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Using Foliar Nutrient Levels to Predict Lodgepole Pine Fertilization Response

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Abstract

Six-year basal area responses to nitrogen fertilizer, either alone or in combination with sulphur, were compared with pre-treatment measures of foliar nitrogen and sulphur in 31 lodgepole pine stands in the Interior of British Columbia. Results from this analysis indicate that pre-fertilization levels of foliar nitrogen, sulphur, and inorganic sulphate-sulphur are useful for predicting whether lodgepole pine will respond significantly to fertilization with either nitrogen alone or a combination of nitrogen and sulphur, and for estimating the magnitude of the expected responses. By using these tools, the chances of making the appropriate fertilizer prescription may be significantly improved.

Introduction

Extensive research has been undertaken to determine the nutritional status of lodgepole pine (*Pinus contorta*) in the Interior of British Columbia, and to document the effectiveness of fertilization in improving the growth of immature stands (Brockley 1996). These studies have confirmed that nitrogen (N) deficiencies are widespread throughout the Interior and that additions of this nutrient often have a substantial, positive effect on tree and stand growth. However, the response of lodgepole pine following additions of N is variable; some stands respond well and others respond poorly. Sulphur (S) has been implicated in limiting the effectiveness of N fertilization in some instances. On some sites, growth responses have been enhanced by combining S with N in fertilizer prescriptions. Unfortunately, methods are not presently available to reliably predict which stands will respond best to N fertilization, or to identify stands where response can be improved by adding S in combination with N. The absence of a reliable prediction system is undoubtedly a major factor limiting the large-scale use of fertilizers in Interior forest operations.

Using Foliar Nutrient Levels to Predict Fertilizer Response

In British Columbia, foliage samples are routinely collected from lodgepole pine stands being considered as candidates for operational fertilization. Foliar nutrient analyses of these samples are compared with published diagnostic criteria (e.g., Ballard and Carter 1986) to confirm N deficiencies, and to infer whether other nutrients will either limit growth or become

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growth-limiting after N is added. Pre-treatment foliar analysis is not presently used to predict which stands will respond best to fertilization. However, by using pre-fertilization foliar nutrient levels, empirical relationships and predictive indices have been successfully developed for other tree species to identify sites that will respond well to fertilization, or to predict the magnitude of the response. The fact that N and S levels in lodgepole pine foliage are often low, and that enhanced growth responses to combined additions of these nutrients have been reported, suggests that pre-treatment foliar analysis may have utility as a predictor of fertilization response for lodgepole pine in British Columbia's interior.

In this extension note, we compare 6-year basal area responses to N fertilizer, alone and in combination with S, with pre-treatment measures of foliar N and S in 31 lodgepole pine stands in the Interior of British Columbia. Our primary objective was to ascertain the utility of these foliar variables as predictors of growth response and determinants of appropriate fertilizer prescriptions.

Study Sites

The growth response data and foliar data used for this analysis were collected from lodgepole pine fertilization research trials established by the B.C. Ministry of Forests from which 6-year growth response data are presently available.

The 31 study sites are located in the Interior of British Columbia between 49° 18' and 54° 39' N latitude, and 115° 30' and 127° 22' W longitude. Twenty of the stands regenerated naturally after wildfires; the remainder were more-or-less equally divided between naturally regenerated, harvest-origin stands and plantations.

All of the naturally regenerated harvest- and fire-origin stands were pre-commercially thinned before fertilization. Post-thinning densities cover the range typically used operationally throughout the region.

Twenty-seven of the installations are located within the Sub-boreal Spruce (SBS) or Montane Spruce (MS) biogeoclimatic zones. This distribution reflects the abundance of immature lodgepole pine and pre-commercial thinning activity in these two zones. Stand age averaged 20 years (range: 13–30 years) at the time of fertilization.

Experimental Design

A combination of conventional, fixed-area plot fertilization installations, "mini-plot" experiments, and "single-tree" fertilizer screening trials were used in this analysis. The research installations were selected from 10 separate experimental projects established between 1981 and 1992 (see Table 1). Because each experiment was established for specific objectives, the experimental designs, plot layouts, and treatments are not consistent. The experimental designs and treatments for many of these experiments have been reported previously (Brockley 1990, 1991, 1995; Brockley and Sheran 1994).

Each conventional, fixed-area plot and mini-plot consisted of an inner measurement plot surrounded by a treated buffer. In fixed-area installations, each treatment was applied to three plots; mini-plot treatments were replicated five times. In single-tree trials, fertilizer treatments were applied to a 5-m radius area surrounding the tree at the centre of each plot. Each treatment was randomly assigned to 15 plots within each installation. In all installation types, the outer boundaries of adjacent treatment plots were separated by a minimum distance of 5 m.

Fertilizer Application

Nitrogen was the only nutrient added in 14 of the 31 installations. The other

TABLE 1 *Distribution of installations by experimental project, plot type, and treatment*

Experimental project no.	Plot type	No. of installations	Treatment[a]	Treatment plot size (ha)	Replicate plots per treatment	Trees measured per plot
886.01-1	Fixed-area	10	C, N	0.059–0.091	3	50
886.01-2	Fixed-area	3	C, N, N + S	0.059–0.091	3	50
886.01-3	Fixed-area	2	C, N, N + S	0.070–0.091	3	50
886.13	Fixed-area	1	C, N, N + S	0.164	3	64
886.12	Mini-plot	1	C, N, N + S	0.031	5	15
886.04-1	Single-tree	3	C, N	0.008	15	1
886.04-2	Single-tree	1	C, N, N + S	0.008	15	1
886.05	Single-tree	1	C, N	0.008	15	1
886.09	Single-tree	7	C, N, N + S	0.008	15	1
886.10	Single-tree	2	C, N, N + S	0.008	15	1

a C = control; N = nitrogen only; N + S = nitrogen plus sulphur.

17 installations received both N and N + S additions. In one experiment, N was applied at a rate of 300 kg/ha; the application rate was 200 kg/ha in all other installations. Urea (46-0-0) was the primary N source in all experiments, although N + S treatments often used a combination of urea and ammonium sulphate (21-0-0). Sulphur was applied as ammonium sulphate or finely divided elemental S at rates between 50 and 75 kg/ha.

Fertilizer was uniformly applied by hand to treatment plots at the beginning of each experiment. One installation was fertilized in the early spring immediately after snowmelt; all others were fertilized in the fall, before snowpack accumulation.

Measurements

For each of the 31 fertilizer trials, 6-year mean individual-tree basal area increments were calculated for each treatment. For each tree, this increment was taken as the difference between the initial and 6-year basal area measurements. For comparative purposes, the difference between treated and control values for each trial was expressed relative to the control value (control = 100).

For each trial, foliage samples collected from unfertilized trees were used to calculate mean foliar N, total S and inorganic sulphate S (SO_4) concentrations, and N:S ratios in current-year needles. The same commercial laboratory (Pacific Soil Analysis Inc.) was used for all foliar analyses.

Regression procedures were used to examine relationships between 6-year relative basal area and fascicle weight responses and foliar N, S, SO_4, and N:S ratios for unfertilized trees.

Basal Area Response to Nitrogen and Nitrogen plus Sulphur Fertilization

The response to N fertilizer varied considerably between installations, as shown by the frequency distribution of relative basal area response (Figure 1). Overall, 6-year response to N fertilization averaged 26% (range: 5–77%). Almost one-half of the installations produced responses in excess of 30%. However, basal area response in almost one-third of the installations was less than 15%, indicating marginal benefit from the fertilizer application in those installations.

In the 17 installations fertilized with both N and N + S treatments, the

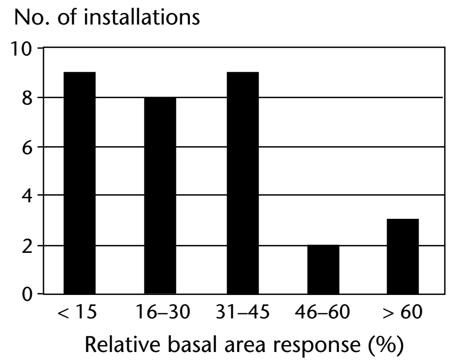

FIGURE 1 *Distribution of relative 6-year basal area response (% increase above control) to fertilization with N alone.*

combined N + S application resulted in a larger mean 6-year basal area response than N alone (28% versus 19%, respectively). A growth response of more than 30% was obtained in one-half of the installations fertilized with N + S. For these 17 installations, a similar response was achieved by less than one-fifth of the stands fertilized with N alone.

Foliar Nutrients as Predictors of Basal Area Response

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 (see Figure 2). 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% of N in the foliage of unfertilized trees. However, the average growth response in installations with greater than 1.2% of 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

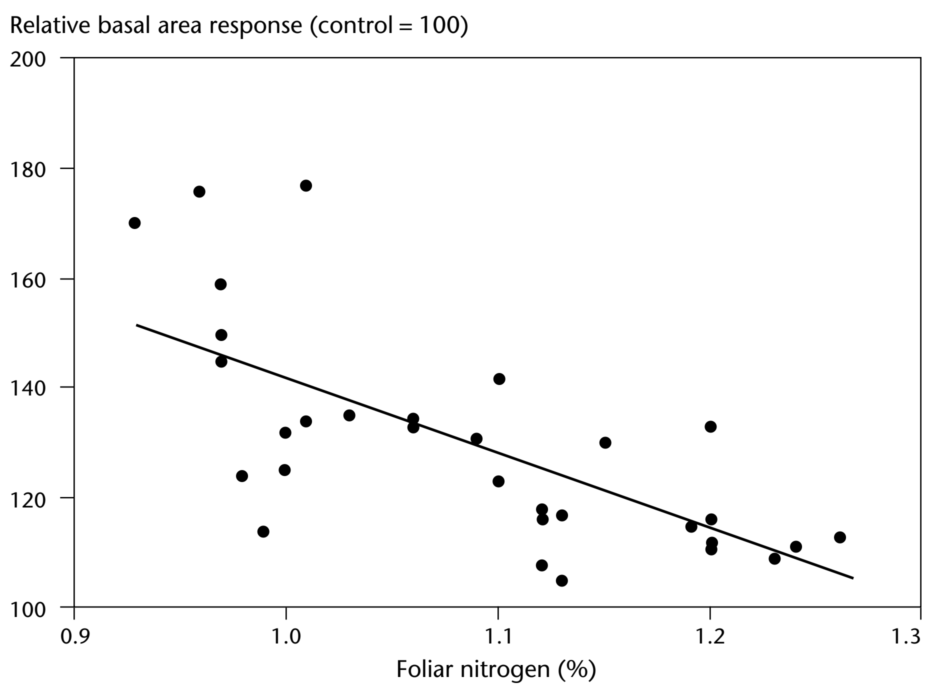

FIGURE 2 *Relationship between relative 6-year basal area response to fertilization with N alone and the concentration of N in foliage of unfertilized trees (n = 31). The regression line is fit from the following equation: BA response (control =100) = 285.8 – 143.6 N (%); (R^2 = 0.49, SE_E = 14.4).*

two-thirds of the installations in this analysis.

A positive relationship was clearly evident between relative basal area response to fertilization with N alone and foliar SO_4 (Figure 3). Pre-fertilization foliar SO_4 explained 55% of the observed variation in relative growth response among installations. Six-year basal area response to fertilization with N alone averaged 47% in installations with 80 ppm or more of SO_4 in unfertilized foliage. The average response for installations with less than 60 ppm of SO_4 was only 15%. Installations in the top response quartile (the eight most responsive stands) had an average foliar SO_4 concentration of 109 ppm. Foliar SO_4 levels in the bottom response quartile averaged only 45 ppm. 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.

A multiple regression model using two independent variables (foliar N and SO_4) explained 68% of the variation in relative 6-year basal area response 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 lodgepole pine fertilization 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 more than 60 ppm of foliar SO_4, or N:S ratios less than 12, rarely showed large incremental S responses.

By consulting Table 2, pre-fertilization foliar levels of N and SO_4 from lodgepole pine candidate stands can be used to determine the likelihood of obtaining growth responses to fertilization with N alone, or N in

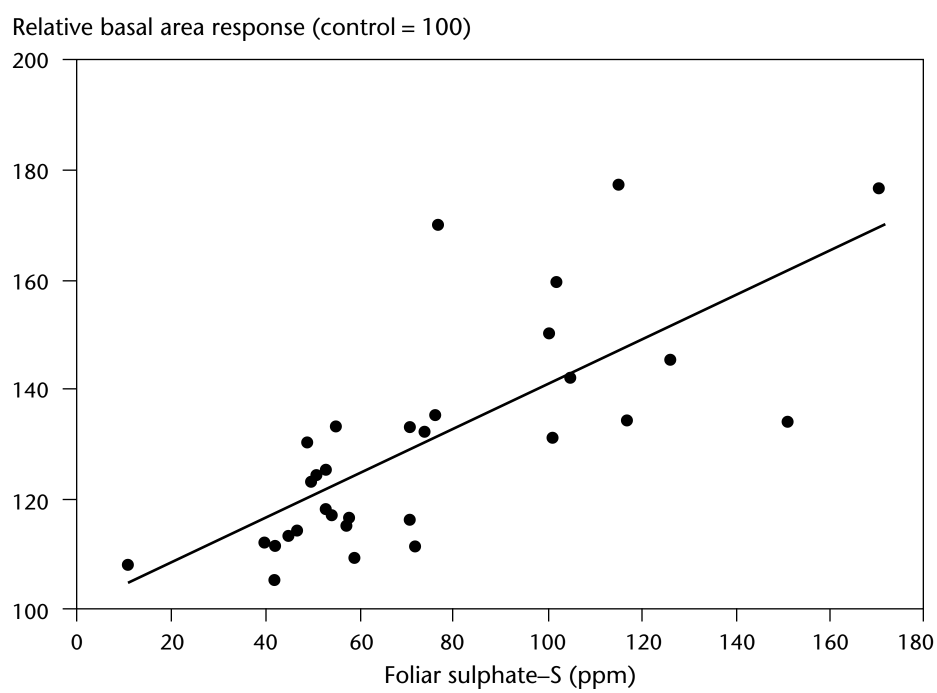

FIGURE 3 *Relationship between relative 6-year basal area response to fertilization with N alone and the concentration of SO_4–S in foliage of unfertilized trees (n = 31). The regression line is fit from the following equation: BA response (control = 100) = 98.9 + 0.41 SO_4–S (ppm); ($R^2 = 0.55$, $SE_E = 13.6$).*

TABLE 2 *The likelihood of obtaining a growth response to fertilization with N alone and N + S predicted from pre-fertilization foliar N and SO_4 levels*

	Foliar N			
	< 1.2%		1.2–1.3%[a]	
Foliar SO_4	N	N + S	N	N + S
≤ 60 ppm	low to moderate (10–30%)[b]	moderate to high (20–40%)	low (0–20%)	moderate to high (20–40%)
> 60 ppm	high (30–60%)	high (30–60%)	low to moderate (10–30%)	low to moderate (10–30%)

a Lodgepole pine stands with greater than 1.3% N are not N deficient and are unlikely to respond to additions of N or N + S.
b Numbers in parentheses indicate the expected range of relative 6-year basal area response.

combination with S. Based on the best available information, the expected ranges of 6-year relative basal area responses to N and N + S additions are also given. Alternatively, and when foliar SO_4 analyses are not available, foliar N and N:S ratios can be used (Table 3).

Management Implications

Results from the 31 fertilization research installations reported here confirm that N is the most important growth-limiting nutrient in Interior lodgepole pine forests. However, the response of lodgepole pine to fertilization with N alone is extremely variable. Although other stand and site factors are undoubtedly involved, results indicate that S deficiencies, either induced or aggravated by additions of N, may have a strong controlling influence on lodgepole pine growth response following fertilization. On some sites, growth responses were significantly improved by adding S in combination with N.

Results from this analysis indicate that pre-fertilization foliar levels of N and SO_4, as well as N:S ratios, are useful for predicting whether lodgepole pine stands in the Interior of British Columbia will respond significantly to fertilization with either N alone or a combination of N and S, and for estimating the magnitude of the expected responses. By using these tools,

TABLE 3 *The likelihood of obtaining a growth response to fertilization with N alone and N + S predicted from pre-fertilization foliar N and N:S levels*

	Foliar N			
	< 1.2%		1.2–1.3%[a]	
Foliar N:S	N	N + S	N	N + S
< 12	high (30–60%)[b]	high (30–60%)	moderate (20–30%)	moderate to high (25–35%)
12–13	moderate (20–30%)	moderate to high (25–40%)	low to moderate (10–30%)	moderate to high (25–35%)
> 13	low (0–20%)	high (30–50%)	low (0–20%)	moderate to high (25–35%)

a Lodgepole pine stands with greater than 1.3% N are not N deficient and are unlikely to respond to additions of N or N + S.
b Numbers in parentheses indicate the expected range of relative 6-year basal area response.

the chances of making the appropriate fertilizer prescription may be significantly improved.

The ability to reliably select responsive stands and to make appropriate fertilizer prescriptions based on the predicted magnitude of growth responses to added N and S will remove much of the uncertainty surrounding lodgepole pine fertilizer operations in the Interior of British Columbia. Future and recently established lodgepole pine fertilization research installations will be used to test and refine predictive models using pre-fertilization foliar levels.

A recent inter-laboratory comparison has shown that choice of commercial laboratory will likely not affect the utility of foliar N as a predictor of lodgepole pine fertilization response potential or interpretations of foliar N status. However, this comparison also indicated that standardized analytical procedures for conifer foliage must be adopted before measures of foliar SO_4 can be reliably used for diagnostic or predictive purposes. Discussions about standardizing foliar SO_4 analytical methods are currently under way with commercial laboratories in the province.

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