Extension Note

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Effects of Repeated Fertilization on Fine Roots, Mycorrhizae, and Soil Mesofauna in Young Lodgepole Pine and Spruce Forests in Central British Columbia

Abstract

The 10-year effects of different regimes of repeated fertilization on fine roots, mycorrhizae, and soil mesofauna were evaluated in young stands of lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) and interior spruce (Picea glauca [Moench] Voss, Picea engelmannii Parry, and their naturally occurring hybrids) in central British Columbia. Fine root attributes and mesofauna responded differently to repeated fertilization regimes at the pine and spruce study sites. The length and vigour of lodgepole pine fine roots, the abundance of active roots, and the percent mycorrhizal colonization decreased with fertilization, especially in the most intensive fertilization regime. In contrast, the fine roots of fertilized interior spruce increased in length and the relative abundance of active and mycorrhizal roots was unaffected by treatment. Repeated fertilization of lodgepole pine altered mycorrhizal community structure and reduced species richness (number of species) and diversity (evenness). However, fertilization had a relatively small effect on mycorrhizal community structure, richness, and diversity at the spruce site. Total Acari (mite) densities declined in the forest floor and upper mineral soil following intensive fertilization of lodgepole pine. In contrast, the density of mites in the soils under interior spruce responded positively to repeated fertilization. It is not possible to ascribe the different responses of fine roots, ectomycorrhizae, and soil mesofauna found at these two sites to a specific cause, nor is it possible to state with certainty that the previously reported differences in aboveground tree growth responses of pine and spruce at these two sites (small and large, respectively) are directly linked with the belowground changes. Root and soil biota characteristics at other lodgepole pine and spruce “maximum productivity” sites are currently being examined to further understand the possible relationship between tree species and above- and belowground changes following repeated fertilization and the functional relevance of these effects.

Introduction

Nutrient deficiencies are widespread throughout the British Columbia interior, and the growth benefits of fertilizing with nitrogen (N) and other nutrients have been well documented for several conifer species. Although a single fertilizer application typically produces only a temporary increase
in tree and stand growth, fertilization research in boreal forests indicates that sustained growth responses and large reductions in rotation length are achievable by repeatedly fertilizing young conifer stands. Similar productivity gains in young lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) and interior spruce (*Picea glauca* [Moench] Voss, *Picea engelmannii* Parry, and their naturally occurring hybrids) sub-boreal forests would be of great benefit in addressing future timber supply challenges in the British Columbia interior. However, repeated nutrient additions may also affect belowground biological components of forest ecosystems. Large and persistent changes in fine root development and in the activity, diversity, and structure of mycorrhizal and mesofaunal communities may potentially affect processes such as nutrient cycling, nutrient uptake, and drought tolerance, in repeatedly fertilized stands.

Beginning in 1992, a small network of lodgepole pine and interior spruce long-term “maximum productivity” research installations (E.P. 886.13) was established by the B.C. Ministry of Forests to document the effects of different regimes and frequencies of repeated fertilization on above- and belowground timber and non-timber forest resources. This Extension Note examines the 10-year effects of annual nutrient additions on fine root length, ectomycorrhizal colonization, and mesofaunal abundance and community structure at two “maximum productivity” study sites (one pine and one spruce) within the Babine Moist Cold variant of the Sub-Boreal Spruce (SBS) biogeoclimatic zone (SBSdw2) (Steen and Coupé 1997). The site is occupied by a naturally regenerated lodgepole pine stand originating from a 1978 clearcut and subsequent drag scarification. At the time of installation establishment in 1992, the 13-year-old stand had an average density of 20 000 trees per hectare. The study area was thinned to a uniform density of 1100 trees per hectare during installation establishment.

The Crow Creek study site is located southeast of Houston, B.C., within the Babine Moist Cold variant of the SBS zone (SBSmc2) (Banner et al. 1993). The site was planted with interior spruce seedlings following clearcutting and broadcast burning. The 9-year-old plantation was thinned to a uniform density of 1100 trees per hectare during installation establishment in 1994.

Each site is arranged in a completely randomized design, with six treatments replicated three times for a total of eighteen 0.164 ha treatment plots. Each treatment plot consists of an inner, 0.058 ha “assessment” area surrounded by a treated buffer. Treatments are described in Table 1. Only three of the six treatments (Control, ON1, and ON2) were included in this study. The ON1 and ON2 treatments are patterned after Swedish “optimum nutrition” experiments (Tamm 1991), and typically receive 50–100 kg N/ha and 100–200 kg N/ha, respectively, each spring. Other nutrients (phosphorus [P], potassium [K], magnesium [Mg], sulphur [S], boron [B]) are added periodically to provide an appropriate nutrient balance and to minimize growth limitations caused by secondary deficiencies. Brockley and Simpson (2004) provide a more complete description of fertilizer regimes.

**Methods**

The Sheridan Creek study site is located northeast of Williams Lake, B.C., within the Blackwater Dry Warm variant of the Sub-Boreal Spruce (SBS) biogeoclimatic zone (SBSdw2) (Steen and Coupé 1997). The site is occupied by a naturally regenerated lodgepole pine stand originating from a 1978 clearcut and subsequent drag scarification. At the time of installation establishment in 1992, the 13-year-old stand had an average density of 20 000 trees per hectare. The study area was thinned to a uniform density of 1100 trees per hectare during installation establishment.

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<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Not fertilized</td>
</tr>
<tr>
<td>NB</td>
<td>Fertilize every 6 years with 200N, 1.5B</td>
</tr>
<tr>
<td>NSB</td>
<td>Fertilize every 6 years with 200N, 50S, 1.5B</td>
</tr>
<tr>
<td>Complete</td>
<td>Fertilize every 6 years with 200N, 100P, 100K, 50S, 25Mg, 1.5B</td>
</tr>
<tr>
<td>ON1</td>
<td>Fertilize yearly to maintain foliar N concentration at 1.3% and other nutrients in balance with foliar N</td>
</tr>
<tr>
<td>ON2</td>
<td>Fertilize yearly to maintain foliar N concentration at 1.6% and other nutrients in balance with foliar N</td>
</tr>
</tbody>
</table>

**Note:** For each treatment, numbers preceding each nutrient symbol represent nutrient application rate (kg/ha). Nutrient abbreviations: B, boron; K, potassium; Mg, magnesium; N, nitrogen; P, phosphorus; S, sulphur.

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At Sheridan Creek, N additions to ON1 and ON2 treatments totalled 700 and 1350 kg/ha, respectively, over 10 years. For both treatments, the total amounts of other added nutrients were (kg/ha): 400P, 279S, 257Mg, and 4.5B. At Crow Creek, ON1 and ON2 plots received 800 and 1400 kg N/ha, respectively, over 10 years. Additions of other nutrients totalled (kg/ha): 350P, 400K, 312S, 232Mg, and 7.5B.

Soil sampling
In mid-September 2002, soil samples were collected from the three replicates of the control, ON1, and ON2 treatments at the Sheridan Creek study site. For soil mesofauna, 10 separate forest floor and upper mineral soil (0–3 cm) subsamples were randomly collected from each plot using a 4.5-cm internal diameter-corning device. For ectomycorrhizae and fine roots, ten 10×10×10 cm combined forest floor and mineral soil samples were randomly collected. Detailed sampling and analytical methodology is provided by Berch et al. (2006). Identical methodology was used to collect samples from the Crow Creek site in September 2004. Soil sampling at both sites coincided with the completion of the 10th growing season following installation establishment.

Fresh soil samples were placed in a modified high-gradient extractor for 1 week and the collected mesofauna samples were sorted and counted under a dissecting microscope. Conifer fine roots (< 2 mm diameter) were extracted by gently washing the soil from the roots over a 1-mm sieve. Root length was estimated by the line intercept method (Tennant 1975). The ectomycorrhizal community was quantified and characterized by cutting the root systems into 2-cm sections, which were randomly selected until 200 active mycorrhizal roots had been encountered (or until all mycorrhizal roots had been counted) in addition to inactive and non-mycorrhizal tips. Ectomycorrhizae were observed under magnification and subsequently classified using the procedure described by Goodman et al. (1996).

Analysis of variance was used to compare mesofauna and fine root values among the three treatments with forest floor and mineral soil samples analyzed separately for mesofauna. If significant differences were found with ANOVA, then Tukey’s pair-wise comparison was used to compare individual treatment means.

Results

Fine roots and ectomycorrhizae
Estimated fine root length was significantly affected by treatment at both sites. At Sheridan Creek, the fine root length of lodgepole pine declined significantly with increasing fertilization intensity (Figure 1). Conversely, repeated fertilization had a positive effect on the length of spruce roots at Crow Creek, especially in the ON1 treatment (Figure 1).

The relative abundance of mycorrhizal pine roots declined following repeated fertilization at Sheridan Creek, especially in the ON2 treatment where mycorrhizal roots accounted for only 30% of the sampled fine root population after 10 years (Figure 2a). Non-mycorrhizal pine roots increased in frequency with increasing fertilization intensity. On average, 58% of the sampled roots in the ON2 treatment at Sheridan Creek were inactive, compared to only 32% inactive roots in the Control treatment (Figure 2a). At Crow Creek, the relative abundance of mycorrhizal and inactive spruce roots was comparatively unaffected by treatment (Figure 2b). No active non-mycorrhizal roots were found at Crow Creek.

Seven dominant ectomycorrhizal types constituted 84% of the total mycorrhizal community over the three treatments at Sheridan Creek. Repeated fertilization altered community structure and reduced mycorrhizal species richness (number of dominant species) and diversity (evenness) at this site, especially in the ON2 treatment (Figure 3a). Some types were more sensitive to fertilization than others. Specifically, fertilization eliminated or greatly reduced the abundance of *Russula* sp., *Suillus* sp., *Piloderma* (white) sp., and

![Figure 1](image-url)  **Figure 1**  Mean fine root length in combined forest floor and mineral soil cores by treatment at Sheridan creek (lodgepole pine) and Crow Creek (interior spruce). For each site, bars topped by different letters are significantly different (p < 0.05).
Cenococcum sp. ectomycorrhizae (Figure 3a). In contrast, other types either increased with fertilization (Wilcoxina sp.) or remained unaffected (Mycelium radicis-atrovirens and Amphinema sp.).

Overall, mycorrhizal species richness was lower at Crow Creek, where five dominant types constituted 91% of the total mycorrhizal community over the three treatments. Fertilization had a relatively small effect on ectomycorrhizal community structure, species richness, and species diversity at Crow Creek (Figure 3b). The relative abundance of Mycelium radicis-atrovirens decreased with increasing fertilization intensity, and that of Wilcoxina sp. increased.

**Soil mesofauna**

At Sheridan Creek, a significant decline in forest floor Acari (mite) densities was evident in the ON2 treatment compared to the Control and ON1 treatments (Figure 4a). In contrast, the density of mites in the forest floor at Crow Creek significantly increased in both ON1 and ON2 treatments compared to the Control (Figure 4b). Although absolute densities of Acari were lower, the treatment effects in mineral soils were similar to the trends observed in forest soils at both sites (Figure 4a,b).

Overall, the effects of fertilization on Collembola (springtails) were relatively small at both sites. However, the density of Collembola was apparently higher in the ON2 treatment compared to the Control and ON1 treatments in forest floors and mineral soils at Sheridan Creek (Figure 4a). In contrast, Collembola densities were unaffected by treatment in forest floors and mineral soils at Crow Creek (Figure 4b).

**Summary and Management Implications**

At Sheridan Creek, negative effects of repeated fertilization on lodgepole pine fine root length and vigour, mycorrhizal colonization, and Acari density (especially at the ON2 level) were associated with relatively small aboveground growth responses (Brockley and Simpson 2004; Brockley 2007a). In the ON1 treatment, yearly additions of fertilizer produced 14 m³/ha more wood than control treatments (a 51% increase) over 9 years at Sheridan Creek. Nine-year gains in stand volume with the ON2 treatment were only 11 m³/ha, representing a relative increase of just 40%. The neutral or positive effects on spruce fine root length and vigour, mycorrhizal colonization, and soil mesofauna after 10 years of annual nutrient additions at Crow Creek were associated with large tree growth responses. After 9 years, stand volume gains (relative to the Control) with the
ON1 and ON2 treatments were 209% and 290%, respectively (Brockley and Simpson 2004). The corresponding absolute stand volume gains were 32 and 45 m$^3$/ha, respectively. Interestingly, similar negative dose-response relationships have been reported for other heavily N-fertilized Pinus species in boreal forests (Weetman et al. 1995; Tamm et al. 1999), whereas the response of Norway spruce (Picea abies L.) to intensive fertilization has generally been very positive (Tamm 1991; Bergh et al. 2005).

It is not possible to ascribe the different responses of fine roots, ectomycorrhizae, and soil mesofauna at the Sheridan Creek and Crow Creek study sites to a specific cause, nor is it possible to state with certainty that the differences in aboveground tree growth responses of these two species are directly linked with the belowground changes. The age of trees and the total amounts of N and other nutrients added between study establishment and soil sampling are very similar at both sites. However, the climatic characteristics vary considerably between the two sites. The climate of the SBSmc biogeoclimatic variant at Crow Creek is wetter and cooler than the SBSdw variant at Sheridan Creek. Also, differences in crown closure and below-canopy light characteristics in unfertilized and fertilized treatment plots at the two sites, and associated differences in microclimate, litterfall, litter decomposition, and understory vegetation, may have affected belowground processes (Brockley and Simpson 2004; Brockley 2007b). Differences in soil nutrient levels in the unfertilized control plots are also evident at the two sites (Berch et al. 2006; Berch et al. 2007). Given these stand and site differences, root and soil biota characteristics at other lodgepole pine and spruce “maximum productivity” sites are currently being examined to further understand the possible relationship between tree species and above- and belowground changes in response to repeated fertilization and the functional relevance of these effects. Less intensive fertilizer regimes that approximate operational treatments are included in these studies to elicit a better understanding of possible management implications.

**Literature Cited**


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**Figure 3** Mean relative abundance of ectomycorrhizal types by treatment at (a) Sheridan Creek (lodgepole pine) and (b) Crow Creek (interior spruce).
Figure 4: Mean mesofauna density in forest floor and mineral soil at (a) Sheridan Creek (lodgepole pine) and (b) Crow Creek (interior spruce). For each soil and mesofauna type, bars topped by different letters are significantly different (p < 0.05).


Web Resources

More information on B.C. Ministry of Forests and Range fertilization research, including project descriptions and links to additional publications, is available at: http://www.for.gov.bc.ca/hre/standman/trtfert.htm

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Citation


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