indicated that, in the case of a conifer stand, (when the sulphur supply is adequate, trees accumulate, as sulphate, any excess S beyond that required to balance the nitrogen available. Then protein formation proceeds at the rate at which N becomes available (Turner 1979). It appears, therefore, that the sulphate - S status of the foliage provides a more sensitive and indicative measure of the sulphur status of both the tree and the site than total S (Lambert and Turner 1977, Freney et. al., 1978). The critical S04-S levels presented in Ballard and Carter (1986) are extrapolated from other species and, therefore, may not be valid for interior spruce. In this study the sulphate-sulphur levels dropped dramatically when nitrogen was applied to the stands, (Figure 11). This indicated that the original S04-S levels were adequate to sustain growth of the unfertilized trees but were inadequate to fully utilize the added supply of N following fertilization.

The re-establishment of adequate sulphur levels by the "complete"mix fertilizer is also indicated by the reduction of the N/S ratio towards the accepted critical value of 14.6 (Ballard and Carter 1986) (Figure 12). Figure 12 also shows how elevated this ratio was when nitrogen was applied alone (also see Table 6). It is important to note, however, that the N/S value for the N 200 + C treatment is still higher than the suggested critical value. This could, perhaps indicate that the amount of sulphur added as a component of the "complete" mix fertilizer is still not high enough to offset the sulphur deficiency induced by 200 $kg{\cdot}ha^{-1}$ of nitrogen.

When sulphur was added as a component of the "complete" mix fertilizer to the N 200 treatment, it was added in the form of sulphate (ie., sulphate of potash-magnesia (Langbeinite)). The form may be important due to the timing of the fertilizer application. Since the "complete" mix fertilizer was applied during the spring, the sulphur component was already present in the sulphate form which could be immediately utilized by the trees. Thus the application of S was able to increase the foliar S concentration levels above those found in the unfertilized trees (Table 6). With these re-established S levels, protein formation could then continue with the availability of both N and S, with the possible result of increasing the needle weight (Figure 10). If the fertilizer had been applied in the fall. the highly mobile sulphate has the potential of being leached below the rooting zone prior to the initiation of new growth the following spring (humid regions), or being retained in the subsoils where iron and aluminum oxides are more prominent (Brady 1984). As well, if the S was added in the form of elemental sulphur, its availability to the trees would depend on the soil chemistry and the presence of oxidizing micro-organisms, thus producing a somewhat slower-acting product (Russell 1973).

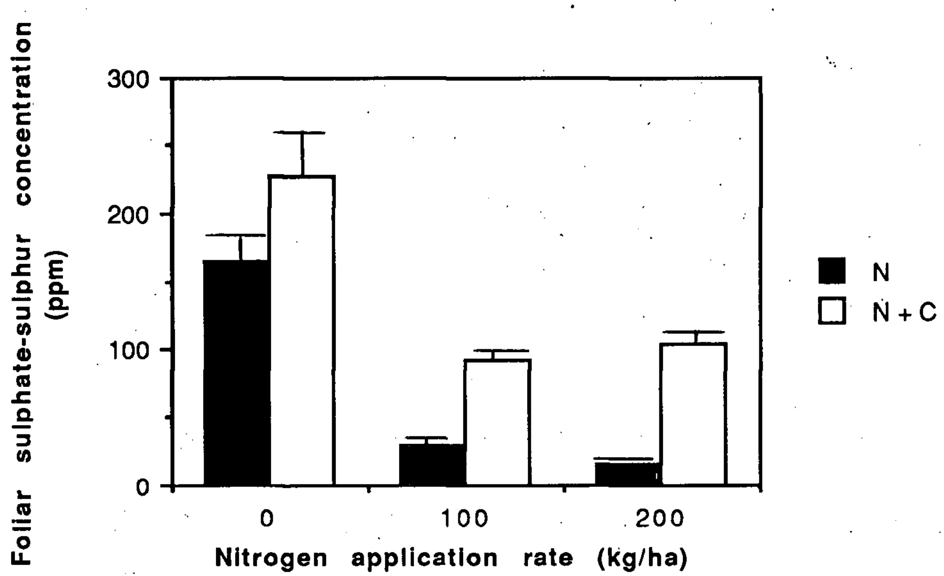


Figure 11. The effect of individual and combined applications of nitrogen and "complete" mix fertilizer on mean foliar sulphate sulphur concentration (including error bars) one growing season after fertilization. Treatment values represent the mean of all trials (n=12).

The presence of a S deficiency in interior spruce growing in the Interior of B. C. is not surprising. Bettany et. al., (1983) in his paper on agricultural soils indicated that sulphur deficiencies in western Canadian soils are measurably increasing. Yang (1985b) and Brockley (1989) also found indications of sulphur deficiencies in lodgepole pine growing in the B. C. interior. These deficiencies were usually found in conjunction with trials where nitrogen-only treatments were applied. From their research, all operational fertilization in the interior of B. C. is now done with a sulphur mix added. (Brockley per comm.). This induction of sulphur deficiency is not found in Scandinavia since their soils tend not to be lacking in S.

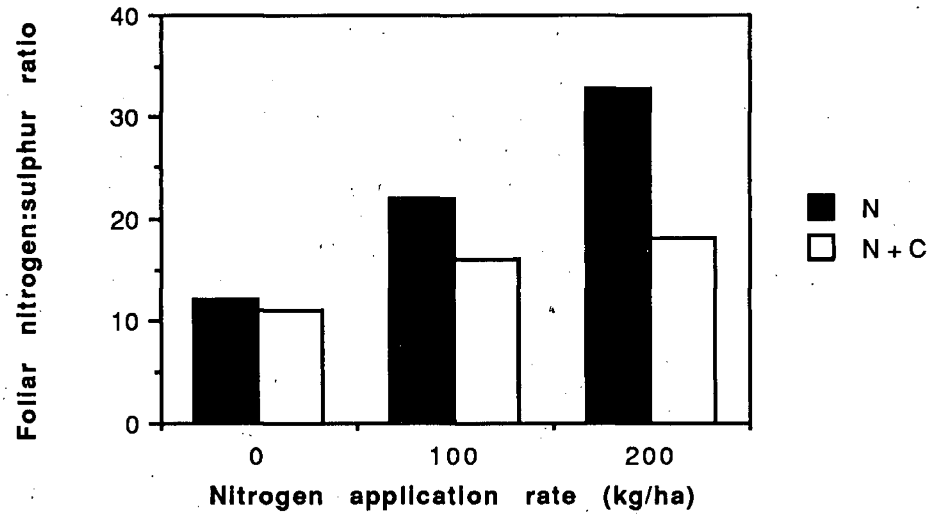


Figure 12. The effect of individual and combined applications of nitrogen and "complete" mix fertilizer on mean foliar nitrogen:sulphur mass ratio one growing season after fertilization. Treatment values represent the mean of all trials (n=12).

From the information presented thus far, it appears that inadequate sulphur nutrition is the most likely factor contributing to the poor response following fertilization with N alone. However, the negative impact of nitrogen additions on K nutrition in the first year following fertilization must also be considered (Figure 9 and Table 6). Although the diluted K levels remained higher than the critical values suggested by Ballard and Carter (1986), these values may not accurately represent the K requirement of interior spruce (i.e., the critical values may indeed be higher than those suggested).

Potassium plays an essential role in plants as an activator of dozens of enzymes responsible for such plant processes as energy metabolism, starch synthesis, nitrate reduction and sugar degradation (Brady 1984). Because of its ease in transport across plant membranes, it is extremely mobile within the plant. It is also found in relatively high concentrations in plant cells where it helps regulate the opening and closing of stomates in the leaves and the uptake of water by root cells (Brady 1984). Potassium is present in relatively large quantities in most soils (Tisdale et. al.,1985).

A possible explaination for the decrease in potassium levels for both the N 200 and the N 200 + C treatments could be due to the mass ion effect. When the nitrogen-only fertilizer is applied to the soil (in the form of ammonium nitrate-NH_4NO_3) the system is flooded with

NH^{4+} cations and NO^{3-} anions. Since the NH^{4+} and K^+ cations are similar in size and valency, the potassium ion tends to get displaced from cation exchange sites on soil colloids by the abundance of the added NH^{4+} ions. Once displaced, the potassium ions could be attracted to the surplus NO^{3-} anions (added as a component of the fertilizer) and subsequently both could be leached from the system. When nitrogen and the "complete" mix fertilizer is added to the soil, the soil system is flooded with added cations such as Ca^{2+}, Mg^{2+}, NH^{4+}, and K^+ as well as added anions such as $H_2PO_4^-$, HPO_4^{2-}, SO_4^{2-}, NO^{3-}, and Cl^-. As in the case of the N 200 treatment, with the addition of the extra ions, mass action will cause the potassium cations to be replaced and subsequently leached out. Since K^+ is added as a component of the "complete" mix fertilizer, some of the extra potassium will most likely remain in the system. It is important to note that although actual foliar concentrations levels of K for the N 200 + C treatments were reduced, their relative content was actually higher than the unfertilized trees. This increase in relative content was due to the increase in needle weight found in these treatments. This, therefore, indicates that perhaps the K levels found in the N 200 + C treatments were the result of a "dilution" effect rather than anything antagonistic.

As indicated earlier, the potassium levels recorded for the N 200 and the N 200 + C treatments were reduced, but not below the accepted critical value. With the reduction of K concentrations due to dilution, combined with the previous interior research information that stands showed little response when potassium was added alone as a fertilizer (Weetman 1981), it appears that K can be eliminated as a nutritional problem with interior spruce. It is important, however, that research be conducted into this problem to verify that indeed the reduction in K levels due to high application of N is not a serious concern as well as a systematic testing of the K requirement of interior spruce so that current deficiency diagnosis can be evaluated.

Foliar Nutrition Concentrations 1989

Table 7 presents a six stand summary of the nutritional information for the different nutrients after the second growing season.

Table 7. 1989 mean foliar interior spruce nutrient concentrations for six installations by treatment after two growing season (n=6).

				%						ppm				
Treatments	N	P	K	Ca	Mg	S	Mn	Fe	A-Fe	Cu	B	Zn	SO4-S	N/S
Control	1.05	0.25	0.66	0.48	0.096	0.094	380	42	30	4	18	43	109	11
N 0 + C	1.08	0.29	0.69	0.41	0.098	0.100	482	51	35	4	27	41	156	11
N 100	1.27	0.24	0.59	0.39	0.079	0.095	330	45	33	3	14	38	57	13
N 100 + C	1.30	0.28	0.65	0.40	0.088	0.112	507	70	44	3	20	44	114	12
N 200	1.62	0.27	0.57	0.44	0.086	0.096	383	54	38	4	15	42	46	17
N 200 + C	1.44	0.28	0.62	0.42	0.087	0.116	515	84	47	3	19	42	102	12
Least significance difference ($p = 0.05$)	0.235	0.030	0.096	0.104	0.009	0.011	215.9	83.4	30.0	0.7	5.3	8.6	42.1	2.3

It can be seen that many of the trends indicated in the 1988 growing season still remain, but to a lesser degree. The extremely high nitrogen concentration levels found in the first year have disappeared, indicating that perhaps photosynthetic efficiency effects are short lived. The reduction in N levels, however, is probably due to the dilution of this element through larger needles and possibly more of them. The elevated N/S ratio, still above the critical 14.6, and low sulphate-sulphur levels in the nitrogen-only treatments indicate that the nitrogen-induced sulphur deficiency persists after the second year. The sulphur, added as a component of the "complete" mix fertilizer, appears to have been more successful in stabilizing the effect of the 200 kg of nitrogen in the second growing season than in the first, thus the possible S deficiency of the N 200 + C treatment may have been aleviated. Foliar K concentration, while still slightly lower in the fertilized than the unfertilized trees, appears to indicate that the apparent "antagonism" of the first growing season is short lived.

SUMMARY AND CONCLUSION

In 1987, a research project was undertaken in order to obtain preliminary fertilization response data for three Interior species. In 1988, as part of this contract, 12 screening trials were established in young interior stands in the north-central interior of B. C. using factorial combinations of nitrogen and "complete" mix fertilizer.

Initial assessment of the foliage obtained from these 12 installations indicated a number of possible nutritional problems. It was found that nitrogen levels were below critical values suggested by many researchers (ie. below 1.50 percent of dry mass). As well, while sulphur levels appeared to be adequate to balance the amount of nitrogen present in the stand, the level may not be adequate to offset the application of nitrogen which could induce a deficiency (Ballard and Carter 1986). Finally, copper and active iron levels appeared to be low. These low values of Cu and AFe may not be due to actual deficiencies in the soil. They may actually be due to problems with the sensitivity limits of the digests conducted on the ground foliage sample and/or problems with the lack of fertilization response information available to verify the tentative levels presented for these nutrients. Although these elements appear to be low, it is important to note that the levels of potassium and calcium found in the unfertilized trees were well above values obtained for any B. C. interior species.

After fertilization, the effects of the treatments were measured in two ways; 1) in needle weight response; 2) in nutrient concentration and subsequent nutrient content response.

In all 12 installations, fertilization had a highly significant effect on the first year needle weights. When applied singly, nitrogen and the "complete" mix fertilizer had little effect on needle weight. In the case of the N 200 treatment, comparisons using LSD showed that this treatment expressed no response in needle weight change whatsoever. Statistically, the main effects of "nitrogen" and "complete mix" were significant in all installations. However, in six of these 12 stands, the interaction of N X C was also significant. This appeared to indicate that the greatest increase in needle weight occurred when nitrogen and the "complete" mix fertilizer were combined. Although this interaction was only significant in half of the installations, the contrast testing N vs N + C showed significance in all but one case, indicating that applications of nitrogen alone showed poor response unless other nutrients were added in conjuction with N.

Nutritionally, N fertilization resulted in large increases in nitrogen concentration, the response related directly to the amount of N applied. Using the interpretations provided by the graphical analysis, this increased level in foliar N concentration, and the subsequent increased content in the presence of a needle weight response, illustrated the "C" shift (Timmer 1979) and implied that levels of nitrogen were limiting.

In the nitrogen-only treatments, the remaining macro and micro nutrients showed a nonsignificant or an enrichment response (ie., relative content increased without an increase in needle weight and without this element being added to the system) except for the elements sulphur and potassium, which decreased.

In the "complete" mix fertilizer treatments, all nutrients showed increases in uptake except for K which still remained low. In the case of S and K, the S component of the "complete" mix fertilizer was successful in increasing the foliar S concentration levels above those found in the N-only treatments and above those found in the unfertilized trees, while the K component was only partially successful.

With regards to S, research had indicated that a more accurate evaluation of sulphur nutrition would be to observe the sulphate-sulphur levels. When nitrogen was applied alone, the S04-S levels dropped below critical values. This indicated that original S04-S levels were adequate to sustain growth at the present N levels, but when N was added, an adequate supply of sulphate was not present to utilize the added supply of N.

A final indication of sulphur nutrition was the N/S ratio. In the nitrogen-only treatments, the N/S ratios were elevated well above the suggested critical value of 14.6 (Ballard and Carter 1986). When the "complete" mix fertilizer was added, S04-S levels were increased and the N/S ratio was decreased. These level changes, however, were apparently not sufficient enough to totally alleviate the sulphur deficiency. An evaluation of the foliage after the second growing season indicated that the sulphur problem, especially in the N-only treatments still existed.

Even though sulphur appeared to be the contributing factor to the poor response following fertilization with N alone, the negative impact of nitrogen additions on K nutrition had to be considered. Although K levels were not below critical values, it appeared that a possible explanation for their decrease was due to dilution in the case of the N 200 + C treatment (since relative content increased after first year), and by the effect of mass action of ions for the N 200 treatment. As well, since earlier research had indicated that interior spruce showed no response to applications of K alone, and since K levels had stabilized after the second growing season, it appeared that potassium was not a serious problem.

Results from this study appear to indicate that interior spruce is responsive to fertilization. The responsiveness will depend, however, on the amount of nitrogen applied and if other nutrients are added in conjunction with the N source. The most probable elements to be added to the nitrogen source are sulphur (in the form of sulphate) and, to a lesser extent, potassium. More research, however, is needed before a more definite conclusion, as to the identity of the required mix of elements, can be made.

RECOMMENDATIONS

1. Although K does not appear to be a problem, the lack of information with regards to potassium indicates a need for systematic testing to be done of the K requirements of interior spruce to confirm or reject the current diagnosis criteria.

2. Since the majority of the elements were applied as a "complete" mix fertilizer, future research trials hould be specifically designed to test the individual deficiencies that have been implied in these screening trials (e.g., S and K). Once isolated, the deficient nutrients can be tested with N in conventional, fixed plot trials.

3. Since no soils information was obtained for this project, a major component of information was missing. For example, information on nitrogen and sulphur mineralization, as well as information on pH and the amount of organic matter present on each site, would have been very helpful. It is important to combine both foliage and soils information in order to help understand the complexity of tree nutrition and the effects of fertilization.

4. Finally, large-scale nitrogen fertilization of interior spruce should not be undertaken until the nutrition and fertilization response potential of interior spruce is more fully understood.

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