Prince George, Prince Rupert and Cariboo Forest Regions

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Note #LTSPS-07

LTSPS RESEARCH NOTE

Short-term Effects of Forest Soil Compaction and Site Organic Matter Removal on Mineralizable Soil Nitrogen in Central British Columbia

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Abstract

Mineralizable nitrogen (min-N) often correlates well with plant-available nitrogen (N) in soils, and might serve as a useful indicator of whether soils are detrimentally affected by timber harvesting practices. We examined how min-N responded to soil compaction and site organic matter removal after 1 and 5 years on three sites in central British Columbia. Mineral soil min-N was found to change after disturbance, increasing on some plots after 5 years by as much as 20 mg kg^{-1}. Some of the lowest min-N concentrations were found after forest floor removal, but inconsistent responses across compaction treatments and sites made it difficult to generalize on the overall effects of soil disturbance. Forest floor min-N increased across all plots in the first years after tree harvest, but returned to pre-harvest levels by year 5, with no effects detected from compaction or whole-tree harvest. The net change in mineral soil min-N was significantly correlated to foliar N of white spruce, but not lodgepole pine. Although levels of min-N were able to demonstrate some differences in soil productivity, its usefulness as a management tool would require a better understanding of mechanisms causing changes in min-N after disturbance.

Introduction

The Long-Term Soil Productivity (LTSP) study seeks to understand the long-term effects of organic matter removal and soil compaction on tree growth and related ecosystem processes. The LTSP study has been replicated across many major soil and forest types in North America. The study tests whether one-time changes in soil porosity and site organic matter could affect site productivity, and if so, determines the duration and consistency of any effects across forest types.

One key soil property likely to be affected by soil disturbance is mineralizable nitrogen (min-N). Min-N, measured through anaerobic laboratory incubation, is a labile pool of soil nitrogen (N) that correlates strongly with microbial biomass (Myrold 1987), and has been found to correlate well with plant-available N in forests (Powers 1980; Kabzems and Klinka 1987; Klinka et al. 1994; Chen et al. 1998). This labile N pool (likely a combination of microbial organisms and other forms of readily decomposable organic matter) could be affected by soil disturbance through changes in soil temperature, moisture content, aeration status, and carbon inputs. Min-N might therefore be used to detect changes in soil nutrient cycling after disturbance.

To be an effective tool, min-N should correlate well with tree growth, and should change consistently and predictably across comparable sites. A useful indicator should also allow a clear, early diagnosis of detrimental effects caused by poor management practices. For these reasons, we examined the change in soil min-N concentrations from pre-harvest to year 1 and year 5 (post-treatment) of the LTSP experiment in central British Columbia. In addition, min-N concentrations from the mineral soils and forest floors were compared with foliar N concentrations of hybrid white spruce (*Picea engelmannii* x *glauca*) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) to determine whether min-N re-

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flected N-availability in young plantations. These results will contribute to our understanding of min-N response to soil disturbance, and further evaluate its potential as an indicator of soil nutrient supply.

Materials and Methods

Three subzones were selected as sites for the LTSP installations to cover the range in climatic conditions within Sub-Boreal Spruce (SBS) forests: the moist, cold SBSmc subzone near Houston, B.C.; the wet, cool SBSwk near Prince George, B.C.; and the dry, warm SBSdw near Williams Lake, B.C. Each site has deep, medium-textured, skeletal soils (> 35% coarse fragments by volume), derived from morainal blankets, with average soil moisture and nutrient status for the subzone (Table 1).

Each site has nine plots (40 x 70 m each), arranged in a factorial combination of three organic matter removal treatments,

1. OM1 - Stem (boles) only removed
2. OM2 - Stems and crowns removed (whole-tree harvesting)
3. OM3 - Whole-tree and forest floor removed (scalped to mineral soil),

and three soil compaction treatments,

1. C0 - No compaction
2. C1 - Light compaction (2-cm impression into mineral soil)
3. C2 - Heavy compaction (4-cm impression).

Forest floor and mineral soils were sampled for chemical properties before tree harvesting (pre-harvest), year 1 after treatment, and again at year 5 after treatment. The soil sampling occurred in June of each year, during the active growing season, when min-N values are typically highest. Mineralizable N was determined through a 2-week anaerobic incubation at 30°C, followed by a 4 *M* KCl (potassium chloride) extraction and colorimetric analysis for ammonium N. Foliar N concentrations were determined from white spruce and lodgepole saplings in September of year 5.

Statistics

The results of this experiment (a randomized complete block design with subsamples) were tested by an analysis of covariance. Plot means in years 1 and 5 were tested with pre-harvest plot means as a covariate, with site and site interactions randomized. The covariate analysis was illustrated graphically by the net change in min-N, determined by subtracting the pre-harvest plot mean

TABLE 1. Site properties for the British Columbia LTSP Sub-Boreal Spruce zone sites

Site Series	SBSwk 01/Spruce—Oak fern	SBSdw 01/Spruce—Douglas-fir—Pinegrass	SBSmc 01/Spruce—Huckleberry
Elevation	785 m	1050 m	1100 m
Mean annual temperature[a]	3.7°C	4.1°C	2.8°C
Mean annual precipitation[a]	615 mm	425 mm	530 mm
Slope	0–3%	Level	2–12%
Soil classification	Gleyed/Eluviated Dystric Brunisol	Orthic Gray Luvisol	Orthic/Gleyed Gray Luvisol
Soil texture[b]	Silt loam over loam	Loam	Loam to clay loam
Coarse fragments[b]	37–41%	30–39%	21–40%
Forest floor	Hemimor, 6.7 cm	Hemimor, 5.2 cm	Hemimor, 6.6 cm
Dominant pre-harvest tree spp.	*Abies lasiocarpa, Pseudotsuga menziesii, Picea glauca* x *engelmannii*	*Pinus contorta, Picea glauca* x *engelmannii*	*Pinus contorta, Abies lasiocarpa, Picea glauca* x *engelmannii*
Site index (m @ 50/yrs)	*Picea glauca*–18.5 *Pseudotsuga menziesii* –19.2	*Pinus contorta*–17.9	*Picea glauca*–16.1 *Pinus contorta*–15.7
Age (years)	140	112	140
Gross vol. (m/ha)	437	161	424

[a] 30-year normals, Environment Canada.
[b] 0–20 cm.

from plot means of years 1 and 5. We tested whether min-N concentrations explained treatment effects on foliar N using a general linear model. Min-N was tested first and then site and treatment effects were added sequentially to the model. Those terms found to be significant were then kept in the model and the resulting parameter estimates determined.

Results

Mineral Soil

Min-N levels of the mineral soil varied by site, with the highest concentrations at the SBSmc site, perhaps reflecting the higher concentrations of soil organic matter and total-N (Table 2). The combined pre-harvest min-N levels ranged from 12 to 24 mg kg^{-1} (Figure 1), and were a significant covariate in the analysis (Table 3). In year 1, there was some evidence of treatment and interaction effects (p values of 0.11 and 0.10, respectively), and the scalped (OM3) plots tended to have the lowest levels of min-N. In year 5, the patterns were similar, but the high standard errors demonstrated the considerable variation in min-N concentrations across treatments. In both years of post-treatment sampling, the light compaction (C1) treatment was an outlier for plots with forest floors retained (OM1 and OM2).

We also plotted the net change in pre-harvest to post-treatment values of soil min-N. In year 1, the smallest change in min-N was generally on scalped plots (OM3), with the exception again of the light compaction (C1) treatment (Figure 2). By year 5, the net change in min-N was more variable across organic matter treatments, with little consistency between compaction treatments, making it difficult to generalize how these disturbances affected min-N. Treatment combinations were not replicated within sites, so testing min-N response by sites separately would be inconclusive and outside our objective of finding broader, consistent patterns of min-N response to soil disturbance.

Min-N concentrations of the mineral soil increased by approximately 20% in year 1 across all plots, which was maintained in year 5 (Figure 3), although variation between plots was high. For treatment means, a net increase of 10 mg kg^{-1} in min-N (Figure 2) represented an average increase of approximately 70% over pre-harvest concentrations. In year 5, the largest net increase we found for any plot was approximately 20 mg kg^{-1}.

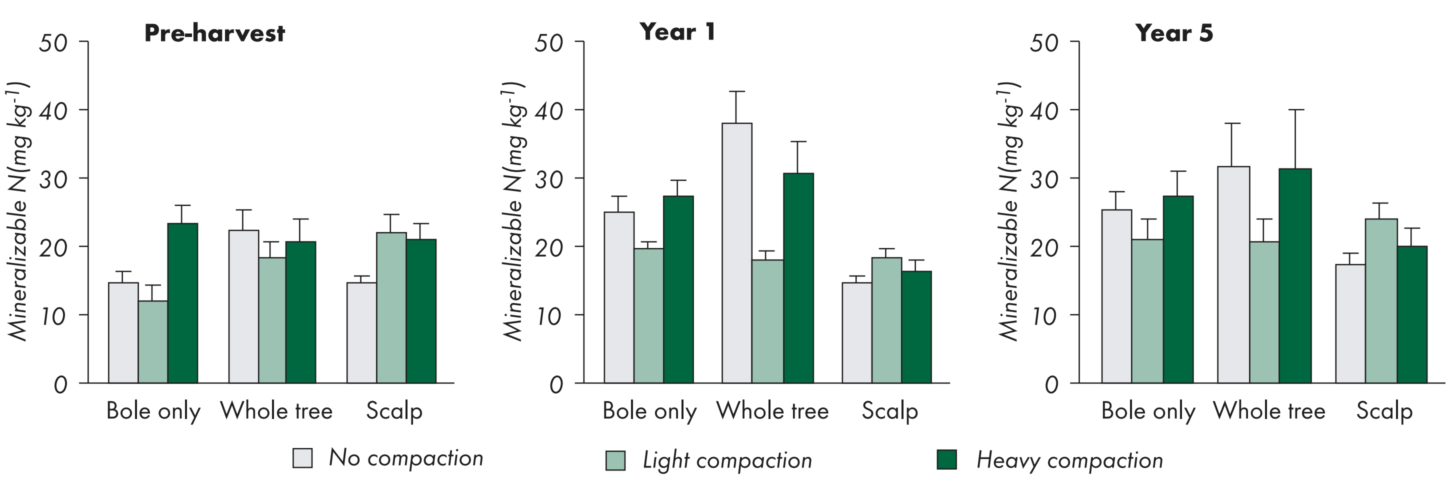
Forest Floor

The forest floor concentrations of min-N were more consistent than mineral soils, and pre-harvest concentrations were not a significant covariate factor in the analysis (Table 3). We could not detect any effects of compaction or organic matter removal on forest floor min-N in year 1 or year 5. Overall, the forest floor min-N concentrations increased by approximately 55% in year 1, but returned to pre-harvest concentrations by year 5 (Figure 3).

Relationship between Mineralizable N and Foliar N

Both the concentrations and net changes in min-N at year 5 were compared with foliar N concentrations to determine if these soil properties served as indi-

FIGURE 1. Mineralizable N (mg kg^{-1}) of the mineral soil, 0–20 cm depth, from (a) pre-harvest to (b) year 1 and (c) year 5 (all sites combined, SE represented by bars).



cators of seedling N status. We found that mineral soils were a better predictor of foliar N than forest floors. For white spruce, the net change in min-N was significantly correlated with foliar N (Figure 4):

Spruce foliar N (%) = 1.062 + 0.017 [Net change in min-N (mg kg^{-1})] $r = 43\%$

Discussion

Min-N is intimately associated with soil properties and seasonal conditions, which might explain some of the low repeatability we found in treatment responses across sites. For example, the SBSdw site was sampled in an extremely wet summer in year 5, and there was little change in min-N on any plot, perhaps as a result of saturated soils in that year. The LTSP experiment also has fairly large plots, which might include soils either slightly drier or wetter within or between plots, making the interpretation more difficult for a microsite-sensitive indicator.

While we were unable to generalize how treatments affected soil min-N, it was clear that these soil disturbances had the potential to greatly alter min-N concentrations. Nitrogen availability generally increases after tree removal, and many studies have reported higher levels of net mineralization (measured by NO_3^- or NH_4^+) in clearcuts. Similarly, we interpret the increase in min-N after tree removal and disturbance as a "surge" in labile N, and a potential increase in soil N availability compared with unharvested stands. The surge in min-N was short-lived in forest floors, and was probably a result of a large input of roots and ectomycorrhizal fungi for decomposition after tree harvest (the "assart effect"; Kimmins 1997). Since sites were sampled in separate

FIGURE 2. Net change in mineralizable N (mg kg^{-1}) of the mineral soil, 0–20 cm depth, in (a) year 1 and (b) year 5 (all sites combined, SE represented by bars).

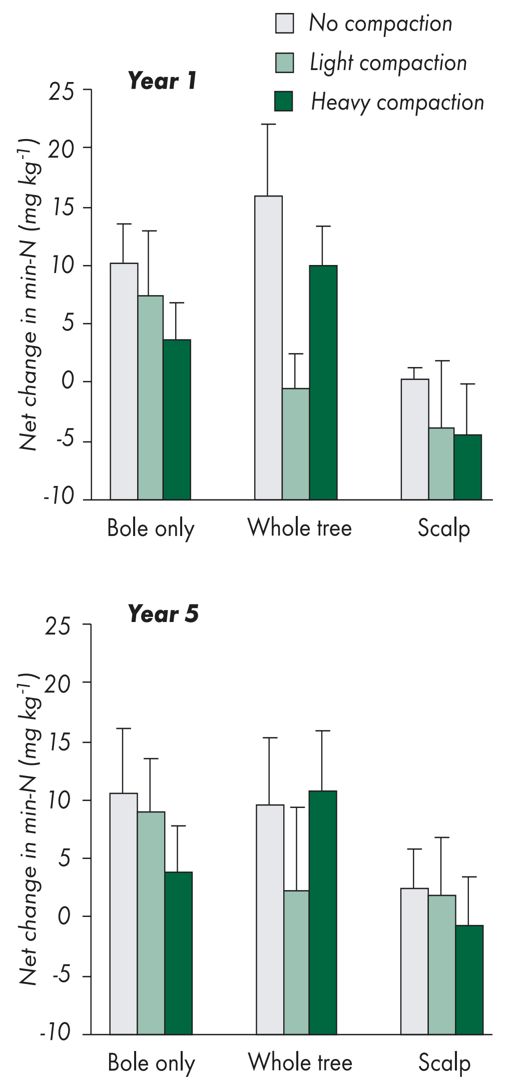


TABLE 2. Selected pre-harvest chemical properties of the Long-Term Site Productivity sites (mean, [SE])

	Total C (g kg^{-1})	Total N (g kg^{-1})	C/N ratio	Min-N (mg kg^{-1})	Avail. P (mg kg^{-1})	pH in H_2O
Mineral soil						
SBSwk	15.9 (0.5)	0.9 (0.04)	18.4 (0.5)	9.6 (0.7)	52.7 (4.1)	4.7 (0.03)
SBSdw	11.2 (0.2)	0.8 (0.01)	13.3 (0.2)	15.9 (0.8)	14.2 (0.9)	5.8 (0.02)
SBSmc	31.5 (1.6)	1.5 (0.08)	21.0 (0.3)	30.8 (2.6)	8.6 (0.8)	5.1 (0.04)
Forest floor						
SBSwk	364 (9.1)	11.1 (0.3)	33 (0.6)	280 (15)	101 (3)	4.4 (0.03)
SBSdw	375 (6.8)	12.3 (0.2)	31 (0.4)	339 (21)	200 (6)	5.0 (0.03)
SBSmc	484 (4.0)	14.1 (0.1)	34 (0.4)	401 (15)	93 (4)	4.4 (0.04)

years, and are hundreds of kilometres apart, it is unlikely that the post-treatment increase in min-N could be attributed to yearly variation in weather.

A similar effect from decaying organic matter would have occurred in mineral soils, but the variability in min-N was still high after 5 years. It is not yet clear how much of the increase in min-N could be attributed to the duration or magnitude of the assart effect, versus how much N supply potential had been more fundamentally altered by changes in soil conditions after treatments. For example, the changes in soil moisture and temperature regimes (from decreased transpiration and increased insolation), the removal of inhibitory root effects (via nutrient uptake, water uptake, and production of allelopathic compounds), the increased inputs of soluble organic carbon from forest floor leachates, or the lower microbial immobilization of N might explain some of the changes in min-N concentrations.

In our study, the net change in min-N seemed to be a more sensitive indicator of soil N supply after disturbance than absolute min-N concentrations; similar comparisons would be interesting to test in other forest and soil types. After tree harvest, the microbial demand for N generally decreases as carbon inputs decline (Prescott 1997), so perhaps any increase in min-N represents wholly available N (leached, for example, from forest floors) that is not competed for by microbes. The poor correlation with lodgepole pine, however, suggests that not all tree species respond similarly, at least in the short term. Lodgepole pine had high foliar N concentrations (1.4%) on scalped plots, despite little change in mineral soil min-N concentrations for these treatments. Perhaps N-fixation had occurred in association with lodgepole pine on these scalped soils, possibly through tuberculate ectomycorrhiza, which can form with *Suillus* spp. fungi, found in abundance on pine seedlings for many of these treatments.

In studies of soil nutrient regimes, Klinka et al. (1994) and Chen et al. (1998) reported forest floor min-N had changed little across sites compared with mineral soils. For the treatments where forest floors were retained, we also found that forest floor min-N was not

FIGURE 3. Mineralizable N (mg kg^{-1}) at pre-harvest (year 0) and years 1 and 5 post-treatment, for mineral soil and forest floors (concentration x 10), all plots combined (SE represented by bars).

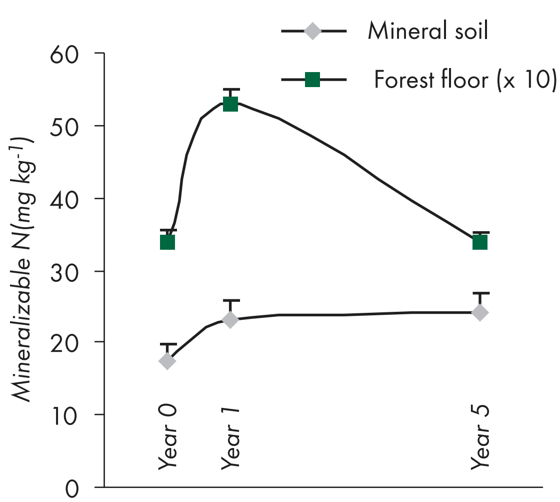


FIGURE 4. Relationship between the net change in min-N (mg kg^{-1}) at year 5, 0–20 cm mineral soil, with white spruce foliar N concentration.

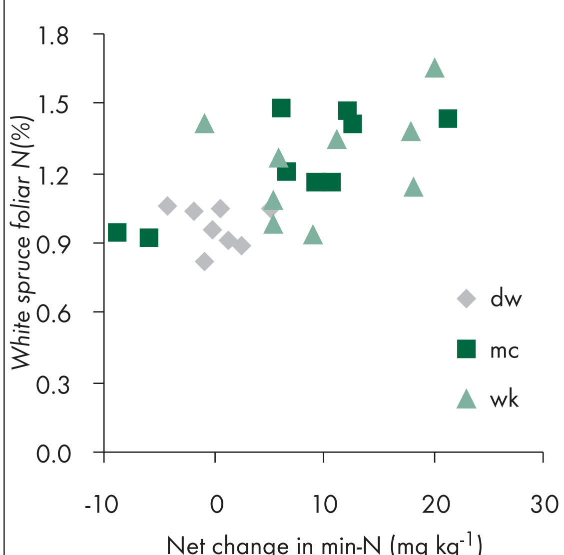


TABLE 3. Min-N analysis of variance for site organic matter removal and soil compaction, years 1 and 5

	Mineral soil (*p* value)	Forest floor (*p* value)
Year 1		
OM removal	0.1111	0.5271
Compaction	0.2681	0.7092
OM x Compaction	0.0959	0.7728
Pre min-N[a]	0.0004	0.3506
Year 5		
OM removal	0.4343	0.9019
Compaction	0.6113	0.8011
OM x Compaction	0.3158	0.9796
Pre min-N	0.0036	0.3378

[a] *Pre-harvest mineralizable N as a covariate.*

OM = organic matter.

Note: Forest floor removal treatment (OM3) not included.

affected by compaction or whole-tree harvesting, and was independent of changes in mineral soil min-N. For this reason forest floor min-N would not likely serve as a useful indicator of changes in site quality from compaction or whole-tree removal, at least in the short term. In addition, we could not detect any effect of forest floor min-N on tree nutrition, in contrast to mineral soils. The role of forest floors in tree nutrition might increase as more roots exploit the organic matter, and we will continue to test the relationship between forest floor min-N and nutrient uptake over time.

Conclusions

Soil min-N often increased in the 5 years following disturbance, perhaps more so when forest floors were retained, but the reasons for these increases (possibly a temporary assart effect or a more fundamental change in soil conditions) are not yet clear. The inconsistent response to treatments across sites and the inherent variability in undisturbed soils demonstrated a complex relationship between min-N and soil microsite. The relationship between mineral soil min-N and spruce foliar N did support the validity of this indicator of soil N status, for this species at least. This finding suggests that any management practice limiting min-N could lead to a reduction in the availability and uptake of N by trees.

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