GROWTH RESPONSE OF LODGEPOLE PINE TO OPERATIONAL FERTILIZER APPLICATION NEAR BURNS LAKE, B.C.

by
R. P. Brockley and D. Yole

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Internal Reports of the Ministry of Forests Research Program
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by

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ABSTRACT

Assessment of 5-year response to operational nitrogen fertilization of a juvenile-spaced lodgepole pine stand near Burns Lake, B.C. indicated a small (13%) increase in radial increment over that which would have been obtained had it remained unfertilized. The magnitude of the response was substantially less than that reported for lodgepole pine fertilization research trials elsewhere in western North America. Lack of soil moisture, combined with a probable nutrient deficiency other than nitrogen--most likely boron, may have reduced the ability of the stand to respond to spacing and nitrogen application.

Stand and location dissimilarities between the control and fertilized blocks complicated response analysis. The confidence associated with the response could not, therefore, be statistically evaluated. Improved procedures for the selection of candidate areas for operational fertilization and post-treatment monitoring are recommended.
ACKNOWLEDGMENTS

The authors wish to express their appreciation to Neil Endacott (Lakes Forest District) for providing information on the fertilizer operation; to Prince Rupert Forest Region Silviculture Section for support funding; and especially to George Franssen for his assistance with field sampling.
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1 INTRODUCTION

Over the past decade, the use of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) in British Columbia has increased significantly and currently represents about 34% of the timber harvested annually from Interior forests (B.C. Ministry of Forests 1983). Among other species, only the spruce contribute a greater amount than lodgepole pine to the provincial total.

Immature stands of the species occupy approximately 20% (8.1 million ha) of the total productive forest land in the British Columbia Interior (B.C. Ministry of Forests 1980). In fact, management of immature stands may be the key to alleviating timber supply deficits that are forecast for some timber supply areas.

Thinning and fertilization are attractive silvicultural options in that they may substantially increase piece size so that the wood produced from these immature stands can be used nearer the time that timber supply deficits are forecast. The ability of lodgepole pine to respond to thinning is well documented (Smithers 1957; Daniel and Barnes 1959; Dahms 1967; Johnstone 1981a, 1981b, 1982). Research studies undertaken in British Columbia and Alberta, although few in number, indicate lodgepole pine may also be responsive to fertilizer application (Boyd and Strand 1975; Bella 1978; Weetman and Fournier 1982; Yang 1985a, b, 1985b). In eastern Canada, favourable growth response to fertilization has been obtained with semi-mature jack pine (*Pinus banksiana* Lamb.) (Morrison et al. 1976, 1977; Krause et al. 1982; Weetman and Fournier 1984), a species that is ecologically similar to, and interbreeds with, lodgepole pine (Critchfield 1980). In fact, the relative responsiveness of jack pine is ranked high in comparison to other species (Foster and Morrison 1983). In Scandinavia, large-scale operational fertilization of Scots pine (*Pinus sylvestris* L.) is a standard silvicultural treatment. Experience with a number of coniferous species indicates fertilization may be especially beneficial when combined with a thinning operation (Weetman 1975; Jonsson and Möller 1976; Hall et al. 1980; University of Washington 1981).
A number of empirical fertilization research installations have recently been established in young, juvenile-spaced lodgepole pine stands throughout the interior of British Columbia.\(^1\) They will improve present understanding of nutritional and environmental factors affecting growth, and will provide site-specific volume response data required for decisions regarding the feasibility of large-scale fertilizer operations. Unfortunately, little useful information will be available from them for some time. Given the reality of the Interior’s wood supply, operational fertilization may proceed in the absence of reliable growth response data. Indeed, the current 5-year Silviculture Plan for the Prince Rupert Forest Region includes 1500 ha of lodgepole pine fertilization.\(^2\) It is important, therefore, that advantage be taken of any opportunity to evaluate the responsiveness of the species to fertilizer addition. In this regard, a fertilization project undertaken in the Prince Rupert Forest Region was assessed during October 1984. The project represents the only documented operational fertilization of lodgepole pine in the British Columbia Interior.

Assessment of the operational trial was complicated by the variety of the spacing methods used (i.e., various combinations of hand- and row-spacing) and the absence of representative control blocks. This paper reports the estimated 5-year radial growth response in one of the fertilized units. Improved procedures for the selection of candidate areas for fertilizer operations and post-treatment monitoring are recommended.


\(^2\)M. Geisler, personal communication, 1984, B.C. Ministry of Forests.
2 METHODS

2.1 Location and Site Description

The project area is located approximately 30 km east of Burns Lake, B.C. within the Lakes Forest District (see Figure 1). The stands of lodgepole pine in the vicinity originate from a mid-1950's wildfire. Eight young, juvenile-spaced stands (a total of 124 ha) were aerially fertilized with urea (46-0-0) in March 1979. Nitrogen was applied by Bell 205 helicopter (Conair Aviation, Abbotsford, B.C.) at a rate of approximately 200 kg/ha⁻¹.

The fertilized units ranged in size from 5.5 to 27.9 ha. Prior to fertilization, stand densities in all units had been reduced by various combinations of machine- and hand-spacing.

The northernmost block, "Unit 3", was selected to assess responsiveness to the fertilization treatment. It is 27.9 ha in size and was hand-spaced in September 1978. A nearby unfertilized stand, exhibiting similar site and stand characteristics, was selected as a control. It is located approximately 1 km north of "Unit 3" and was hand-spaced in July 1979. It is approximately 14 ha in size.

The fertilized and control units are located within the SBS biogeoclimatic subzone at an elevation of 1100 m. The climate is described as cold sub-boreal, continental humid type, characterized by severe snowy winters and fairly warm, moist summers (Pojar et al. 1984). Soils have formed on coarse-textured morainal till. The overlying ablation till has a large volume of cobbles and stones that are of acidic, igneous intrusive lithology. The underlying basal till is more clay-rich with fewer coarse fragments.

Soil and vegetation reconnaissance indicates the two sites belong to the SBSel/04 (submesic bunchberry-moss) ecosystem association. Soil development is transitional between Gray Luvisols and Podzolic Gray Luvisols (Canada Soil Survey Committee 1978). Further site/stand
characteristics of the control and fertilized units are described below:

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Fertilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>0-5%</td>
<td>0-5%</td>
</tr>
<tr>
<td>Age</td>
<td>27 years</td>
<td>27 years</td>
</tr>
<tr>
<td>Average diameter (cm)</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Average height (m)</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Pre-spacing density (stems/ha)</td>
<td>~8000</td>
<td>~5000</td>
</tr>
<tr>
<td>Post-spacing density (stems/ha)</td>
<td>~1600</td>
<td>~1100</td>
</tr>
</tbody>
</table>

2.2 Sampling Methodology

Thirty sampling points were systematically located at paced intervals along parallel transect lines in both the control and fertilized stands. Transects and sampling points were evenly distributed throughout each area. In the fertilized stand, transects were established perpendicular to the assumed direction of aerial fertilizer application to account for possible variability in nitrogen application rate.

At each sampling point, the nearest relatively healthy, dominant or co-dominant tree was felled and a 2- to 4-cm disc cut from it at breast height (1.3 m). Current year's foliage was collected from the upper crown of each sample tree. The 30 foliage samples from each stand were randomly grouped into three composite samples (i.e., 10 trees per composite). Discs and foliage were frozen while awaiting measurement and analysis.

Subsequent to the above field sampling, twenty 0.05-ha temporary cluster plots were established in the fertilized stand to assess the incidence of red squirrel (Tamiasciurus hudsonicus Erxleben) barking injuries and top die-back. Plots were systematically located at paced intervals along transect lines which were distributed throughout the fertilized area. Within each cluster, the presence or absence of squirrel barking injury or dead top was recorded for each crop tree.
FIGURE 1. Location of 1979 fertilization assessment in the Lakes District of the Prince Rupert Forest Region (reduced for report). Scale approximately 1:28 000.
The proportion of dead tops and squirrel-damaged stems within the fertilized stand was estimated by the ratio-of-means (Freese 1962).

2.3 Disc Measurement

The average radius of each disc was calculated from the following formula:

\[ r = 0.5 \left( D_1 D_2 \right)^{1/2} \]  

(1)

where \( D_1 \) is the size of the largest inside bark diameter and \( D_2 \) is the size of the perpendicular bisector of \( D_1 \). The calculated radius will give the correct disc area when it is substituted in the equation for the area of a circle, if the shape of the disc is elliptical (Husch et al. 1972).

Two average radii, measured from the pith to the inside of the bark, were located and marked on each disc. Five-year pre-treatment (1974-1978) and post-treatment (1980-1984) periods were measured to the nearest 0.1 mm along both average radii. The mean was recorded for each of the two measurement periods per disc.

2.4 Analysis

The conventional method of assessing response to fertilizer application compares the growth of fertilized and control plots (or individual trees) according to their measurement at the time of treatment, and again at the end of a specific response period.

The average treatment response is calculated as follows:

\[ \text{av}(R_f) = \text{av}(A_f) - \text{av}(A_u) \]  

(2)

where

- \( A = \) radial increment during the post-fertilization increment period
- \( R = \) absolute magnitude of radial increment response
- \( \text{av} = \) the average of all replicates
- \( f = \) fertilized
- \( u = \) unfertilized.
This type of evaluation assumes site and stand conditions are similar in fertilized and control plots, and any differences in growth rates after treatment are the result of fertilizer addition. Statistical analysis requires that treatment and control plots be replicated and properly randomized so that location variability can be separated from treatment response.

In this study, evaluation of treatment response was confounded by stand differences between the control and treated blocks. The former was hand-spaced approximately 1 year after the fertilized stand, and shorter, smaller diameter trees reflected higher pre-spacing density, as well as other possible site differences.

A technique commonly referred to as the "quotient method" was used to at least partially compensate for these differences. Many variations of the technique have been used in the analysis of European fertilization experiments (Lipas 1979). Although it has been most commonly used to analyze volume response data from conventional, fixed-area fertilization research plots, it was applied here to the analysis of radial increments of individual trees within the control and fertilized stands in a fashion similar to that proposed by Ballard and Majid (1985).

The objective of the method is to estimate the radial growth of fertilized trees had they not been fertilized, and to subtract this estimate from their measured post-treatment radial increment. Average response for several trees may be calculated as follows:

\[
\text{av}(R_f) = \text{av}(A_f) - \text{av}[(B_f) \text{ av}(A_u/B_u)]
\]  

(3)

where \( A, R, \text{av}, f, \) and \( u \) are as defined for Equation 2, and

\( B \) = radial increment during the pre-fertilization period.

Although there will be some variation among different trees, Equation 3 assumes that \( (A_u/B_u) \) is fairly insensitive to site and stand differences between the fertilized and control units. Results reported by Ballard and Majid (1985) support this assumption, provided that substantial between-site differences in soil moisture regime and climate do not exist.
Radial increment measurements from the 30 discs per stand were applied to Equation 3. Unfortunately, treatment differences remained partially confounded by location variability. Therefore, the statistical significance of differences on the right of Equation 3 (n=30) could not be tested.
RESULTS AND DISCUSSION

Comparison of unfertilized radial increments for the pre- and post-fertilization periods ($B_U$ and $A_U$, respectively) indicates that trees within the control stand did not respond positively to the 1979 juvenile-spacing operation (Table 1). In fact, results suggest a slight decline in radial increment for the 5-year period following spacing. This is contrary to results generally reported for young lodgepole pine (Johnstone 1981a, 1981b; 1982) and indicates that nutrients and/or moisture are probably important growth-limiting factors on this site.

<table>
<thead>
<tr>
<th>TABLE 1.</th>
<th>Mean radial increment ($\bar{x}$) of control and fertilized stands during the pre- and post-fertilization period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radial increment period</td>
</tr>
<tr>
<td></td>
<td>1974 - 1978</td>
</tr>
<tr>
<td></td>
<td>Control ($B_U$)</td>
</tr>
<tr>
<td></td>
<td>Control ($A_U$)</td>
</tr>
<tr>
<td>$\bar{x}$ (cm)</td>
<td>0.91</td>
</tr>
<tr>
<td>Coefficient of variation (c.v.)</td>
<td>0.11</td>
</tr>
<tr>
<td># samples</td>
<td>13</td>
</tr>
</tbody>
</table>

$^a$Means based on 30 replicates of each treatment.

$^b$Number of samples necessary to achieve a precision of $\pm$ 0.05 cm at the 90% confidence level.

The use of Equation 2 indicates a favourable (37.5%) radial increment response to nitrogen fertilization (Table 2). However, the large difference in pre-treatment growth rates between the fertilized and control stand ($B_F$ and $B_U$, respectively, in Table 1) substantially reduces the reliability of this result and clearly illustrates the weakness of using unadjusted data in
response analysis. The larger increment value for \( B_f \) is probably largely a function of greater average diameter and lower pre-spacing density of the fertilized stand.

As indicated in Table 2, use of the "quotient method" (i.e., Equation 3) compensated for the difference in diameter between the control and fertilized stand, as well as for the slight reduction in radial increment of the unfertilized trees during the post-fertilization period. Consequently, the estimated 5-year radial increment response (13\%) was much smaller than that calculated from Equation 2.

<table>
<thead>
<tr>
<th></th>
<th>( A_U )</th>
<th>( A_f )</th>
<th>( (B_f)_{av} (A_U/B_U) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n )</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Mean</td>
<td>0.88</td>
<td>1.21</td>
<td>1.07</td>
</tr>
<tr>
<td>Coefficient of</td>
<td>0.17</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>variation (c.v.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>0.33 (37.5%)</td>
<td>0.14 (13%)</td>
<td></td>
</tr>
<tr>
<td>Parameter Equation</td>
<td>av(R)</td>
<td>av(R)</td>
<td></td>
</tr>
<tr>
<td>Equation</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

The box plots in Figure 2 give a diagrammic display of the sample mean and associated variation for variables used in Equations 2 and 3. In a single figure they convey size of variability, skewness, location of mean and median, and range, and allow readers to make their own judgements regarding
the confidence or reliability of any given mean estimate (Tukey 1977). Box plots contain the following information:

![Box plot diagram]

The magnitude of the estimated response (13%) is substantially less than that reported for lodgepole pine fertilization research trials elsewhere in western North America. Bella (1978) reported a 30% increase in mean diameter increment over the 7-year period following nitrogen fertilization of a thinned, 70-year-old lodgepole pine stand in Alberta. In another Alberta study, diameter responses as high as 100% were obtained over the 10-year period following fertilization of 30-year-old lodgepole pine (Yang 1985b). In Oregon, Cochran (1979) reported a 102% response in diameter increment 8 years after a heavy application of NPS fertilizer.

Although undoubtedly attributable in part to operational "falldown" (i.e., the difference between predicted and measured growth response caused by variability in stand structure and fertilizer application rate), the small response may be largely explained by other site-related factors. Trees growing in the study area likely experience periods of moisture stress during the growing season.\(^3\) Insufficient soil water would certainly reduce the

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\(^3\) R. Trowbridge, personal communication, 1984, B.C. Ministry of Forests.
FIGURE 2. Box plots of 5-year radial increment before (B) and after (A) fertilization in control (U) and fertilized (F) stands.
ability of the stand to respond to the fertilizer treatment, and may also account for the inability of the control stand to respond positively to juvenile-spacing. In addition, a nutrient deficiency other than nitrogen may have limited the response to nitrogen fertilization. Two adjacent nitrogen fertilization research installations established in 1982 have been tentatively diagnosed as boron-deficient based on extremely low foliar boron concentrations (<5 ppm) and a small response in foliage dry mass in the year following nitrogen application (R. Brockley, unpubl. data, 1983, B.C. Ministry of Forests). The fact that the operationally fertilized stand exhibits many of the visual characteristics observed in the research installations (i.e., leader die-back, excessive forking, heavy branching, swelling of stem nodes) indicates that it may also suffer from a similar nutrient disorder despite slightly higher foliar boron concentrations (see Appendix 1).

Although boron deficiencies have not been documented in forests elsewhere in the British Columbia Interior, they commonly occur in agricultural crops (B.C. Ministry of Agriculture 1978). Moreover, Carter et al. (1984) reported boron deficiency symptoms in a number of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) plantations throughout the submontane variant of the CWHb biogeoclimatic subzone. First- and 2nd-year results from fertilizer trials showed dramatic improvement in needle colour, needle length, and branch elongation following boron application. Boron deficiencies in Scandinavian forests are well documented (Braekke 1979; Kolari 1979; Möller 1983; Veijalainen et al. 1984).

Many lodgepole pine trees in the fertilized stand exhibited top die-back and red squirrel barking injuries (16% and 13%, respectively). Neither of these symptoms was evident in the control stand.

The slightly lower foliar boron concentrations and relatively high incidence of top die-back (Figure 3) within the fertilized stand indicate boron deficiency may have been intensified by nitrogen fertilization. As a result of the observed frequency of top die-back following nitrogen

\[4\] R. Carter, personal communication, 1984, University of British Columbia.
FIGURE 3. Top die-back following operational nitrogen fertilization in a lodgepole pine stand near Burns Lake, B.C. Visual symptoms and foliar boron concentrations are indicative of boron deficiency.
application in Sweden, it is now recommended that boron be mixed with nitrogen when fertilizers are applied north of 60° latitude (Möller 1983).

A fertilization research trial was established in the control stand during October 1984 to determine whether boron fertilization—alone and in conjunction with urea—can improve the vigour of this stand.\textsuperscript{5}

The incidence of squirrel damage in the fertilized stand agrees with results from research undertaken elsewhere in the British Columbia Interior. Sullivan and Sullivan (1982) indicated that fertilized lodgepole pine trees may sustain up to 3-4 times the amount of tissue loss compared to unfertilized trees in the same stand. Measurement of squirrel damage in a lodgepole pine fertilization research trial near Kamloops, B.C., showed damage in fertilized plots to be significantly greater than that in unfertilized plots (R. Brockley, unpubl. data, 1984, B.C. Ministry of Forests).

4 CONCLUSIONS AND RECOMMENDATIONS

Results indicate a small (13%) increase in radial increment in the fertilized stand over that which would have been obtained if it had remained unfertilized during the 5-year period following fertilization. Lack of soil moisture, combined with a probable nutrient deficiency other than nitrogen—most likely boron, may have reduced the ability of the stand to respond to nitrogen application.

Dissimilarities between the control and fertilized stands complicated assessment of the operational trial, and treatment differences were partially confounded by location variability. The confidence associated with the response, therefore, could not be statistically evaluated.

Experience gained from this project has been of value in identifying factors that should be considered in future fertilizer operations:

1. The fertilizer operation must be well documented. Information on direction of flight, uniformity of application, and weather at the time of, and immediately following, fertilizer application should be noted, even if collection of detailed information is not feasible. These factors may not only affect response, but can also aid in the development of assessment strategy and in the interpretation of results.

2. The response potential of candidate stands should be evaluated prior to fertilization. Those sites where non-nutritional factors (e.g., soil moisture) are limiting or near-limiting should be assigned lower priority for operational fertilization.

Foliar sampling should be undertaken in all candidate stands to evaluate the nutrient status of the site and determine those nutrients most likely limiting growth. However, foliar analysis alone may not permit an accurate prediction of fertilizer response potential. Identification of potentially responsive stands may be improved by the estimation of the nitrogen mineralization potential of soil samples collected from candidate sites. Promising relationships have been reported between mineralization indices of soil nitrogen availability and growth response following nitrogen fertilization (Shumway and Atkinson 1978; Powers 1980). The fertilizer screening technique outlined by Weetman and Fournier (1982) may also facilitate the selection process. Screening trials have been found to be time- and cost-efficient, and produce foliage biomass response data and nutrient status diagnosis within 1 year of fertilizer application.
Prediction of the potential responsiveness of a stand to fertilization is complicated when multiple nutrient deficiencies are suspected. It is recommended, therefore, that large-scale operational projects undertaken in the foreseeable future concentrate on stands where severe nutrient deficiencies are diagnosed for one or two nutrient elements only.

3. The potential risk of small mammal damage should be considered when candidate stands for operational fertilization are selected. Stands in which damage is noted during the pre-treatment survey should be assigned lower priorities. The development of damage in fertilized stands should be monitored over time.

4. Strategy for assessing growth response must be developed prior to operational fertilization. Control blocks should reflect, as closely as possible, the stand and site characteristics of the area to be fertilized (i.e., soil properties, age, diameter, height, pre- and post-spacing density). It is also important that control and fertilized stands share similar treatment history (i.e., method and date of juvenile-spacing). Efficient and reliable methodologies for monitoring growth response to operational fertilization must be developed.

5. Irregular dispersal and variable stand and site conditions within operational areas make quantitative measurement of treatment response extremely difficult. Moreover, because large treatment areas are generally required for economical aerial fertilization, it is virtually impossible to provide sufficient replication and randomization of control and fertilized treatments to enable evaluation of the statistical confidence associated with response to fertilizer application. Reliable growth response information can only be obtained from well-designed fertilization research experiments. Although expensive to establish, they are essential if the resource manager is to be provided with the data necessary to make informed decisions on operational forest fertilization.
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APPENDIX 1. Foliar nutrient concentrations in fertilized and control stands 5 years following fertilization. (Means are based on three composite samples.)

<table>
<thead>
<tr>
<th>Element</th>
<th>Fertilized</th>
<th>Control</th>
<th>Deficiency level$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N%</td>
<td>1.20</td>
<td>1.18</td>
<td>1.20</td>
</tr>
<tr>
<td>P%</td>
<td>0.15</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>K%</td>
<td>0.45</td>
<td>0.49</td>
<td>0.40</td>
</tr>
<tr>
<td>Ca%</td>
<td>0.16</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>Mg%</td>
<td>0.09</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>4</td>
<td>5</td>
<td>2.6 - 4</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>47</td>
<td>53</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Fe ppm</td>
<td>48</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>Mn ppm</td>
<td>228</td>
<td>509</td>
<td>25</td>
</tr>
<tr>
<td>B ppm</td>
<td>7</td>
<td>10</td>
<td>10 - 20</td>
</tr>
</tbody>
</table>

$^a$Based on preliminary diagnostic criteria reported by Ballard (1980).