Soil microclimate and nitrogen availability 10 years after mechanical site preparation in northern British Columbia

M.D. MacKenzie, M.G. Schmidt, and L. Bedford

Abstract: Mechanical site preparation (MSP) changes the distribution and character of forest floor and mineral soil and may affect soil nutrient availability, soil water content, and soil temperature. The effects of different kinds of MSP were compared to a control in the tenth growin3f6(b0c6g82.4(a)0.1)-3 TJT*(results)-372.5(with)-372.5(those)-372.5(of)-372.5(the)-372.5(nat
indicate that the use of MSP has increased in the recent past. In 1986, 7% of the land replanted in British Columbia (B.C.) received some form of MSP, while in 1991, 54% of the land replanted had some form of MSP (Anonymous 1993; Runyon

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Table 1. Summary of the site characteristics for the Bednesti and Inga Lake sites.

Site characteristics	Bednesti	Inga Lake
Slope (%)	0–2	0–5
Aspect (°)	0–5	350–355
Elevation (m)	700	845
Soil classification	Orthic Humo-ferric Podzol	Orthic Gleyed Luvisol
Textural class	Silty clay loam to sandy loam	Clay loam to silty clay
Biogeoclimatic zone	SBSdw3	BWBSmw1
Nutrient regime	Submesotrophic, B[a]	Mesotrophic, C[a]
Moisture regime	Mesic (4[a])	Mesic (4[a])

[a]Nutrient and moisture regime designations from the BC Biogeoclimatic Ecosystem Classification (DeLong and Tanner 1993).

1991). Unfortunately, scientific knowledge of the long-term effects of MSP is generally lacking in boreal regions (Munson and Timmer 1995; Orlander et al. 1996; Schmidt et al. 1996).

MSP has the potential to change soil microclimate and soil nutrient turnover (Burger 1996; Munson and Timmer 1995). MSP generally increases nitrogen (N) mineralization and nitrification, but may reduce fertility, because increased nitrification may lead to net N loss (NO_3^- leaching) and cation losses (Krause and Ramlal 1987). Some forms of MSP have been shown to lower the concentration of total carbon (C) and total N in surface soils (Tuttle et al. 1985). Over time, this may reduce the concentration of available phosphorus and reduce plant uptake (Krause and Ramlal 1987; Munson et al. 1993; Tew et al. 1986).

In 1987, the B.C. Ministry of Forests established a series of permanent plots in the northern interior that have become some of the oldest and best documented plots in B.C. The project was established as a means of examining methods to combat the growing backlog of not satisfactorily restocked forestlands. The effects of MSP on soil properties and tree growth were assessed in 1997, 10 years after MSP treatment, and the results represent the mid- to long-term (10–20 years) nutrient dynamics in a forest regenerated with MSP.

The objectives of this study are to examine the potential differences created by various MSP techniques on tree growth and soil properties at two sites in northern B.C. Therefore, in this paper we report on the impacts of MSP on soil properties including bulk density, soil microclimate (temperature and soil water), soil pH, cation exchange capacity (CEC), percent base saturation, total C, total N, NH_4^+ and NO_3^- concentrations, and potential mineralizable N (PMN). We also used ion-exchange resin bags to measure in situ organic matter (OM) mineralization over the growing season. Crop-tree height will be included as a means of comparing treatment effectiveness.

Materials and methods

Study sites

The study was conducted at two sites located in northern B.C. (Table 1). The Bednesti site is in the Sub-boreal Spruce biogeoclimatic zone, at 53°52′N and 123°29′W, in the Prince George Forest District (DeLong and Tanner 1993). The climate is subtemperate, with long cold winters and summers with a short growing season, hot days, and cool nights (Haeussler et al. 1999; McMinn and Bedford 1989). The total annual precipitation is 614 mm, and the mean annual temperature is 3.7 °C, with a maximum temperature of 22.1 °C in July and a minimum temperature of –14.1 °C in January. Soils of the Bednesti site are classified as Orthic Humo-ferric Podzols, with a texture of sandy loam to loam, a poor nutrient regime, and a mesic moisture regime. The loamy parent material consists of coarsely stratified basal till that is slightly stony and water modified (Haeussler et al. 1999; McMinn and Bedford 1989). The previous stand of lodgepole pine (*Pin con o a* Dougl.) and black spruce (*Picea ma iana* (Mill.) B.S.P.) was strip-logged in 1963, with the residual strips logged in 1971. In 1986, a stocking survey determined the block to be not satisfactorily restocked. The Ministry of Forests chose to use this site to study MSP the following year. Rehabilitation consisted of shearing all regeneration, piling stems into windrows, and burning. Disturbance to the forest floor and mineral soil was minimized by shearing and piling in January, when the soil was frozen. MSP treatments were completed that fall (see Experimental design), and lodgepole pine was planted in the spring (McMinn and Bedford 1989).

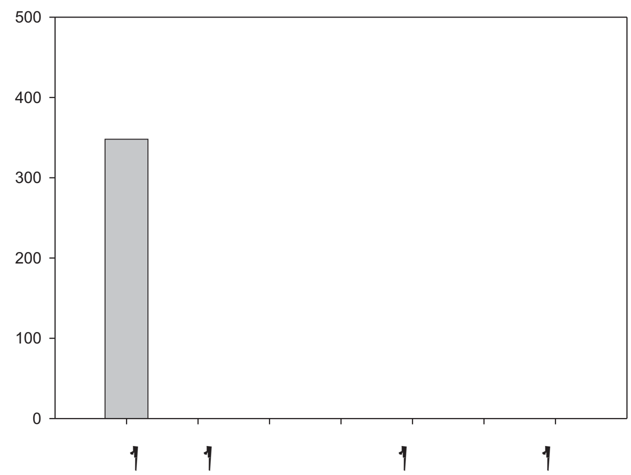
The Inga Lake site is in the Boreal White and Black Spruce biogeoclimatic zone, at 56°35′N and 121°36′W, in the Fort St. John Forest District (DeLong and Tanner 1993) (Table 1). The overall climate is subtemperate, again with long cold winters and a short growing season characterized by warm days and frequent thunderstorms. The total annual precipitation is 492 mm, and the mean annual temperature is 1.3 °C, with a maximum temperature of 21.9 °C in July and a minimum temperature of –21.9 °C in January. The soil is classified as an Orthic Gray Luvisol, has a texture of silty loam to clay loam, a moderate nutrient regime, and a mesic moisture regime. The parent material here is made up of clayey to loamy basal till (McMinn et al. 1989). There is no history of logging on this site, but in 1950 a wildfire led to aspen (*Po l em loide* Michx.) and willow (*Sali* L. sp.) regeneration. In 1987, the Ministry of Forests decided to use this block in the MSP study, and it was also sheared, piled, and burned in January. In the fall, MSP treatments were implemented (see Experimental design), and blocks were planted with hybrid spruce in the spring (*Picea gla ca* (Moench) Voss × *Picea engelmannii* Parry) (McMinn et al. 1989).

Experimental design

A randomized block design was used to compare the soil properties of untreated (control) plots to those created by various MSP treatments. Seven treatment plots (approximately 40 m × 35 m), including the control, were established and examined within each of five blocks. The MSP treatments ex-

amined in this study were
microsites), bedding plow, b
(Fig. 1). A burned windrow treatment (fire) was incl

mixing, inverting, and raising the planting microsite. These categories can be used to describe the five MSP treatments examined here. Delta trenching creates three distinct microsites: a low microsite in the furrow, one on the hinge of the furrow and the berm, and one on top of the berm. The furrow represents a bladed microsite, while the hinge is on the edge of a raised and mixed microsite. The breaking plow creates a continuous bed of mineral soil on top of forest floor by cutting out strips of forest floor and mineral soil and flipping them side by side to produce an inverted microsite. The bedding plow incorporates a series of discs that break up the forest floor, mix it with the mineral soil, and deposit the material for a mixed and raised microsite. The madge rotoclear consists of a toothed cylindrical drum that rotates at 300 r/min. In one pass the madge mixes the forest floor and mineral soil to a depth of 12–15 cm and a width of 1.75 m producing a homogeneously mixed microsite. Bedford and Sutton (2000) provide full descriptions of all treatments established at both sites.



Tree growth

Tree height and basal diameter have been measured every year since establishment at both the Bednesti and Inga Lake sites. Towards the end of the growing season (late July), the height and basal diameter of each tree were measured for all treatments, at both sites. Tenth-year height data are presented for treatment comparisons, but a more detailed analysis of the growth trends for all ten growing seasons is available from Bedford and Sutton (2000) and Haeussler et al. (1999).

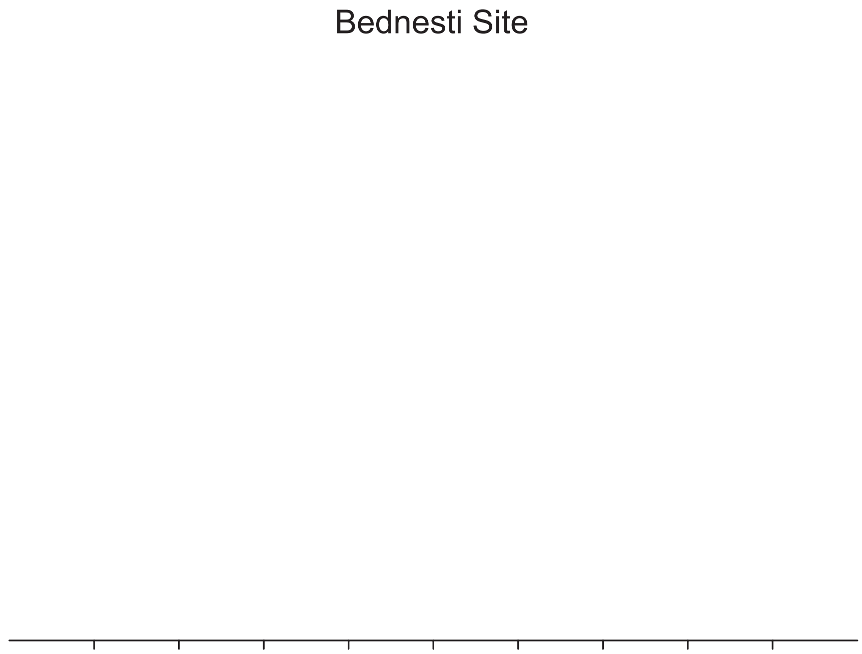
Soil sampling and physical analysis

Soil samples were collected in June and July 1997 (approximately 10 years after the crop trees were planted). All crop trees were individually numbered, and a list of random numbers was generated to locate sampling spots. All soil samples were taken 0.5 m away from these randomly chosen crop trees. Since treatments differ with regard to how they bury or mix OM, samples were taken from the planting microsite of each treatment. A round 10 cm × 10 cm core and core hammer were used to remove all samples. Eight samples per plot were collected from the upper mineral soil (0–10 cm), and six samples per plot were collected from the lower mineral soil (10–20 cm), except on the furrow and hinge treatments. At both depths, half of the samples were composited for physical analysis and the other half for chemical analysis. Samples set aside for physical analysis were oven dried at 105 °C for 24 h. When dry, the samples were sieved to 2 mm and both the coarse and fine fractions weighed. Bulk density (D_b) was calculated for both the fine fraction and the total soil as soil mass divided by soil volume.

The spring and summer soil water and soil temperature were measured for the control, furrow, hinge, bedding plow, and madge treatments. Soil temperature measurements were made with copper-constantan thermocouples installed at 10 cm depths in the planting microsite. An Omega digital temperature meter was used to take the readings. In an attempt to measure maximum daily temperatures, soil temperature measurements were made in late afternoon because of the lag time involved in atmospheric–soil heat transfer. Volumetric field water content was determined with a Delta T probe and meter at the same time as soil temperature. The Delta T probe measures an apparent change in the dielectric constant of a soil, similar to a time-domain reflectometry process (Whalley 1993; White et al. 1994). The probe measures soil water from an area of 3 cm in diameter and 6 cm in depth created by four steel prongs inserted into the ground. Soil water and temperature data were collected at 2-week intervals for the growing season and then once a month for the rest of the frost free season.

Soil chemical analysis

Soil pH was determined in a 2:1 slurry of 0.01 mol/L $CaCl_2$ and soil. The slurry was left to stand for 30 min, and pH was measured on a Fischer Scientific Accumet pH meter (McLean 1982). CEC was measured using the manual leaching and vacuum extraction method (Kalra and Maynard 1991). Exchangeable bases were measured by extraction with 1 mol/L NH_4OAc adjusted to pH 7.0, and base cation concentration was determined by atomic absorption spectophotometry (Thomas 1982). Percent base saturation (%BS) was then calculated as base cation concentration divided by CEC. Total C was measured using a LECO induction furnace (Nelson



and Sommers 1982). Total N was determined using a semimicro Kjeldahl digest followed by colorimetric determination of N concentration using a Technicon II autoanalyzer (Bremner and Mulvaney 1982). The C:N ratio was calculated from the total C and total N data. Twenty-five grams of field-fresh soil was extracted with 50 mL of 2 mol/L KCl. NH_4^+-N concentrations were determined by the salicilate–nitroprusside method, while NO_3^--N concentrations were determined by the cadmium reduction method, and both were analyzed on a Technicon II autoanalyzer (Keeney and Nelson 1982). Potential mineralizable N (PMN) was determined by incubating soil samples in 20 mL of deionized water under a head space of N_2 gas for 2 weeks at 30 °C (Bremner and Mulvaney 1982). Samples were then extracted with an equal amount of 4 mol/L KCl, and NH_4^+-N was determined by the same colorimetric analysis described previously.

(a)

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Ion-exchange resin analysis

To measure seasonal nutrient availability we used ion-exchange resins (IER) following the methods of Binkley and Matson (1983), Krause and Ramlal (1987), Munson et al. (1993), and Munson and Timmer (1995). The IER method was selected because it is sensitive to changing field conditions throughout the growing season and provides an accurate estimate of in situ mineralizable N. A mixed-bed resin was obtained from JTBaker Laboratory Inc. and was prepared by adding approximately 8 g of resin to 5 cm × 5 cm nylon bags. The bags were first rinsed in deionized water for 24 h, loaded with 1 mol/L NaCl (25 mL per bag) for 24 h, and rinsed in deionized water again for 24 h (Krause and Ramlal 1987). Four IER bags were installed at each block on 5 May at the Bednesti site and on 17 May at the Inga Lake site. The resin bags were installed individually by creating a straight slit in the ground with a shovel at a 45° angle, as described by Munson and Timmer (1995). The resin bags were then placed horizontally at a depth of 10 cm. The resin bags were collected on 2 October at Inga Lake and on 3 October at Bednesti. After removal from the field, the resins were extracted using 0.1 mol/L NaCl, and the concentrations of NH_4^+-N and NO_3^--N were determined using the same methods described previously.

Foliar N analysis

Foliar samples were collected at both sites in October 1997, from the top third of dominant trees for each replicate. Samples from 15 trees were composited to one sample per

MSP significantly influenced total C, total N, and the C:N ratio at both sites (Table 4). The bedding plow had significantly greater total C, total N, and C:N ratio compared to the control, at both depths and both sites, indicating that OM had been incorporated to the full depth in this treatment. However, the bedding plow had a C:N ratio much greater than 30:1 at Bednesti, which is generally considered a threshold for N mineralization (Sutherland and Foreman 1995), indicating that N availability might be reduced in this treatment. In fact, all treatments at Bednesti had C:N ratios greater than 30:1 except for the control, fire, and furrow treatments at the 0–10 cm and the control and fire treatments at 10–20 cm depth. At Inga Lake, the C:N ratio is less than 20:1 for most treatments except for the bedding plow and hinge at 0–10 cm and the bedding and breaking plow at 10–20 cm, indicating that N mineralization should not be inhibited.

MSP had a significant effect on NH

ment morphology, low D_b and high C concentrations in the surface soil of the bedding plow and madge, it is likely that these treatments have increased drainage of excess soil water in the spring, allowing soil heating to begin earlier in the season. Increasing soil temperature has been shown to improve net photosynthetic rate and nutrient mobilization by stimulating microbial activity and OM decomposition (Munson et al. 1993). The increased soil temperature on the madge treatment may have led to increased nutrient uptake (Munson and Timmer 1995).

The positive effect of fire on height growth at both sites may also be related to temperature. Fire increases soil temperature for a short period of time by replacing the forest floor with a thin layer of ash, which allows more solar radiation to penetrate the soil (Kimmins 1996; MacKenzie et al. 2004).

MSP techniques that raise and invert the forest floor and mineral soil, such as the bedding plow, have been shown to significantly increase crop-tree growth in other studies (Attiwill et al. 1985; Macadam and Bedford 1998), as have trenching and ripping techniques, such as Delta trench (Sutton and Weldon 1993, 1995). The hinge microsite improved tree growth, but after 10 years it is not clearly related to soil microclimate, *D* not help managers identify easily measurable characteristics for determining long-term productivity.

The bedding plow and breaking plow both deposit forest floor to a given depth in the mineral soil, and this has reduced the rate of decomposition, perhaps making N more available through time, where both treatments have elevated N indices compared to the control. However, at Bednesti the breaking plow crop-tree performance was not significantly different from that of the control, while at Inga Lake it was significantly greater. This is the first indication that something other than N availabilore4vilabiloree was the same for all treatments at both sites; however, it is unlikely that N availability was consistently the same through treatment, nutrient availability was only reduced by MSP techniques that removed the forest floor completely, such as blading and the furrow microsite associated with trenching (Schmidt et al. 1996). A retrospective study from interior B.C. found that nutrient availability was not reduced by fire or MSP when compared to a control 15 to 20 years after treatment (Bulmer et al. 1998), and the authors hypothesized that it may take upwards of 20–30 years to determine the cumulative effects of MSP on fertility. Finally, a study from northern Ontario showed that seasonal N availability, measured with IER, was lowest early in the season and varied substantially for each period that it was measured (Munson and Timmer 1995).

Conclusions

Results from this study indicate that 10 years after MSP, soil N availability is not the primary limiting factor for these treatments when compared to an untreated control. N availability on MSP blocks was not reduced, and in some cases enhanced, compared with control blocks. Seasonal N availability was not statistically different between treatments, but was only measured once for the entire growing season. Soil temperature (Inga Lake) and soil water (both sites) were significantly different between treatments throughout the growing season; soil microclimate better explained differences in crop-tree height among treatments.

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