Use of Wood Waste in Rehabilitation of Landings Constructed on Fine-Textured Soils, Central Interior British Columbia, Canada

Paul Sanborn, *Ecosystem Science and Management Program, University of Northern British Columbia, 3333 University Way, Prince George, BC, Canada V2N 4Z9;* **Chuck Bulmer,** *Kalamalka Research Station, BC Ministry of Forests, 3401 Reservoir Road, Vernon, BC, Canada V1B 2C7; and* **Dave Coopersmith,** *6325 Chatham Street, West Vancouver, BC, Canada V7W 2E1.*

ABSTRACT: *Rehabilitation of temporary landings and roads constructed on fine-textured Alfisols must ameliorate poor soil structure, high bulk densities, and greatly reduced organic matter. A long-term field experiment in the central interior of British Columbia (BC) was begun in 1995 to compare soil properties and seedling growth on landings rehabilitated with three operationally feasible treatments: (1) incorporation of waste wood chips (140 t/ha, oven-dry basis), supplemented with 600 kg N/ha; (2) subsoiling; and (3) shallow tillage combined with recovery and spreading of topsoil. After 4 years, soil bulk density at 7–14 cm depth was lowest in the chip incorporation treatment. Although total C, N, and S, and mineralizable N concentrations were highest in the topsoil recovery treatment, the chip incorporation treatment had the highest 3-year growth rates of hybrid white spruce (*Picea glauca × engelmannii*). Foliar analyses indicated that macro- and micronutrient concentrations were generally adequate, with only S and Mg being of concern. Establishment of paper birch (*Betula papyrifera*) did not succeed due to severe rodent damage to seedlings, perhaps encouraged by rapid and dense revegetation by seeded agronomic legumes. Silviculturists should consider treatments involving incorporation of chipped wood wastes, with appropriate supplementary N fertilization, in rehabilitation of access structures on fine-textured soils in the BC central interior.* West. J. Appl. For. 19(3):175–183.*

Key Words: Hybrid white spruce, paper birch, soil nutrients, bulk density.

During the 1990s, soil conservation provisions of the Forest Practices Code of British Columbia restricted the extent of access structures (e.g., roads, landings) and required rehabilitation of those not needed for permanent access (Bulmer 1998). Simultaneously, new provincial programs made large investments in rehabilitating the backlog of older landings and roads no longer needed for forest management purposes. These initiatives were supported by a network of research installations, established in the 1980s, that tested and demonstrated simple tillage and soil handling methods for operational soil rehabilitation (Carr 1988). By the mid-1990s, these trials and accumulated operational experience were sufficient to provide detailed practical guidance on soil rehabilitation methods to foresters in the Forest Practices Code Soil Rehabilitation Guidebook (BC Ministry of Forests 1997). Despite these significant efforts, there remained site conditions and treatment options that had not been well-studied: (1) the rehabilitation of access structures constructed on fine-textured soils, which are widespread in central interior BC (Dawson 1989); and (2) the operational use of wood wastes and other organic soil amendments in forest soil rehabilitation (Bulmer 1998, Sanborn et al. 1999).

NOTE: Paul Sanborn can be reached at (250) 960-6661; Fax: (250) 960-5539; sanborn@unbc.ca. Financial support for this study was provided by Forest Renewal BC (Project OP97075-RE), the Prince George Forest Region, and the Ministry of Forests Research Branch. We thank Mike Jull, Manager of the Aleza Lake Research Forest, for his support of our work, and our contractors, collaborators, field assistants, and the Prince George Forest District for their important assistance. Wendy Bergerud and Peter Ott (Ministry of Forests Research Branch) provided statistical advice, and Rob Brockley (Kalamalka Research Station) assisted with interpretation of foliar analysis data.

Recent evaluations of timber supply for the Prince George Timber Supply Area estimated the amount of productive land to be lost to roads, landings, and trails as a result of existing and planned forest development in the coming decades at 170,197 ha or 4–5% of the landbase (BC Ministry of Forests 2001). Reclamation of those access structures that are only needed on a temporary basis is an obvious strategy to prevent or mitigate such losses in growing site.

Operational rehabilitation of access structures on fine-textured soils has generally not been practiced in central interior BC and has not been recommended by Forest Districts, presumably due to limited experience and a lack of successful examples. Rehabilitation of degraded fine-textured soils is challenging because tillage may be only partly effective (McNabb 1994) and because stable aggregate structures, required to ensure adequate water retention and aeration in the root zone, are closely associated with soil organic matter (Golchin et al. 1994), which may be lacking.

Organic amendments have the potential to increase soil organic matter levels (Vetterlein and Huttl 1999) and to improve plant growth (Schuman et al. 2000), but the results depend on the characteristics of the amendment. Paustian et al. (1990) showed that the increased soil organic matter on long-term plots amended with straw and sawdust was attributed primarily to direct effects of the amendment, but indirect effects associated with improved plant growth also played a role. In the case of agricultural application of pulp mill sludge, crop yield was inversely related to the C:N ratio of the sludge (Vagstad et al. 2001). Hallsby (1995) showed that mixed mounds containing chipped slash suppressed the growth of Norway spruce (*Picea abies*), compared to mixed mounds containing forest floor material. Plant growth was enhanced where fertilizer N was added along with the carbon-rich materials (Paustian et al. 1990).

To address knowledge gaps surrounding reclamation of fine-textured soils, we began a long-term field experiment in 1995 with the following objectives: (1) to test and compare operationally realistic methods (including the use of wood wastes), for restoring productivity to landings constructed on fine-textured soils in the BC central interior; and (2) to assess the effects of these treatments on soil properties and tree growth.

Methods

Study Area

The low-relief, undulating landscape of the 10,000 ha Aleza Lake Research Forest (ALRF), 60 km E of Prince

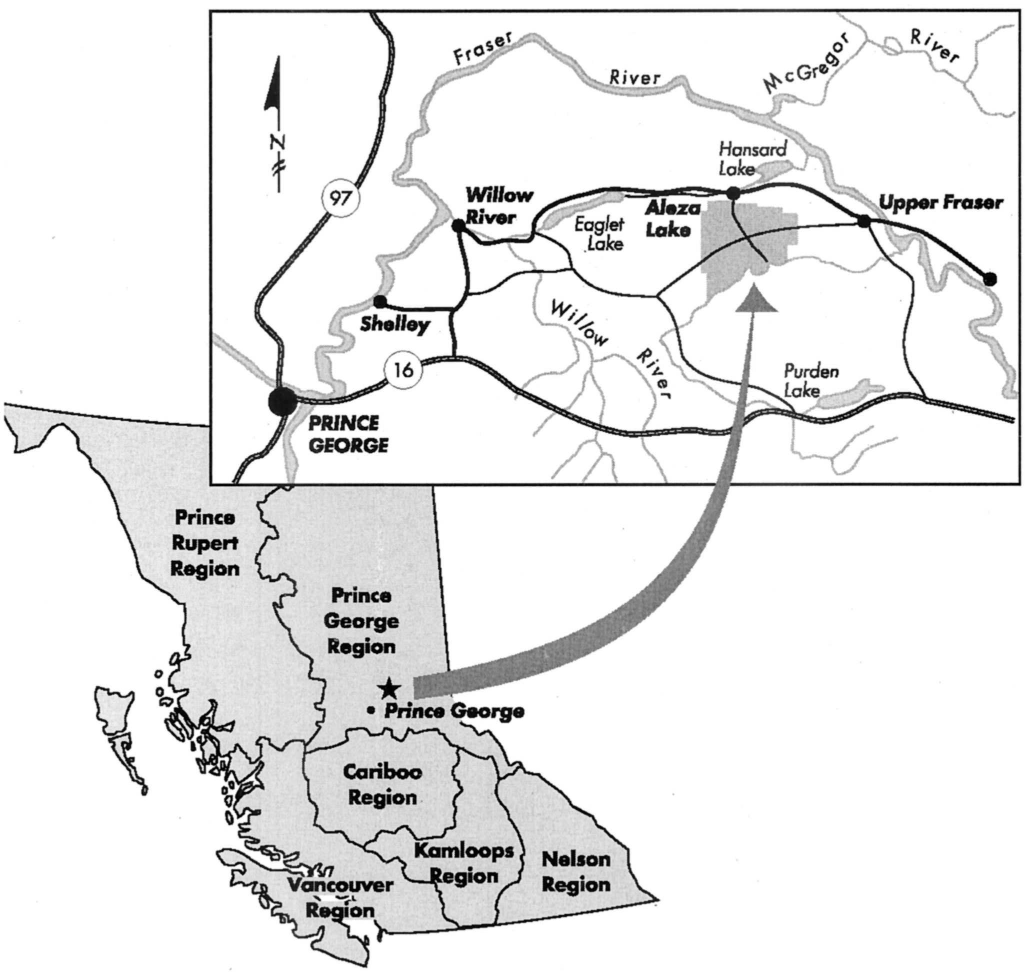

Figure 1. Location of the Aleza Lake Research Forest, British Columbia.

George (54°4′ N, 122°5′ W) (Figure 1), is underlain largely by fine-textured glaciolacustrine deposits on which strongly developed Luvisolic soils (Alfisols) have formed. Similar parent materials occupy almost 25% of the 1.5 million ha Prince George-McLeod Lake soil survey map area (Dawson 1989), and comprise an even larger proportion of the easily accessible forest land-base suitable for intensive management in the southern portion of the Prince George Timber Supply Area.

These soils are characterized by depletion of clay and some accumulation of organic matter in the surface Ahe horizon, combined with distinct blocky structures in the much denser, clay-enriched Bt horizon (Arocena and Sanborn 1999). Roots are almost entirely confined to the forest floor and A horizons, which typically extend to a depth of 15–25 cm

The ALRF is located within the Willow Wet Cool variant of the Sub-Boreal Spruce (SBSwk1) biogeoclimatic subzone (DeLong 2003), comprising over 8% of the SBS zone that dominates the British Columbia central interior (D. Meidinger, BC Ministry of Forests, May 5, 2003). Mean annual temperature is 3° C, and mean annual precipitation is 930 mm (Jull 1992). Mature and old-growth forests are dominated by hybrid white spruce (*Picea glauca* × *engelmannii*) and subalpine fir (*Abies lasiocarpa*), with scattered veteran interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) on higher landscape positions. Paper birch (*Betula papyrifera*) is most abundant in early seral communities, but also persists in many older forests. Lodgepole pine (*Pinus contorta* var. *latifolia*), although widely planted on coarser soils in recently harvested areas in this subzone, is uncommon in mature forests on mesic sites.

Treatments and Experimental Design

In designing rehabilitation treatments to restore soil productivity, we wanted to accomplish the following changes in soil properties: (1) reduction of bulk densities; (2) restoration of organic matter; (3) restoration of beneficial soil structure or aggregation in the rooting zone; and (4) replacement of nutrients lost by soil and forest floor displacement.

Our treatments also took into account the following observations and principles: (1) equipment used for tillage treatments had to be readily available in the central interior of BC; (2) given the naturally shallow rooting zones in Luvisolic soils at ALRF, the treatments would emphasize restoration of surface soil conditions; (3) any organic soil amendments would have to be readily available in field situations; (4) tree species selection should include the preferred commercial species for undisturbed sites with similar soil types (i.e., hybrid white spruce), because its performance would be a good test of the treatments' success; (5) the dominant local broadleaf species (i.e., paper birch) should be included, because it is an important component of local seral communities, and has been shown to increase significantly the nutrient content of aggrading forest floors on degraded sites (Sanborn 2001); and (6) there would be no untreated control, because there were abundant local examples of very poor tree growth on roads and landings constructed on similar soils (Figure 2): the most useful long-term comparison would be with trees growing on adjacent undisturbed areas (Plotnikoff et al. 2002).

We designed three rehabilitation treatments that would allow us to compare the biological effectiveness of wood waste incorporation with commonly used or operationally feasible practices (Table 1). Although economic and efficiency studies of the Subsoiler and Topsoil treatments were performed in 1995 (Lawrie et al. 1996), the use of wood wastes for soil rehabilitation was untested for these soil and site conditions, and this study was intended only to examine the silvicultural and soil effects of this treatment. Cost and productivity data were not collected because field conditions necessitated major (and expensive) departures from an operational implementation of this treatment. Chipping and incorporation of waste wood from debris piles adjacent to landings would be the operational practice that our first treatment was intended to simulate, but debris piles at the available landings had been burned prior to this study, so we used a tub grinder to chip locally obtained pulp logs and trucked the chips up to 4 km to our experimental sites. The "topsoil" applied in the third treatment consisted of a mixture of surface mineral soil and forest floor pushed into spoil piles adjacent to the landings during their construction by crawler tractors. Both the chip incorporation and topsoil recovery/tillage operations were carried out with a 5-tine site preparation rake mounted on a hydraulic excavator (Figures 3 and 4).

Based on accessibility, size, and similarity of surface (0–20 cm) soil texture (clay loam to heavy clay), we selected 15 landings located in cutblocks harvested between 1987 and 1990. These landings had been constructed as part of operational harvesting, and no special care had been taken to facilitate their later rehabilitation. The basic treatment unit was an individual landing to be of a size suitable for a companion study of tillage methods (Lawrie et al.

Figure 2. Sept. 2002, view of conifers (Douglas-fir, hybrid white spruce) planted in 1989 on an untreated landing at Aleza Lake Research Forest, British Columbia (foreground). Trees in background are predominantly Douglas-fir, planted in 1989, on undisturbed area of adjacent cutblock.

Table 1. Summary of rehabilitation treatments.

Treatment	Rationale	Procedures and materials[a]
Chips	Uses an organic amendment that would be readily available at most sites if woody debris piles at landings were chipped	Application of 10–15 cm of chipped waste wood (approx. 140 t/ha, oven-dry basis), along with 600 kg/ha of N (as urea-$(NH_4)_2SO_4$); chips incorporated to 30–35 cm depth with excavator-mounted site preparation rake
Subsoiler	Cheapest, simplest treatment, similar to much previous operational rehabilitation in central BC	Tillage to 60 cm with winged subsoiler (Tilth Inc., Monroe, OR) mounted on Caterpillar D7F crawler tractor
Topsoil	Emphasizes rehabilitation of shallow surface soil layer comparable to depth of rooting zone in fine-textured Luvisols	Shallow tillage (approx. 20 cm) with Caterpillar EL200B hydraulic excavator equipped with hydraulic thumb and 5-tined site preparation rake; without traveling over the tilled surface, excavator was used to apply a layer of topsoil (approx. 5–10 cm thick) reclaimed from adjacent spoil

[a] Within 2 weeks of tillage, all treatments received 400 kg/ha of 18–18–18 (N-P_2O_5-K_2O) fertilizer and 50 kg/ha of *Rhizobium*-inoculated legume seed: 20% alfalfa (*Medicago sativa*), 25% birdsfoot trefoil (*Lotus corniculatus*), 10% red clover (*Trifolium pretense*), 20% alsike clover (*T. hybridum*), 25% white clover (*T. repens*).

Figure 3. Site preparation rake attachment, mounted on hydraulic excavator, being used to incorporate waste wood chips.

Figure 4. Close-up of incorporation of 10- to 15-cm layer of waste wood chips into upper 30–35 cm of surface soil on fine-textured landing (July 1996).

1996). Therefore, there were five replicates of each of the three treatment combinations (Table 1).

Each landing was split into three subplots for planting (2 × 2 m spacing) with three tree species combinations: (1) hybrid white spruce (100%); (2) paper birch (100%); and (3) birch (50%)–spruce (50%) mixture. Although landings differed considerably in size (0.25–1.0 ha) and shape, a subset of 100 seedlings will be monitored for long-term growth and survival on each subplot. A standard 400-m^2 measurement plot for soil sampling was permanently marked within each subplot.

The Subsoiler and Topsoil treatments were implemented in July-Aug. 1995 and the Chips treatment in July-Aug. 1996, with paper birch and hybrid white spruce seedlings (1+0 315 container stock) planted in May-June 1997. Severe over-winter rodent damage occurred to the paper birch seedlings, and after unsuccessful replanting in 1998, the pure birch subplots were replanted with lodgepole pine in 2000.

Measurement Methods

Soil bulk density (Blake and Hartge 1986) was determined from intact cores (7 × 10 cm diameter) obtained at two depths (0–7 cm, 7–14 cm) collected with a slide hammer in July-Aug. 2000 at 10 random locations in the inner 400-m^2 measurement plot in each tree species subplot. Soil for chemical analysis (0–20 cm depth) was sampled at another 10 random locations in each measurement plot, air-dried, and sieved (2 mm) prior to analysis.

Soil chemical analyses consisted of pH (measured with a Radiometer pH meter in a 1:2 soil to 0.01 M $CaCl_2$ slurry), total C (LECO C analyzer, St. Joseph, MI), total N (Technicon Auto-Analyser, semi-micro Kjeldahl digestion), total S (LECO S analyzer), mineralizable N (2 week, 30° C anaerobic incubation), and exchangeable cations (1 N ammonium acetate, pH 7). All chemical data are reported on an oven-dry basis.

The hybrid white spruce seedlings were measured after four growing seasons in Aug. 2000 (total height, rootcollar diameter, current-year height increment), but only the data for the pure spruce subplots are reported here. A single composite sample of current-year foliage was prepared in Sept. 2000 from 20 randomly selected spruce trees in each pure spruce subplot. Foliage was oven-dried (70° C, 48 h) and analyzed by microwave digestion (Kalra and Maynard

1991) and ICP determination of total macro- and micronutrients. Total N and S were determined by a Fisons (Carlo-Erba) NA-1500 NCS analyzer.

Statistical Analyses

The bulk density data were analyzed as a completely randomized split-split plot analysis of variance (ANOVA), with treatment as the main plot factor, split by tree species and sampling depth, while the soil chemical data were treated as a completely randomized split plot design (species). Spruce seedling growth and foliar nutrient concentrations were analyzed as completely randomized (with subsampling) one-way ANOVAs, because the design involved only treatment as an effect. All analyses were carried out with SYSTAT v. 10 software (SPSS Inc. 2000).

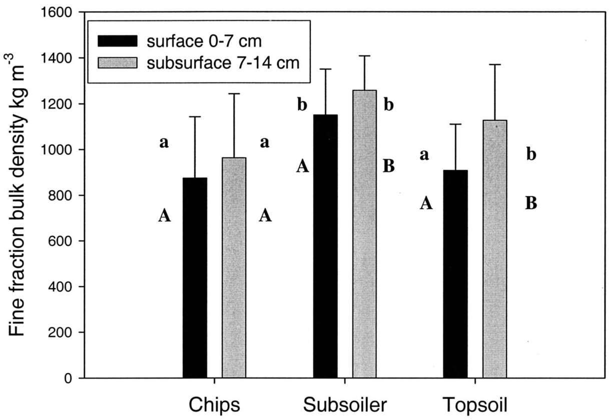

Figure 5. Bulk density of surface (0–7 cm) and subsurface (7–14 cm) soil, sampled July-Aug. 2000, from landings rehabilitated with three treatments (wood chip incorporation, subsoiling, topsoil recovery + shallow tillage). Error bars indicate standard deviations. Significant differences between treatments are indicated by different lower-case letters for a given depth, and between depths by upper-case letters for a given treatment (Bonferroni adjusted multiple comparison, $P < 0.05$).

Table 2. ANOVA table for soil bulk density of rehabilitated landings, Aleza Lake Research Forest (multiple R^2 = 0.468).

Source[a]	*df*	Error term	*F* statistic	*P*-value
T	2	L(T)	15.503	<0.0001
L(T)	12			
S	2	S*L(T)	3.070	0.065
S*T	4	S*L(T)	1.899	0.143
S*L(T)	24			
D	1	D*L(T)	69.461	<0.0001
D*T	2	D*L(T)	5.951	0.016
D*L(T)	12			
D*S	2	D*S*L(T)	0.019	0.982
D*S*T	4	D*S*L(T)	0.738	0.575
D*S*L(T)	24			
Subsampling error	809			

[a] Abbreviations for factors: T = treatment, L = landing, S = species, D = depth.

Results

Soil Bulk Density

Soil bulk densities were highest in the Subsoiler treatment and in cores taken at the lower (7–14 cm) sampling depth (Figure 5). ANOVA found significant effects of treatment and sampling depth, but no effect of species, no significant two-way interactions between species and treatment, and species and depth, and no significant three-way interactions (Table 2). Depth × treatment interaction was significant, and with species removed from the model, sampling depth had a significant effect only in the Subsoiler and Topsoil treatments, and with lower bulk densities in the surface cores (0–7 cm). For the surface cores, multiple comparisons found no significant differences between the Chips and Topsoil treatments, whereas for the subsurface cores, the Subsoiler and Topsoil treatments were not significantly different (Figure 5).

Soil Chemical Properties

For all soil chemical properties examined, no effect of species was detected, and there were no significant interactions between species and treatment (Table 3). Of the soil chemical properties analyzed, only total C, total N, total S, mineralizable N, and exchangeable Mg^{2+} were significantly affected by the treatments (Table 3, Figure 6), and except for the latter property, concentrations were lowest in the Subsoiler treatment. For these five properties, the Bonferroni adjusted multiple comparison indicated that for all but total C concentration, the chips and subsoiler treatments did not differ significantly from each other (Figure 6).

Spruce Seedling Growth and Foliar Chemistry

Survival of white spruce seedlings across all treatments averaged 93% (data not shown). Treatment effects were significant for all seedling growth measurements (df = 2,12): rootcollar diameter (F = 13.808, P = 0.001), total height (F = 5.064, P = 0.025), and current year height

Table 3. ANOVA table for selected soil chemical properties.

			Total C		Total N		Min N		Total S		Exch Mg	
		Multiple R^2	0.484		0.558		0.457		0.580		0.783	
Source[a]	*df*	Error term	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
T	2	L(T)	11.688	0.002	12.483	0.001	10.439	0.002	5.186	0.024	5.921	0.016
L(T)	12											
S	2	S*L(T)	0.630	0.541	0.362	0.700	0.943	0.403	0.233	0.794	0.819	0.453
S*T	4	S*L(T)	0.571	0.687	0.523	0.719	0.701	0.599	0.577	0.682	0.760	0.562
S*L(T)	24											
Subsampling error	405											

[a] Abbreviations for factors and statistics: T = treatment, L = landing, S = species, D = depth, F = *F* statistic, P = *P*-value.

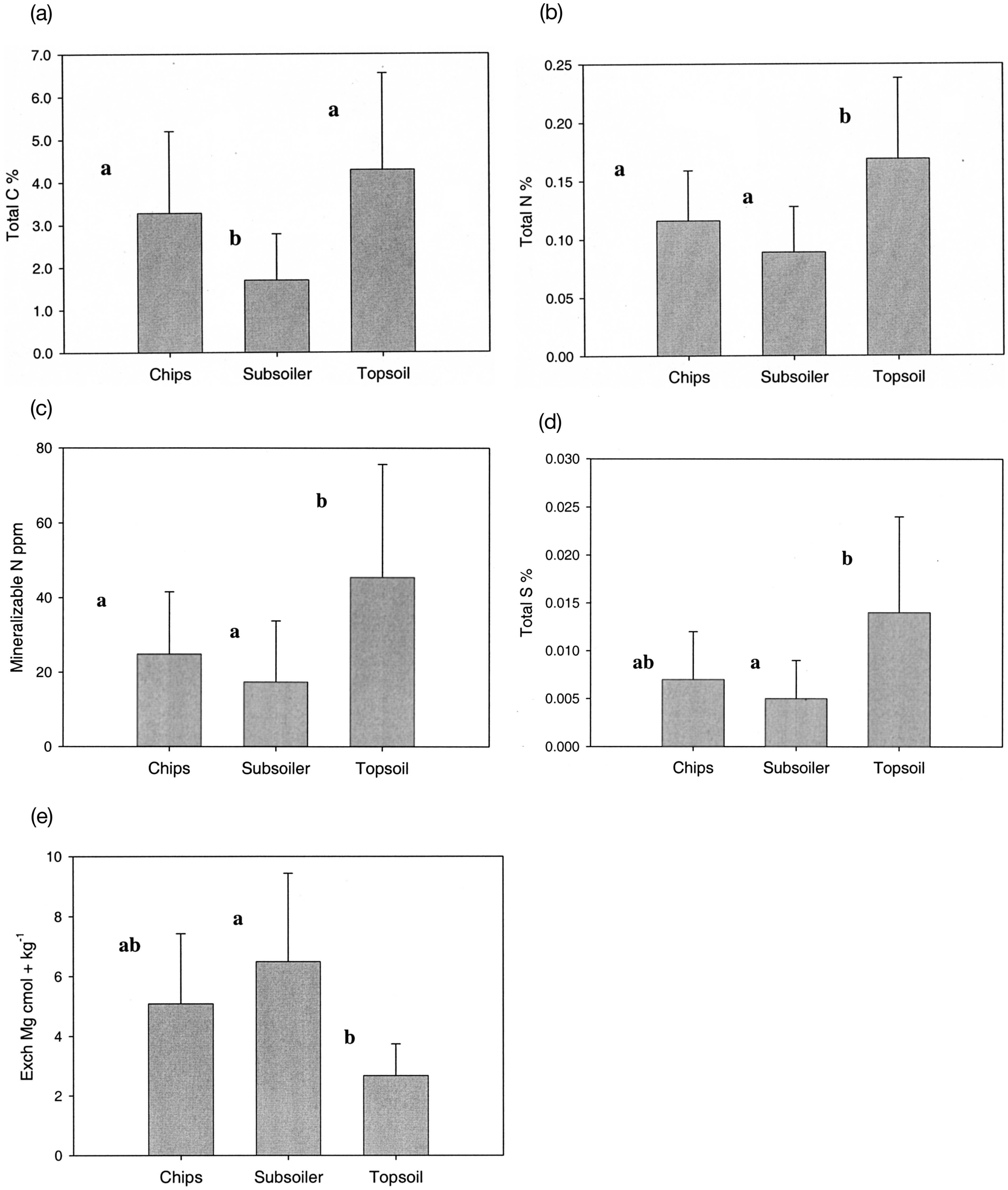

Figure 6. Selected chemical properties of surface soil (0–20 cm depth, sampled July-Aug., 2000) of landings rehabilitated with three treatments (wood chip incorporation, subsoiling, topsoil recovery + shallow tillage): (a) total carbon, (b) total nitrogen, (c) mineralizable nitrogen, (d) total sulfur, and (e) exchangeable magnesium. Error bars indicate standard deviations. Bars for treatments labeled with the same letter are not significantly different (Bonferroni adjusted multiple comparison, $P < 0.05$).

increment ($F = 6.148$, $P = 0.015$). For all measures of seedling growth, spruce performance was superior in the chips treatment (Figure 7) and the Subsoiler and Topsoil treatments did not differ significantly from each other. ANOVA of nutrient concentrations in current-year foliage (not shown) indicated significant treatment effects only for Mg, P, and Fe; mean concentrations are summarized in Table 4.

Discussion

The absence of any effect of species on soil properties was expected, given the short time since seedling establishment on these treatments and replacement of birch by lodgepole pine in 2000. Tree species is unlikely to influence soil properties until forest floor accumulation accelerates after canopy closure (Sanborn 2001).

For total C, N, and S, and mineralizable N in the <2 mm mineral soil (excluding the larger wood chip fragments), the relative ranking of the treatments was the same (Topsoil > Chips > Subsoiler), reflecting the close association of C, N, and S in soil organic matter. The low concentrations of total S (and N) in the Subsoiler and Chips treatments are consistent with those found in B horizons of forest soils elsewhere in the BC interior (Kishchuk and Brockley 2002), while the much higher S (and N) concentrations in the Topsoil treatment resulted from incorporation of forest floor materials in the spoil piles created during landing construction.

Although the soil total C concentration of Chips treatment was almost twice that of the Subsoiler treatment, this does not fully account for the C added in the form of wood chips. Although an ongoing in situ decomposition experiment (P. Sanborn, unpublished data) has found rapid mass loss (>60% in 4 years) by wood chips buried in these treatment plots, a large proportion of the added wood waste remains in large fragments (>0.5 cm minimum diameter) that are excluded by sieving during soil sample preparation. Qualitatively, the abundance of legume roots appeared greatest in the Chips treatment, suggesting that future inputs of organic matter from that source, along with continued fragmentation of the wood chips, will help to maintain C concentration in the soil fine fraction (<2 mm) as the wood chips continue to decompose. This treatment has significantly ameliorated both bulk density and soil nutrients, and spruce seedling performance appears to have benefited. In the absence of either chip incorporation or topsoil recovery, bulk densities in the Subsoiler treatment remain high, approaching those found in the running surfaces of untreated landings at ALRF in 1994 (Sanborn et al. 1999).

Of the exchangeable cations, only Mg^{2+} was significantly affected by the treatments, with the lowest concentrations observed in the Topsoil treatment. This is consistent with the pattern observed in undisturbed soil profiles at ALRF, which have lower exchangeable Mg:Ca ratios in the forest floor and uppermost mineral soil horizons than in Bt horizons and parent materials (Arocena and Sanborn 1998). The running surfaces of untreated landings consist primarily of exposed B-horizon material, so in the absence of topsoil replacement, the exchangeable Mg concentrations of surface mineral soils in the Chips and Subsoiler treatments should be similar to B horizons and parent materials of undisturbed soils.

Based on interpretive criteria for spruce foliar nutrients used by the BC Ministry of Forests (R. Brockley, BC Ministry of Forests, Dec. 3, 2003) and similar to those presented by Carter (1992), the nutrients of greatest concern across all treatments are Mg and S. The higher levels of foliar Mg in the Subsoiler treatment are consistent with the treatment effect noted for soil exchangeable Mg. Because widespread S deficiencies in BC interior forests have been well documented for lodgepole pine (Brockley 1996), it is reasonable to interpret the low foliar S concentrations in these hybrid white spruce seedlings as another expression of a regional pattern. The supplementary N fertilizer added with the chips appears to have offset N immobilization by the decomposing wood waste, and maintained satisfactory foliar N concentrations.

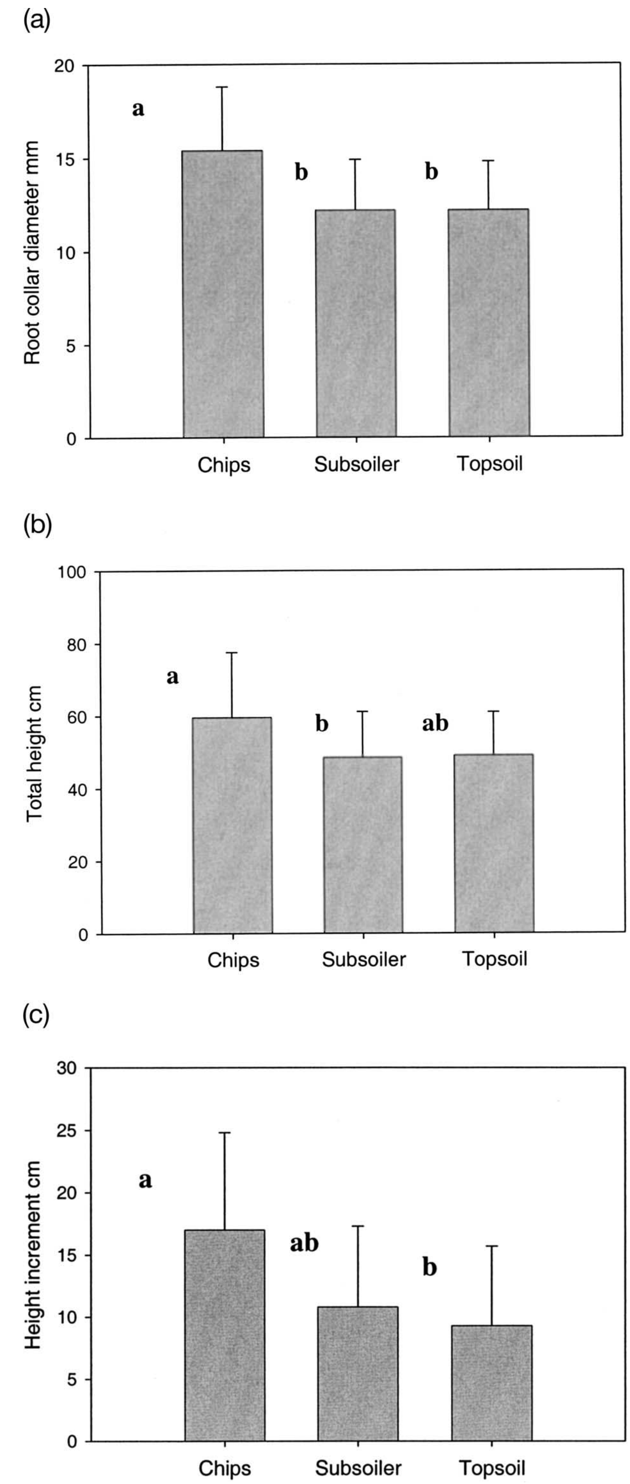

Figure 7. Seedling measurements (Aug. 2000) for hybrid interior spruce planted 1997 on landings rehabilitated with three treatments (wood chip incorporation, subsoiling, topsoil recovery + shallow tillage): (a) rootcollar diameter, (b) total height, and (c) height increment. Error bars indicate standard deviations. Bars for treatments labeled with the same letter are not significantly different (Bonferroni adjusted multiple comparison, $P < 0.05$).

Table 4. Nutrient concentrations in current-year (2000) spruce foliage (means [$n = 5$] and standard deviations [*italic*]).

Treatment	Ca	K	Mg	N	P	S	B	Cu	Fe	Zn
	%						mg/kg			
Chips	0.402	0.588	0.072	1.43	0.198	0.0768	8.1	2.4	28.1	46.6
	0.066	*0.019*	*0.005*	*0.15*	*0.010*	*0.0092*	*1.5*	*0.2*	*5.0*	*5.3*
Subsoiler	0.401	0.598	0.084	1.32	0.213	0.0688	8.3	2.3	27.6	49.7
	0.074	*0.023*	*0.009*	*0.18*	*0.009*	*0.0119*	*0.6*	*0.3*	*2.1*	*5.7*
Topsoil	0.385	0.577	0.072	1.36	0.195	0.0684	9.6	2.2	35.2	51.3
	0.039	*0.033*	*0.009*	*0.10*	*0.010*	*0.0076*	*1.7*	*0.2*	*6.1*	*0.8*

Management Implications and Conclusions

Three years after planting and 4 years after incorporation of chipped wood waste, growth rates of hybrid interior spruce seedlings on these rehabilitated landings exceeded those of seedlings growing on landings treated with simpler methods involving topsoil recovery and/or tillage. Although topsoil recovery created higher concentrations of C, N, and S in the rehabilitated surface soil, this treatment did not lead to correspondingly improved spruce growth. Because the depth of soil decompaction was shallowest in this treatment, it may be that physical factors have an overriding influence. For example, we noticed that temporary ponding of water after snowmelt was most pronounced on this treatment, suggesting that deeper tillage is needed to enhance infiltration in these fine-textured soils. In interpreting these initial results, it is important to remember that the landings used for this experiment were not originally designed or constructed so as to facilitate future rehabilitation. Additional care taken at the time of landing construction, particularly in salvaging forest floor and surface soil, and in ensuring drainage of the running surfaces, would likely improve the effectiveness of the combined topsoil recovery/tillage treatment.

Rapid establishment of agronomic legumes on all rehabilitation treatments created a mat of herbaceous vegetation that was pressed down by the winter snowpack and tended to crush seedlings, particularly in the case of paper birch. For future operational treatments, use of lower-growing agronomic species [e.g., white clover (*Trifolium repens*)] and/or lower seeding rates would be preferable. Although broadleaf woody species are a desirable component of rehabilitation treatments, to assist in restoring forest floor organic matter and nutrient capital, species with less vulnerability to rodent damage, such as Sitka alder (*Alnus viridis* ssp. s*inuata*) should be considered.

These results have demonstrated that simple rehabilitation treatments can restore productivity to severely degraded fine-textured soils and allow satisfactory establishment and nutrition of hybrid white spruce seedlings under BC central interior conditions. Along with monitoring of seedling growth and survival, future assessment of these treatments should include more detailed characterization of soil physical properties affecting soil mechanical resistance and water availability, to verify that the apparent amelioration of soil properties and restoration of site productivity are persisting. Once the planted seedlings have reached at least 5 years breast height age, it will be possible to estimate site index for these treatments for comparison with spruce growing in adjacent plantations on undisturbed sites (Nigh and Martin 2001).

The apparent success of wood chip incorporation in improving seedling growing conditions highlights the importance of ameliorating the high bulk density of these degraded fine-textured soils. The supplementary N addition in this treatment was sufficient to prevent excessive N immobilization by the incorporated wood waste at the expense of seedling nutrition. Although this experiment required additional efforts and expense that would not apply to operational use of wood wastes, there are field-portable chipping systems available that can produce chips suitable for soil rehabilitation purposes from on-site logging residues (Bulley 1996). Based on these promising early results, silviculturists should consider incorporation of chipped wood wastes as part of soil rehabilitation treatments for access structures constructed on fine-textured soils. Soils similar to those at ALRF occupy a large proportion of the most accessible managed forest lands in the BC central interior, so more intensive treatments may be justified to ensure their continued productivity.

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