

**IMPACTS OF DIFFERENT METHODS
OF MECHANICAL SITE PREPARATION
ON FOLIAR NUTRIENTS OF
PLANTED WHITE SPRUCE SEEDLINGS**

1996

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Abstract

The impacts of different methods of mechanical site preparation (MSP) treatments on foliar nutrients of planted plug+1 white spruce seedlings were examined at two mixed-wood boreal forest sites (Judy Creek, Fox Creek in Alberta, Canada). The treatments included three types of MSP: disc trench, ripper plough, and bladed which included 'thin' and 'thick' microsites; as well as a harvested-control (no MSP) and an adjacent unharvested area. Seedlings were planted four months after MSP and foliar element contents (N, P, K, Ca, Mg, S, Mn, Fe, Al) were assessed 17, 27, 29, and 32 months after MSP. MSP treatments resulted in initially higher foliar nutrient content (N, S, Mg; July 1992, 17 months after MSP). Foliar Fe and Al were dramatically increased and levels indicated potential toxic effects. The elevation of foliar nutrient content in site-prepared areas was still evident 27 months after treatment (N, P, K, S, Ca, Mg, Mn; May 1993). Foliar Al was still elevated in seedlings at Fox Creek at this time. By 29 months following MSP the effect of the treatments had diminished and, in some cases, seedlings in MSP-areas had lower foliar nutrient content (K, Mn) than those in harvested-control. By 32 months (October 1993) seedlings in the MSP treated areas showed significantly lower foliar content for several nutrients (Mn, P, Mg) while still showing elevated Fe. There were few clear differences among the different MSP treatments. In general, however, blading (particularly the 'thin' microsite) resulted in the largest initial increases in foliar element content and, subsequently, the greatest reductions in these elements.

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INTRODUCTION

Upon planting, conifer seedlings must immediately begin acquiring water and nutrients in order to support photosynthesis and future growth, thus ensuring survival (Margolis and Brand 1990). Several factors will influence a seedling's ability to acquire sufficient nutrients including: nutrient availability in the soil, soil temperature, soil water, root growth, and establishment of mycorrhizal relationships. Mechanical site preparation (MSP) is a widely-used silvicultural tool which is often used to manipulate the first three and could, in turn, impact the latter two. MSP typically involves the disturbance and exposure of surface soils to provide a better growing environment for planted seedlings (McMinn and Hedin 1990). This is attempted through removal or reduction of the litter layer, exposure of mineral soil, and mixing of soil and organic material to achieve one or more of the following: increased soil temperature, reduced competing vegetation, improved soil physical properties, improved soil water availability, increased nutrient availability, and/or improved planter access.

While an important objective of mechanical site preparation is to improve nutrient availability to planted seedlings, MSP has been associated with negative impacts on site nutrient relations. MSP may result in increased mineralization and nitrification (Vitousek and Matson 1985, Fox et al. 1986, Smethurst and Nambiar 1990, Vitousek et al. 1992, Munson et al. 1993) which can lead to leaching of cations (Krause and Ramlal 1987). MSP may also cause reductions in available P (Krause and Ramlal 1987) as well as reduced N and C in surface soils (Tuttle et al. 1985, Munson et al. 1993).

Few data are available which address the effectiveness of MSP for improving seedling performance or survival on harvested areas in the mixed-wood boreal forest and comparisons among the different forms of MSP, or the planting microsites they create, are unavailable. A study was initiated in 1990 to examine the impacts of harvesting and various methods of MSP on mixed-wood boreal sites in west central Alberta (Montero 1994). In our previous report (Schmidt et al. 1994) we demonstrated that MSP tended to reduce total N and available P in surface mineral soils while increasing exchangeable bases. In this report we discuss the impacts of different MSP methods on foliar nutrients and aluminium in planted white spruce seedlings.

METHODS AND MATERIALS

Site description

The two study sites (Judy Creek at 54°24'N, 115 40'W, 1010 m elevation, slope: 20%, aspect: 270° and Fox Creek at 54°15'N, 116 49'W, 975 m, slope: 6%, aspect: 350°) were located in the Whitecourt Forest in west-central Alberta, Canada. Both are in the Lower Boreal Cordilleran Ecoregion (Corns and Annas 1986). Prior to harvest they hosted mature (approximately 100 year old) mixed-wood forests dominated by white spruce (*Picea glauca* (Moench) Voss, approximately 18 - 24 m in height, 50 - 70% crown density) and trembling aspen (*Populus tremuloides* Michx.). Both sites have sloping terrain with relatively homogeneous topography, soils, aspect, and stand types (see Schmidt et al. 1994 for a full site description).

MSP treatments

Harvesting (clear-cut) took place in November 1990 and mechanical site preparation was carried out in February and March, 1991. The sites were divided into two blocks and, within each block, three mechanical site preparation (MSP) treatments were applied in randomly assigned rows of 20 m width running up and down slope. The treatments included those commonly used in the region: disc trench, ripper plough, bladed, as well as no MSP (harvested-control). Part of the original forest stand adjacent to each block was left unharvested.

Disc trenching was carried out with a Donaren 180D powered disc trencher mounted on a John Deere 640 skidder. The trencher consisted of two toothed disks mounted on two separate, articulating arms hydraulically activated to vary downward pressure at an angle to the direction of travel. As the disks turn, the soil surface is ripped and mineral soil is exposed in a trench bordered on the upper side by a berm (Hunt and McMinn 1988). Ripper ploughing was carried out with a modified standard ripper tooth mounted on the back of a tractor. The ripper tooth digs into the frozen ground and the plough displaces blocks of frozen soil laterally and partially turns them over, creating a berm (Coates and Haeussler 1987). Blading was carried out with a front-mounted straight-blade which was scraped over the soil surface, displacing slash and surface organic material to small central piles.

The cutblocks were planted in June 1991 with 'plug+1' white spruce seedlings. These seedlings were sown in February 1990 in containers and transplanted to outdoor nursery beds in June 1990 at Pine Ridge Forest Nursery (Smoky Lake, Alberta). For the disc trench and ripper plough treatments seedlings were planted in the 'hinge' microsite. This is a level planting spot at the junction of the mineral soil, exposed at the furrow, and the surface organic layer at the edge of the berm. The microsites in the bladed area were level areas of at least 0.16 m² (45 cm diameter circle) where some reduction of the surface organic layer occurred. Seedlings were planted in two microsites: 'thin' (organic layer depth <2 cm) and 'thick' (organic layer depth >2 cm).

Sampling and analyses

Foliar samples were collected from seedlings from four different MSP treatments and associated microsites: disc and ripper ('hinge' position for both), blade-'thin', blade-'thick', plus the harvested control (no MSP). In addition, seedlings growing naturally in the understory of the adjacent unharvested forest were also sampled. For each MSP treatment, within each block, samples were collected along two transects, which followed the rows of MSP treatment. In the unharvested area, samples were collected along two transects, with similar orientation to those in the harvested area, within each block. Each sample was comprised of equal amounts of current-year foliage from three adjacent seedlings. At each sampling time a total of 240 samples were collected: 10 reps X 2 sites X 2 blocks X 6 treatments.

Foliar samples were collected at four different times: July 1992, May 1993, July 1993, and October 1993. These sampling times were selected for two reasons. First, we wanted to examine the response of seedlings through the second and third growing seasons following MSP and, secondly, seasonal variation in foliar nutrient levels suggests that detection of nutrient limitations may vary depending on the sampling time. For white spruce seedlings we expected a peak in July with a low in October (Everard 1973) and, perhaps, an abrupt seasonal low during bud break in May (van den Driessche 1974). During the dormant season (October) we expected that foliar nutrient content would be in

equilibrium with soil availability and by sampling in May and July, physiologically important deficiencies might be observed (van den Driessche 1974).

Samples were returned to the lab and oven-dried at 70°C for 48 hours. Needles were removed from the stem and mean needle weight was determined for each sample by counting out a batch of 100 needles and weighing it. Samples were then ground with a Wiley mill. Part of each sample was wet-ashed in a microwave oven in a digest of nitric acid and hydrogen peroxide (Kalra et al. 1989) and then analysed for P, K, Ca, Mg, S, Mn, Fe, and Al using an inductively coupled plasma-atomic emission spectrometer (Anonymous 1990). The remainder of the sample was analysed for total nitrogen by means of a micro-Kjeldahl digest (Parkinson and Allen 1975) followed by colorimetric determination of NH_4^+ using a Technicon autoanalyzer (Bremner and Mulvaney 1982). Results were expressed on a percent dry weight and on a content ($\mu\text{g needle}^{-1}$) basis. Since a significant effect of treatment on unit needle weight was found in the preliminary analysis subsequent analyses utilised the foliar content values. These are most appropriate to avoid dilution and concentration complications arising from treatment effects on foliar mass (Ballard and Carter 1986).

Statistical analyses

The data were analysed using analysis of variance (ANOVA) with the aid of the SPSS PC computer package. For the purposes of statistical analysis each transect (within MSP treatment within block within site) was considered to be the experimental unit.

The general model for the analysis was: $Y_{ijk} = \mu + S_i + B_j + T_k + LT_{ik} + e_{(ijk)}$ where S is site ($i=1$ or 2); B is block ($j = 1$ or 2); and T is treatment ($k=1,2,\dots,6$) and e is random error within site X treatment combination.

When there was a significant effect ($p \leq 0.05$) of treatment or site X treatment, planned comparisons were used to further compare means as follows: unharvested versus harvested-control; harvested-control versus all MSP-treatments (as a group); harvested-control versus each of the MSP treatments; blade-'thick' versus blade-'thin'. If the site or site X treatment effect was significant this was done for each site, separately. Planned comparisons were not carried out for needle weights.

RESULTS

The two sites differed in the levels of several foliar elements and there were significant effects of treatment on most foliar elements examined at each of the sampling times (Table 1). In many cases there was a significant site X treatment interaction, although this typically indicated a difference in the level, rather than the direction, of response (see Tables 2-5). For three out of four sampling times there was a significant effect of treatment on mean needle weight (Table 1). Therefore, foliar element content ($\mu\text{g needle}^{-1}$) was used in all subsequent analyses. Comparing the two sites by examining the data for seedlings in the unharvested area, [particularly for July 1992 (Table 2) and October 1993 (Table 5)] we see that those at Judy Creek generally had higher levels of all foliar elements, except Mn which was higher for seedlings at Fox Creek.

Table 1. Results (p) of analysis of variance testing for effects of treatment (T), site (S), and treatment by site interaction (T x S) on needle weight (NDLWT), and foliar element content: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), iron (Fe) and aluminum (Al) of white spruce seedlings for each of the four different collection times.

Variable	Jul-92			May-93		
	T x S	T	S	T x S	T	S
NDLWT	0.14	<0.01	0.19	0.58	<0.01	0.01
N	0.09	<0.01	0.69	0.14	<0.01	0.06
P	0.16	<0.01	0.05	0.34	<0.01	0.39
K	0.10	0.01	<0.01	0.13	<0.01	0.20
Ca	0.05	<0.01	<0.01	<0.01	<0.01	0.04
Mg	0.03	<0.01	0.03	<0.01	0.10	0.43
S	0.15	<0.01	0.18	0.44	<0.01	0.94
Mn	0.13	<0.01	<0.01	0.07	<0.01	<0.01
Fe	0.99	0.01	0.71	0.14	0.49	<0.01
Al	0.80	<0.01	0.06	0.01	<0.01	<0.01

Variable	Jul-93			Oct-93		
	T x S	T	S	T x S	T	S
NDLWT	0.03	0.09	<0.01	0.55	<0.01	<0.01
N	0.32	0.95	<0.01	0.47	<0.01	<0.01
P	0.06	0.45	<0.01	0.13	<0.01	<0.01
K	<0.01	<0.01	<0.01	0.66	<0.01	<0.01
Ca	<0.01	0.20	<0.01	0.53	<0.01	<0.01
Mg	0.02	0.46	<0.01	<0.01	<0.01	<0.01
S	0.06	0.93	<0.01	0.34	<0.01	<0.01
Mn	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe	0.50	0.13	0.59	<0.01	<0.01	0.01
Al	0.03	<0.01	<0.01	0.50	0.05	0.24

There were some differences in foliar element content between planted seedlings in the harvested-control (no MSP) area and the natural understory seedlings. In July 1992 at Fox Creek foliar Mn and Al content was higher in the planted seedlings (harvested-control) than the natural seedlings (unharvested). At the time of bud expansion in May 1993, there were no differences between seedlings in the harvested-control and unharvested areas (Table 3). In July 1993 planted seedlings had higher Mn content (Fox Creek) and lower K and Ca (Judy Creek) (Table 4). In October 1993 the planted seedlings, compared to the natural seedlings, were characterised by significantly higher content of N, P, K, Ca, Mg, S (both sites) and Mn (Judy Creek only) (Table 5).

Table 2. Mean values of foliar element content (N, P, K, Ca, Mg, S, Mn, Fe, Al $\mu\text{g needle}^{-1}$) and needle weight (NDLWT, mg needle^{-1}) of white spruce seedlings in July 1992 for the unharvested area (UNHARV), the harvested control (CONTRL), and the various mechanical site preparation (MSP) treatments: disc trench (DISC), ripper plough (RIPPER), blade-'thick' microsite (BLADE, THICK), and blade- 'thin' microsite (BLADE, THIN) at Judy Creek (J) and Fox Creek (F). In cases where ANOVA showed no significant effect the two sites are pooled ($p > 0.05$ for site and site X treatment) (Table 1). In brackets are concentrations (ppm) for Fe and Al.

Jul-92		UNHARV	CONTRL	DISC	RIPPER	BLADE THICK	BLADE THIN
N	BOTH	32.2	35.8+	46.3	59.0	49.7	40.0
P	J	4.11	3.52	5.00	4.89	4.22	3.99
	F	2.69	3.55	3.46	5.28	4.37	3.17
K	J	13.70	9.16	12.66	12.15	10.44	8.76
	F	8.47	7.89	6.95	10.89	9.09	7.20
Ca	J	6.26	4.81	7.03	7.75	6.21	6.53
	F	2.62	4.16	3.29	7.13	5.65	5.27
Mg	J	1.64	1.40+	<u>2.12</u>	<u>2.20</u>	1.65	1.81
	F	0.98	1.48	1.32	2.19	1.90	1.72
S	BOTH	1.35	1.49+	1.81	2.31	1.95	1.66
Mn	J	0.348	0.353	0.380	<u>0.704</u>	0.401	0.465
	F	0.577*	0.968	0.794	1.390	1.125	0.587
Fe	BOTH	0.035	0.046+	<u>0.075</u>	<u>0.099</u>	<u>0.118</u>	<u>0.255#</u>
		(10)	(7)	(40)	(46)	(52)	(150)
Al	BOTH	0.006*	0.029+	0.048	<u>0.082</u>	<u>0.079</u>	<u>0.478#</u>
		(4)	(17)	(28)	(38)	(37)	(105)
NDL WT	J	1.7	1.5	2.1	2.1	2.5	1.8
	F	1.0	1.8	1.6	2.2	2.0	1.6

Results of planned comparisons (within a row):

*significant difference between unharvested and harvested-control;

+ significant difference between harvested-control and MSP treatments (as a group);

underlined MSP treatments were significantly different from the harvested control;

significant difference between 'thick' and 'thin' microsites for bladed.

Table 3. Mean values of foliar element content (N, P, K, Ca, Mg, S, Mn, Fe, Al $\mu\text{g needle}^{-1}$) and needle weight (NDLWT, mg needle^{-1}) of white spruce seedlings in May 1993 for the unharvested area (UNHARV), the harvested control (CONTRL), and the various mechanical site preparation (MSP) treatments: disc trench (DISC), ripper plough (RIPPER), bladed-'thick' microsite (BLADE, THICK), and bladed-'thin' microsite (BLADE, THIN) at Judy Creek (J) and Fox Creek (F) sites. In cases where ANOVA showed no significant effect the range is given ($p > 0.05$ for treatment and site X treatment) or data from the two sites are pooled ($p > 0.05$ for site and site X treatment) (Table 1). In brackets are concentrations (%) for Ca.

May-93		UNHARV	CONTRL	DISC	RIPPER	BLADE THICK	BLADE THIN
N	BOTH	9.05	7.8+	<u>9.6</u>	<u>9.8</u>	<u>10.1</u>	<u>10.3</u>
P	BOTH	1.31	1.42+	<u>1.79</u>	<u>1.72</u>	<u>1.70</u>	<u>1.76</u>
K	BOTH	3.54	3.77+	<u>4.76</u>	<u>4.86</u>	<u>4.75</u>	<u>4.94</u>
Ca	J	0.21	0.22	0.31	0.20	0.20	0.26#
		(0.11)	(0.07)	(0.10)	(0.07)	(0.07)	(0.09)
	F	0.21	0.14+	0.20	<u>0.31</u>	<u>0.39</u>	<u>0.41</u>
		(0.07)	(0.05)	(0.07)	(0.08)	(0.10)	(0.10)
Mg	J	0.34	0.40	0.51	0.43	0.30	0.33
	F	0.36	0.28+	<u>0.35</u>	<u>0.46</u>	<u>0.47</u>	<u>0.51</u>
S	BOTH	0.42	0.44+	<u>0.55</u>	<u>0.57</u>	<u>0.56</u>	<u>0.60</u>
Mn	J	0.021	0.035	0.037	0.048	0.042	0.031
	F	0.048	0.046+	<u>0.074</u>	0.058	<u>0.069</u>	0.046#
Fe	J	RANGE: 0.0054- 0.0096					
	F	RANGE: 0.0085- 0.0257					
Al	J	0.0007	0.0008+	0.0009	0.0010	<u>0.0048</u>	<u>0.0054</u>
	F	0.0021	0.0002+	0.0003	0.0036	<u>0.0064</u>	<u>0.0098</u>
NDL WT	J	0.20	0.30	0.30	0.30	0.30	0.30
	F	0.30	0.30	0.30	0.40	0.40	0.40

Results of planned comparisons (within a row):

*significant difference between unharvested and harvested-control;

+ significant difference between harvested-control and MSP treatments (as a group);

underlined MSP treatments were significantly different from the harvested control;

significant difference between 'thick' and 'thin' microsites for bladed.

Table 4. Mean values of foliar element content (N, P, K, Ca, Mg, S, Mn, Fe, Al $\mu\text{g needle}^{-1}$) and needle weight (NDLWT, mg needle^{-1}) of white spruce seedlings in July 1993 for the unharvested area (UNHARV), the harvested control (CONTRL), and the various mechanical site preparation (MSP) treatments: disc trench (DISC), ripper plough (RIPPER), bladed-'thick' microsite (BLADE, THICK), and bladed-'thin' microsite (BLADE, THIN) at Judy Creek (J) and Fox Creek (F). In cases where ANOVA showed no significant effect the range is given ($p > 0.05$ for treatment and site X treatment) or data from the two sites are pooled ($p > 0.05$ for site and site X treatment) (Table 1). In brackets are concentrations (ppm) for Al at Fox Creek.

July-93		UNHARV	CONTRL	DISC	RIPPER	BLADE THICK	BLADE THIN
N	J	RANGE: 18.4-20.8					
	F	RANGE: 13.4-18.2					
P	J	RANGE: 3.17-4.04					
	F	RANGE: 2.55-2.92					
K	J	15.09*	11.47+	9.68	9.81	<u>8.96</u>	<u>9.07</u>
	F	8.35	7.71	6.61	7.05	6.57	7.18
Ca	J	8.07*	6.36	6.58	5.48	5.74	5.86
	F	3.29	3.27	3.24	4.50	4.25	3.34
Mg	J	1.71	1.57	1.46	1.43	1.41	1.52
	F	1.02	1.16	1.13	1.27	1.32	1.47
S	J	RANGE: 1.37-1.70					
	F	RANGE: 1.03-1.33					
Mn	J	0.527	0.677+	0.446	<u>0.357</u>	0.446	0.430
	F	0.495*	0.882	0.862	0.838	0.627	0.476
Fe	BOTH	RANGE: 0.048-0.099					
Al	J	0.018	0.019	0.014	0.016	0.008	0.029
	F	0.003	0.025+	0.048	0.041	0.057	0.099
		(2)	(16)	(32)	(24)	(36)	(58)
NDL WT	J	1.1	2.0	1.9	1.8	1.8	1.9
	F	1.1	1.6	1.5	1.7	1.6	1.7

Results of planned comparisons (within a row):

*significant difference between unharvested and harvested-control;

+ significant difference between harvested-control and MSP treatments (as a group);

underlined MSP treatments were significantly different from the harvested control;

significant difference between 'thick' and 'thin' microsites for bladed.

Table 5. Mean values of foliar element content (N, P, K, Ca, Mg, S, Mn, Fe, Al $\mu\text{g needle}^{-1}$) and needle weight (NDLWT, mg needle^{-1}) of white spruce seedlings in October 1993 for the unharvested area (UNHARV), the harvested control (CONTRL), and the various mechanical site preparation (MSP) treatments: disc trench (DISC), ripper plough (RIPPER), blade-'thick' microsite (BLADE, THICK), and blade-'thin' microsite (BLADE, THIN) at Judy Creek (J) and Fox Creek (F). In brackets are concentrations (%) for S.

Oct-93		UNHARV	CONTRL	DISC	RIPPER	BLADE THICK	BLADE THIN
N	J	15.6*	25.9	21.9	22.0	25.5	20.0
	F	10.1*	20.0	20.0	20.6	18.4	17.5
P	J	2.73*	4.44+	3.62	3.33	3.72	<u>3.25</u>
	F	1.67*	3.16	3.01	3.11	3.00	2.88
K	J	8.74*	12.27	10.86	9.60	10.85	10.40
	F	5.86*	8.70	8.40	8.04	8.25	8.20
Ca	J	5.59*	9.55	9.20	8.77	9.23	8.69
	F	2.90*	5.68	5.19	6.74	6.87	7.11
Mg	J	1.30*	2.14+	1.82	1.71	<u>1.65</u>	<u>1.61</u>
	F	1.00*	1.40+	1.43	1.62	<u>1.71</u>	<u>1.90</u>
S	J	1.21*	1.87	1.53	1.49	1.67	1.41
		(0.09)	(0.09)	(0.08)	(0.08)	(0.09)	(0.07)
	F	0.91*	1.41	1.36	1.43	1.33	1.33
Mn		(0.10)	(0.09)	(0.09)	(0.10)	(0.08)	(0.08)
	J	0.605*	1.519+	<u>0.721</u>	0.985	1.123	<u>0.801</u>
	F	1.444	1.529+	1.470	1.181	1.154	<u>0.817</u>
Fe	J	0.071	0.103	0.096	0.145	0.099	0.109
	F	0.020	0.037+	0.047	<u>0.076</u>	<u>0.091</u>	<u>0.210#</u>
Al	J	0.010	0.058	0.053	0.056	0.010	0.028
	F	0.006	0.044	0.058	0.064	0.083	0.096
NDL WT	J	1.3	2.0	1.9	1.7	1.9	1.9
	F	0.9	1.5	1.5	1.5	1.6	1.7

Results of planned comparisons (within a row):

*significant difference between unharvested and harvested-control;

+ significant difference between harvested-control and MSP treatments (as a group);

underlined MSP treatments were significantly different from the harvested control;

significant difference between 'thick' and 'thin' microsites for bladed.

In general, the various mechanical site preparation (MSP) treatments resulted in initially higher levels of foliar elements but by the end of the sampling period (32 months after MSP) this trend was reversed. At the time of the initial sampling (July 1992) seedlings in the MSP areas (as a group) had significantly greater foliar N, S, Fe (both sites) and Mg (Judy Creek only) than those

in the harvested-control (Table 2). There was a seasonal low in foliar nutrient content at the time of bud expansion in May 1993 as a result of very small needles (Table 3). Still seedlings in MSP-treated areas (as a group) had higher foliar N, P, K, S, Al (both sites) Ca, Mg, and Mn (Fox Creek only) than those in harvested-control (Table 3). By July 1993 seedlings in the MSP-areas (as a group compared to harvested-control) had significantly lower K and Mn (Judy Creek) but maintained higher Al (Fox Creek). In October 1993 seedlings planted in MSP-areas (as a group) had significantly lower foliar Mn (both sites) P, and Mg (Judy Creek) while still maintaining higher Mg and Fe (Fox Creek) than seedlings in the harvested-control.

In terms of the impact of specific MSP treatments: in July 1992 ripper areas showed the highest foliar Mg, Mn (significant for Judy Creek only) while seedlings in the blade-'thin' areas had the highest foliar Fe and Al (both sites) (Table 2). In May 1993 seedlings in the blade-'thin' microsite had the highest foliar N, K, S, Al (both sites) Mg and Ca (Fox Creek only) whereas those in the disc areas had the highest P (both sites) and Mn (Fox Creek). In July 1993 seedlings in the bladed areas had the lowest foliar K (Judy Creek) while those in the ripper areas had the lowest Mn (Judy Creek). By October 1993 seedlings in the blade-'thin' areas showed the lowest foliar P, Mg (Judy Creek) and Mn (Fox Creek) but the highest Mg and Fe (Fox Creek). Seedlings in the disc areas had the lowest Mn at Judy Creek.

DISCUSSION

Effects of MSP on foliar element content

The results show that MSP was effective, at both sites, in improving foliar nutrient content but that the effect lasted for only two or three growing seasons. By the third growing season following MSP seedlings in the treated areas showed lower foliar nutrient content than those in the harvested-control. The positive effects of MSP treatment observed in July 1992 were still evident at the time of bud flush in May 1993, when there would have been a very high seasonal nutrient demand. By July 1993, however, positive effects of the MSP treatments had diminished, particularly at Judy Creek. Sampling of dormant seedlings in October 1993 provided evidence that MSP may have a negative effect on foliar nutrient status. In contrast, foliar Fe and Al in seedlings in MSP treated areas remained high throughout our sampling period.

Our results agree with those from other studies which have demonstrated an increase in foliar nutrients shortly after site preparation (slash pine, Burger and Pritchett 1988) but reduced foliar nutrient status a few years after scarification (eight years, Weber et al. 1985). Other studies in white spruce-aspen mixed-woods have produced conflicting results. Brand and Janas (1988) provided evidence of negative effects of site preparation on foliar nutrient status even in the first or second (Brand 1991) growing seasons following treatment. In contrast, Munson et al. (1993) found slightly increased foliar N and K, but reduced P, four years after scarification. At the same time they (Munson et al. 1995) found that October foliar nutrient content of white spruce seedlings in scarified areas were similar to those in control areas for current needles but slightly higher for one-year-old needles. This was attributed to reduced retranslocation of N, P, K and Ca out of 1-year-old needles for seedlings in scarified areas. Although we didn't specifically examine retranslocation or foliar content of older needles the largest negative impact of MSP was evident in the October sampling when seasonal

retranslocation would be complete and the dormant seedlings are expected to be in equilibrium with the soil (van den Driessche 1974). Further sampling would be required to determine how long the nutrient status of seedlings in MSP-treated areas would remain lower than those in the control.

Based on estimations of critical foliar nutrient concentrations for white spruce (Morrison 1974; Ballard and Carter 1986; van den Driessche 1989) the seedlings we measured were generally above critical levels for N (1.1%), P (0.1%), K (0.3%), Ca (0.12%), Mg (0.06%), S (0.1%) and Mn (10 ppm). However, at the time of rapid bud expansion in May 1993 seedling Ca concentration was sub-optimal for seedlings in all treatments and, although the MSP treatments increased foliar Ca at Fox Creek, they did not bring seedlings into the sufficient range (Table 2). In addition, in October 1993, all seedlings were below the critical level for foliar S (Table 5).

The results show that the apparently positive effect of MSP on foliar element content could, in fact, result in toxic effects as a result of increases in foliar Fe and Al. Van den Driessche (1989) reported that 30 ppm was the critical toxicity level for foliar Fe for white spruce seedlings while Ingestad (1959) reported that Norway spruce (*Picea abies* Karst.) seedlings showed maximum growth at 60 ppm foliar Fe. Foliar Fe for seedlings in MSP-treated areas ranged from 40 to 150 ppm in July 1992 (both sites) and from 32 to 58 ppm in July 1993 at Fox Creek with seedlings in blade-'thin' having the highest levels at both times (Table 2). Foliar Al content was also increased by MSP treatments. The increase in foliar Al and Fe can be attributed to increased importance of mineral soil in providing elements to planted seedlings in site prepared areas. Harvested (versus unharvested) areas showed increased Fe and Al in the litter layer, presumably as a result of the mixing in of mineral soil (Schmidt et al. 1994).

Exposure to aluminium causes reduced root growth in white spruce seedlings and the species has been reported to respond to very low concentrations (Nosko et al. 1988). We found no data which identifies the critical toxicity level of foliar Al for white spruce seedlings. McLaughlin et al. (1991) reported significant increases in dark respiration, and declines in the ratio of photosynthesis to respiration, associated with foliar Al levels of 65 ppm in red spruce. In contrast, Beaton et al. (1965) reported that foliar Al concentrations for mature Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*) and western hemlock (*Tsuga heterophylla*) ranged from 175 to 787 ppm. We postulate that in July 1992 seedlings in the blade-'thin' area, at least, were near the critical toxicity level for Al (Table 2). Nosko and Kershaw (1992) suggest that Al could limit natural regeneration of white spruce by preventing seedling establishment through effects on early shoot and root growth. In our study, many seedlings planted in the blade-'thin' microsites showed chlorosis, discolouration or loss of needles.

The results do not clearly point to any particular MSP treatment as being superior in terms of positive effects on seedling nutrient status. The various MSP treatments differed in their effectiveness between sites and over time. This can be attributed to differences in the effect of MSP treatments on soil physical and chemical properties, and in the time response of these, or to differences in the way MSP treatments were applied at each site. Blading (particularly the 'thin' microsite) generally resulted in the greatest increases for several elements initially and, subsequently, in the greatest reductions in some of them. At the same time, this treatment caused

the greatest increases in foliar Fe and Al throughout the sampling period. The removal of the litter layer and heavy disturbance of surface soils during blading likely led to initially increased availability of soil elements. Later, however, the removal of the supply source (litter) plus changed microclimate conditions may have lead to increased leaching and, ultimately, lower nutrient availability and a drop in foliar nutrient levels.

Comparison with soils data

Effects of treatments on soil nutrients were not expected to be perfectly reflected in seedling nutrient status because of confounding factors of nutrient availability and uptake as well as the potential for seedlings to show some nutrient carry-over effects from the nursery. At the time of soil sampling (July 1992), MSP had resulted in reduced levels of total N, $\text{NH}_4\text{-N}$, and mineralizable-N in surface soils (Schmidt et al. 1994) but seedlings in MSP-treated areas generally had higher foliar N than those in the harvested-control. Though the soil analyses indicated that the N-supplying power of the soil was lower for the MSP-treated areas, the microclimatic conditions (warmer and moister) may have been more conducive to N mineralization and seedlings may have had more N available to them. Furthermore, the MSP-treated areas supported less competitive vegetation than the harvested-control and, thus, the white spruce seedlings may have been able to take up greater quantities of nitrogen. The MSP-treated areas showed increased base saturation and exchangeable base contents in surface soils and this was reflected in higher foliar Mg (Judy Creek only). The results for the soil analyses (Schmidt et al. 1994) showed that disc, ripper and blade-'thick' areas had, generally, higher soil N than blade-'thin' and this is reflective of our results for foliar N content of seedlings in July 1992.

Comparison of sites and effects of harvesting

Naturally regenerated seedlings at Judy Creek generally had higher levels of foliar nutrients than those at Fox Creek. This corresponds to higher nutrient levels in the forest floor and surface mineral soil at Judy Creek (Schmidt et al. 1994). Differences in rooting, past history, and nutrient demand complicate comparisons of foliar nutrient contents of seedlings planted into the harvested-control with those of naturally regenerated seedlings in the unharvested areas. Though harvesting of these sites resulted in reduced total N and exchangeable base contents in the forest floor and surface mineral soils (Schmidt et al. 1994), foliar nutrient contents were unaffected or were increased. At the time of soil sampling (July 1992) the only significant differences in foliar element contents was higher Mn (Fox Creek only) and Al (both sites) in planted seedlings. These could be reflective of increased soil availability as a result of harvesting, although we have no soils data for these elements. However, fifteen months after soil sampling (October 1993) planted seedlings had significantly higher contents of almost all measured nutrients, when compared with naturally regenerated seedlings.

CONCLUSIONS

Our results show that, for these boreal mixed-wood forest sites, mechanical site preparation may result in improved seedling nutrient status but that these effects may last only two or three growing seasons. In the longer term, MSP may result in reduced seedling nutrient status. In

addition, MSP, particularly treatments that greatly reduce the organic layer, may result in large, and potentially toxic, increases in foliar Fe and Al.

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