Soil Rehabilitation Research at the Aleza Lake Research Forest: Techniques for restoring productivity to fine-textured soils

by Paul Sanborn1, Chuck Bulmer2, Dave Coopersmith1, Angela Dale3, & Dan Erikson4

Introduction

In the BC central interior, fine-textured glaciolacustrine sediments are an important soil parent material on many productive forest sites, particularly along major river valleys such as the Fraser and Nechako. With easy proximity to major transportation routes and wood processing facilities, many such sites were harvested early in the history of logging in this region, long before the advent of soil conservation policies in forestry. Part of the legacy of this early development is that substantial areas of productive growing sites have been converted to landings and other access structures on a scale which would not be consistent by current standards set by the Forest Practices Code. Displacement of nutrient-rich forest floors and well-structured surface mineral horizons, and the compaction and exposure of dense subsoils, have led to greatly reduced forest productivity on such access structures.

Despite the long history of soil rehabilitation research in the Prince George Forest Region, dating back to the early 1980s, little effort had been devoted to developing treatments suitable for landings and other access structures constructed on fine-textured soils (Sanborn et al., 1999). Another recognized knowledge gap was in the large-scale use of wood wastes as a soil amendment in rehabilitation treatments (Bulmer, 1998). Although some interesting initial operational trials had been established near Prince George by The Pas Lumber Co. in the mid-1990s, there was a need for field experiments with careful control and documentation of details such as application rates, fertilization treatments, and rates of decomposition of the incorporated residues.

With the advent of substantial Forest Renewal BC-funded landing rehabilitation programs in the central interior in the late 1990s, it was important to direct operational investments to the areas where success was most likely, while initiating research to identify and test operationally feasible methods to treat difficult sites, including those with degraded fine-textured soils.

In recognition of these knowledge gaps and the need to provide practical assistance and extension opportunities for the planning of “backlog” rehabilitation projects, we began a study at the Aleza Lake Research Forest, 60 km east of Prince George, in 1994 (Fig. 1).

Study Area

The 10,000 hectare Aleza Lake Research Forest (ALRF), established in 1924, is underlain largely by fine-textured glaciolacustrine deposits on which strongly-developed Luvisolic soils have formed. Similar soils occupy more than 20% of the Prince George-McLeod Lake soil survey area (Dawson, 1989). Luvisolic and related Luvic Gleysolic soils at ALRF are characterized by accumulation of organic matter and depletion of clay in the surface

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Ahe horizon, combined with large and distinct blocky structures in the much denser, clay-enriched Bt or Btg horizon (Table 1; Arocena and Sanborn, 1999). Root occupancy is almost entirely confined to the forest floor and A horizons.

The ALRF is located within the Willow Wet Cool Sub-Boreal Spruce (SBSwk1) biogeoclimatic subzone (DeLong, 1996). Long-term climatic records (1941-1970) indicate a mean annual temperature of 3°C and mean annual precipitation of 930 mm (Jull, 1992). Mature and old-growth forests are dominated by hybrid white spruce (*Picea glauca* x *engelmannii*) and subalpine fir (*Abies lasiocarpa*), with scattered veteran interior Douglas-fir (*Pseudotsuga menziesii* var. *littoralis*), although widely planted on coarser soils in this subzone, is uncommon in mature forests on mesic sites.

**Treatments and Study Design**

**Pre-treatment Soil Conditions**

Through reconnaissance field work in the fall of 1994, we identified a large number of extensive (up to 1 hectare) and easily accessible landings in openings created between 1987 and 1990. In most cases, no attempt had been made to reforest these structures, but where planting had occurred, the surviving seedlings were much smaller and had much poorer vigour than in the adjacent cutblocks.

We initially characterized surface soil conditions for landings and on-block spur roads with a wide range of textures (heavy clay to loamy sand). Only for the finer textures (clay content > 30-50%) were aeration porosity values (Figure 2) below the 10% level at which root growth is restricted (Baver et al., 1972). Such relationships may account for anecdotal observations of apparently satisfactory tree growth on some untreated landings.

A subset of 15 landings with textures ranging from clay loam to heavy clay was selected for research purposes, and we sampled surface soils (0-20 cm depth) to characterize pre-treatment conditions (Table 2). The high bulk densities were quite similar to those observed in the undisturbed Bt horizons elsewhere at ALRF (Table 1), suggesting that little additional compaction had occurred during construction and use of these landings. Organic matter concentrations were low (1.4% carbon (C)), along with levels of nutrients usually associated with organic matter (nitrogen (N), phosphorus (P), sulphur (S)).

**Requirements for Successful Rehabilitation**

Based on these initial conditions, our proposed rehabilitation treatments were designed to meet several technical requirements:

- reduction of bulk densities (and increasing aeration porosity)

Table 1. Selected physical and chemical data for a typical Luvic Gleysolic soil on glaciolacustrine sediments at the Aleza Lake Research Forest (Arocena and Sanborn, 1999).

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Bulk density (kg/m³)</th>
<th>Sand</th>
<th>Clay</th>
<th>C</th>
<th>N</th>
<th>S</th>
<th>Available P (ppm)</th>
<th>pH</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>4.5-0</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>42.5</td>
<td>1.37</td>
<td>0.1006</td>
<td>137.8</td>
<td>n.d.</td>
<td>2.62</td>
<td>48.20</td>
<td>7.7</td>
</tr>
<tr>
<td>Ahe</td>
<td>0.10</td>
<td>820</td>
<td>16.2</td>
<td>50.2</td>
<td>2.2</td>
<td>0.19</td>
<td>0.0066</td>
<td>19.6</td>
<td>4.0</td>
<td>0.37</td>
<td>7.61</td>
<td>5.5</td>
</tr>
<tr>
<td>Btg</td>
<td>10.37</td>
<td>1360</td>
<td>4.3</td>
<td>79.5</td>
<td>0.7</td>
<td>0.13</td>
<td>0.0059</td>
<td>4.6</td>
<td>4.5</td>
<td>0.37</td>
<td>13.90</td>
<td>15.0</td>
</tr>
<tr>
<td>BCg</td>
<td>37-57</td>
<td>1200</td>
<td>5.5</td>
<td>74.5</td>
<td>0.5</td>
<td>0.10</td>
<td>0.0057</td>
<td>0.0</td>
<td>6.4</td>
<td>0.32</td>
<td>14.30</td>
<td>14.7</td>
</tr>
<tr>
<td>Ckg</td>
<td>57-105+1370</td>
<td></td>
<td>2.4</td>
<td>81.8</td>
<td>0.4</td>
<td>0.07</td>
<td>0.0051</td>
<td>0.2</td>
<td>7.5</td>
<td>0.39</td>
<td>14.70</td>
<td>14.0</td>
</tr>
</tbody>
</table>

5 Aeration porosity indicates the proportion of total soil volume which is occupied by air-filled pores after an initially saturated soil sample is allowed to equilibrate with a tension of 1/3 atmosphere (Baver et al., 1972).
porosities),
• restoration of organic matter, either by replacement of
displaced topsoil and/or forest floor, or by addition of
organic soil amendments,
• restoration of beneficial soil structure or aggregation in
the surface rooting zone of the soil profile, and
• replacement of nutrients lost by soil and forest floor
displacement

**Rationale for Treatment Selections**

Our treatments also took into account the following observations and principles:
• equipment used for tillage treatments had to be readily
available in the central interior of BC;
• given the naturally shallow rooting zones in undisturbed
soil profiles in this area, the treatments would empha-
size restoration of surface soil conditions;
• any organic amendments would have to use materials
which are readily available in field situations — the
most likely candidate was chipped woody debris from
landing waste piles;
• tree species selection should include the dominant com-
mercial species preferred for undisturbed sites with simi-
lar soil types (i.e. hybrid white spruce) — this was felt
to be the most realistic long-term test of the success of
the treatments;
• planting of a hardwood species (i.e. paper birch) should
be included, since these are an important element of
seral communities, and a local retrospective study indi-
cated that the presence of birch significantly increased
the nutrient content of recovering forest floors on de-
graded sites;
• there would be no untreated control, since we already
knew that tree growth is extremely poor on these struc-
tures in the absence of rehabilitation — the most rel-
levant long-term comparison would be with trees grow-
ing on adjacent undisturbed areas

Based on these considerations, we settled on three
treatments, each being a combination of elements that re-
acted broadly differing strategies of soil rehabilitation
(Table 3).

**Experimental Design**

Formally, this study used a completely randomized
design with 5 replicates of each treatment, with superim-
posed split-plots to allow comparison of the 3 tree species
combinations. We deliberately rejected a more complex
factorial design that would have required a much larger
experimental area, and/or larger numbers of much smaller
plots. Our basic treatment units were individual landings
so that observations of equipment operations and costs
would have some relevance to operational practices. (See

**TABLE 2.** Pre-treatment soil properties for fine-textured landings and
associated topsoil piles, Aleza Lake Research Forest (1994).

<table>
<thead>
<tr>
<th>Property</th>
<th>Landing Surface</th>
<th>Topsoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density (kg/m³)</td>
<td>1357</td>
<td>n.d.</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>7.2</td>
<td>15.9</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>50.9</td>
<td>40.6</td>
</tr>
<tr>
<td>Total C (%)</td>
<td>1.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>Total S (%)</td>
<td>0.007</td>
<td>0.021</td>
</tr>
<tr>
<td>Available P (ppm)</td>
<td>29</td>
<td>66</td>
</tr>
<tr>
<td>Exchangeable K* (m.e./100 g)</td>
<td>0.32</td>
<td>0.48</td>
</tr>
<tr>
<td>Exchangeable Ca’ “ ”</td>
<td>7.00</td>
<td>7.30</td>
</tr>
<tr>
<td>Exchangeable Mg’ “ ”</td>
<td>4.96</td>
<td>3.95</td>
</tr>
</tbody>
</table>

*Data for exchangeable cations in Tables 1 & 2 are not directly comparable, as different
extraction methods were used.

**TABLE 3. Summary of rehabilitation treatments**

<table>
<thead>
<tr>
<th>Treatment (Rehabilitation Strategy)</th>
<th>Procedures and materials*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsoiler</td>
<td>• Tillage to 60 cm with winged subsoiler (Tilth Inc., Monroe, Oregon) mounted on Caterpillar D7F crawler tractor</td>
</tr>
<tr>
<td>(Cheapest, minimal treatment, comparable to much operational rehabilitation in BC interior)</td>
<td></td>
</tr>
<tr>
<td>Topsoil (Emphasizes restoration of relatively shallow surface soil layer, to depth comparable to typical natural rooting zone of fine-textured Luvisols)</td>
<td>• Shallow tillage (approx. 20 cm) with Caterpillar EL200B hydraulic excavator equipped with hydraulic thumb and 5-tined site preparation rake</td>
</tr>
<tr>
<td></td>
<td>• Without travelling over the tilled surface, the excavator was used to apply a layer of topsoil (approx. 5-10 cm thick) reclaimed from adjacent spoil</td>
</tr>
<tr>
<td>Chips (Tests the benefits of using an organic amendment which would be readily available at most sites)</td>
<td>• Application of 10-15 cm of chipped waste wood (approx. 140 t/ha), along with 600 kg/ha of N (as 34-0-0-12 fertilizer)</td>
</tr>
<tr>
<td></td>
<td>• Incorporation of chips to depth of 30-35 cm with excavator-mounted site preparation rake</td>
</tr>
</tbody>
</table>

*Within 2 weeks of tillage, all treatments received 400 kg/ha of 18-18-18
(N—P₂O₅—K₂O) fertilizer and 50 kg/ha of Rhizobium-inoculated legume seed (alfalfa 20%), birdsfoot trefoil (25%), red clover (10%), alsike clover (20%), white clover (25%).
Each landing was split into 3 subplots to accommodate 3 tree species combinations (spruce, paper birch, and a 50:50 spruce:birch mixture), planted at a 2 x 2 m spacing.

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Lawrie et al. (1996) for detailed time and cost comparisons.)

In addition to the primary research component of this project, we carried out associated demonstration projects to provide examples of other methods of rehabilitation and revegetation on both coarse- and fine-textured soils, and on other disturbance types (Table 4).

**Observations on Treatment Implementation**

Treatments were installed in 1995 and 1996 (Table 5). The original plan had been to complete all treatments in 1995, but wet weather and poor road conditions delayed the production and hauling of wood chips for the soil amendment treatment until 1996.

1. **Subsoiler:**
The winged subsoiler (Figure 3) was originally developed in Oregon in the early 1980s (Cafferata, 1992) and has been widely used in previous soil rehabilitation studies in the BC interior (Sanborn et al., 1999). This robust implement is well suited to tillage operations in forest land, and achieves its greatest efficiency when dealing with large features such as landings or roads. However, we experienced delays when the subsoiler encountered buried stumps and logs. The tillage depth can be adjusted as needed, and our choice of 60 cm was similar to settings used in previous studies.

2. **Topsoil replacement and excavator tillage:**
The hydraulic excavator, equipped with a “thumb” and 5-tined site preparation rake (Figure 4), was chosen for its adaptability and ready availability. It is quite likely that excavators would be used in operational rehabilitation, especially in projects which require other operations to be carried out in the same areas (e.g., site preparation, debris piling, and road deactivation). The excavator was particularly effective in reclaiming topsoil from spoil piles adjacent to landings. These piles often included large amounts of woody debris which were easily removed with the thumb. Although the excavator’s tillage cost per unit area was 2-3 times higher than for the subsoiler (Lawrie et al., 1996), the versatility of the former tends to offset this disadvantage.

3. **Wood chip incorporation:**
Although the subsoiling and excavator tillage/topsoil treatments were implemented in a manner that was opera-

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**TABLE 4. Rehabilitation and Revegetation Demonstration Projects**

<table>
<thead>
<tr>
<th>Site Characteristics</th>
<th>Soil Treatments</th>
<th>Revegetation Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandoned sawmill site (1.5 ha): sandy soils</td>
<td>• 3 treatments (1995): tillage with winged subsoiler or excavator-mounted site prep rake, incorporation of rotted sawdust with site prep rake</td>
<td>• planted 1996 &amp; 1997 with Fd, Pl, Sx mixtures</td>
</tr>
<tr>
<td>Major road allowance (400 x 25 m): sandy, gravelly soils</td>
<td>• split into equal areas for excavator and subsoiler tillage (1995)</td>
<td>• planted 1997 with alternate rows of Ep-Fd mix and Sx</td>
</tr>
<tr>
<td>Abandoned gravel pit (1 ha)</td>
<td>• tilled with excavator (1996)</td>
<td>• planted 1997 with Pl-Dg mixture</td>
</tr>
<tr>
<td>Coarse-textured landings and spur-roads (various sizes and locations)</td>
<td>• tilled with excavator (1996)</td>
<td>• planted with Fd-Ep, or Fd-Ep-Pl mixtures</td>
</tr>
<tr>
<td>Spur-roads (fine-textured soils)</td>
<td>• tilled with excavator (1995 &amp; 1996)</td>
<td>• planted 1996 &amp; 1997 with Sx, Sx-Ep mix, or alternating segments of Pl or Sx, with or without Dg</td>
</tr>
</tbody>
</table>

*all demonstration areas were seeded with same legume mixture and fertilized at same rate as main study treatments; species codes: Fd = Douglas-fir, Pl = lodgepole pine, Sx = interior hybrid spruce, Ep = paper birch, Dg = Sitka alder*
titionally realistic, this was not the case for the organic amendment treatment. Although landing debris piles would be the most likely raw material available in operational forestry conditions, our landings dated from the mid-1980s and early 1990s, and no debris piles remained on-site. We had to obtain whole waste logs from other local sources and chip them with a mobile tub grinder (Figure 5). This material has an extremely wide C:N ratio approaching 600:1, so a large addition of N fertilizer was needed to prevent complete immobilization of available N after this amendment was incorporated in the soil. If typical slash materials had been available, consisting mostly of the more nutrient-rich tops and branches, considerably less N fertilizer would have been needed.

**FIGURE 5.** Production of chipped wood waste soil amendment with tub grinder (July, 1996).

Weather conditions during the wet summer of 1995, coupled with the great spatial variability in soil moisture content in these fine-textured soils, meant that some of the tillage operations may have been carried out under sub-optimal conditions. However, we recognize that logistical and timing problems would cause similar difficulties in operational rehabilitation projects. Achieving optimal moisture conditions for tillage of fine-textured soils will always be a challenge in cool, moist climates with short growing seasons (McNabb, 1994).

**Initial Results**

**Soil Properties**:  

1. Bulk Density

Of the 3 treatments, chip incorporation was the most successful in reducing bulk densities (Figure 6). Subsoiling apparently provided the least improvement over untreated conditions, although these shallow measurements would not detect any benefits of this method at depths greater than 14 cm. For all 3 treatments, the differences between bulk densities at the 2 depths were significant, although in differing directions. In the case of the topsoil treatment, the lower bulk density in the uppermost 7 cm likely corresponds to the higher organic matter content of the recovered topsoil, which ranged from 5 to 10 cm in thickness. For the subsoiling treatment, this difference is smaller and may reflect the limited degree of natural decompaction that would have occurred over the previous 7-10 years since landing construction. The chip treatment, in contrast, had higher bulk densities at the surface, which may simply reflect very efficient incorporation of the chips by the site preparation rake.

Although the chip treatment has initially produced surface soil bulk densities which are comparable to those in undisturbed soil profiles on similar parent materials (Table 1), it remains to be seen whether this degree of amelio-

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**TABLE 5.** Chronology of treatment installations and monitoring

<table>
<thead>
<tr>
<th>Dates</th>
<th>Work Performed or Scheduled</th>
</tr>
</thead>
<tbody>
<tr>
<td>August, 1994</td>
<td>• Obtained 1:5000 colour air photography for candidate study area at Aleza Lake Research Forest</td>
</tr>
<tr>
<td>September-October, 1994</td>
<td>• Ground assessment of landings; pre-treatment soil sampling for bulk density, aeration porosity, chemical properties, texture</td>
</tr>
<tr>
<td>November, 1994 — March, 1995</td>
<td>• Selection of 15 landings for core study</td>
</tr>
<tr>
<td>May, 1995</td>
<td>• Selection of treatments</td>
</tr>
<tr>
<td></td>
<td>• Development of experimental design</td>
</tr>
<tr>
<td>May — June, 1997</td>
<td>• Plot photography</td>
</tr>
<tr>
<td>July — August, 1995</td>
<td>• Installation of subsoiling and excavator tillage/topsoil treatments (5 landings for each); fertilization and legume seeding of treated plots</td>
</tr>
<tr>
<td>September, 1995</td>
<td>• Repeat 1:5000 colour air photography</td>
</tr>
<tr>
<td>March, 1996</td>
<td>• Purchase and stockpile waste pulp logs</td>
</tr>
<tr>
<td>July, 1996</td>
<td>• Chipping of waste wood with tub grinder</td>
</tr>
<tr>
<td>August, 1996</td>
<td>• Hauling and spreading of wood chips</td>
</tr>
<tr>
<td></td>
<td>• Addition of N fertilizer prior to incorporation of chips with excavator</td>
</tr>
<tr>
<td></td>
<td>• Legume seeding and fertilization of chip-treated plots</td>
</tr>
<tr>
<td>May — June, 1997</td>
<td>• Planting of birch and spruce seedlings</td>
</tr>
<tr>
<td>July — August, 1997</td>
<td>• Bulk density measurements and soil sampling</td>
</tr>
<tr>
<td></td>
<td>• Plot photography</td>
</tr>
<tr>
<td>May, 1998</td>
<td>• Assessment of seedling condition and replacement of mortality</td>
</tr>
<tr>
<td>August, 1998</td>
<td>• Plot photography</td>
</tr>
<tr>
<td>August — September, 2000</td>
<td>• Repeat of soil sampling and bulk density measurements</td>
</tr>
<tr>
<td></td>
<td>• Seedling assessment and measurement</td>
</tr>
<tr>
<td></td>
<td>• Plot photography</td>
</tr>
</tbody>
</table>
ration will be maintained.

2. Carbon

Total C concentration in the surface soils, which can be taken as an index of organic matter content, was most improved by the topsoil recovery treatment and least by the subsoiling (Figure 7). Despite the substantial amount of C added by the wood chips (approximately 70 tonnes/hectare), the soil sampling and analysis procedures excludes all particles coarser than 2 mm, so the bulk of the C added by this amendment would not be reflected in these determinations.

3. Nitrogen, sulphur and phosphorus

Most soil N, S and P is usually associated with organic matter, so the relative concentrations of these nutrients were affected by the rehabilitation treatments in a pattern identical to that displayed by C. As with C, the highest total N and S concentrations were observed in the topsoil recovery treatment.

Mineralizable N is an index of the short-term ability of soils to provide N in plant-available form through biologically-controlled processes that release ammonium. The mean mineralizable N values by treatment paralleled the pattern observed for total C, N, and S — the topsoil treatment was highest, followed by the chip and subsoiling treatments (Figure 8). However, in this instance, the treatment effects were not statistically significant. Such a finding is still important, because it suggests that the amount of fertilizer added with the chip amendment was sufficient to offset any short-term tendency for N immobilization by such a large addition of N-poor organic residues. This interpretation is supported by our 1998 observations of spruce seedling vigour, which indicated that the chip treatment consistently had the highest proportion of spruce seedlings with healthy green foliage. (Foliar sampling and analysis planned for 2000 will determine whether this impression is correct.)

Phosphorus concentrations were measured by an extraction method which removes that portion of the soil P which is most available to plants. Although the relative ranking of mean P concentrations by treatment was the same as observed for other organic matter-associated nutrient elements, these treatment effects were not statistically significant.

4. Exchangeable cations

Of the 3 major nutrients which occur in exchangeable form in soils, only Mg was significantly affected by the treatments (Figure 9). Unlike the pattern displayed by C, N, and S, exchangeable Mg concentrations were lowest in the topsoil treatment. Since the recovered topsoil consisted mostly of forest floor and A horizon material displaced from the landing site, this is consistent with the apparent depletion of Mg from surface horizons of undisturbed soil profiles of similar texture at Aleza Lake (Table 1).

Decomposition of Wood Chips

Apart from its availability, one of the major reasons for using wood chips as a soil amendment is that this material should be persistent enough that reduced bulk densities will be maintained for several years after tillage. To help assess the lifespan of this material in the soil, including its ability to restore long-term organic matter reserves, we are conducting a decomposition study, using the litterbag method.

During the chipping operation in July 1996, we set aside pure samples of spruce and birch chips for later use. In October 1996, we manufactured and installed litterbags containing either birch or spruce chips in 2 size classes: 2.0 – 6.3 and 6.3 – 12.5 mm minimum particle diameter. The bags were placed both on the surface and buried at 10 cm depth in the 5 landings which had received the wood chip treatment. Sufficient replicates were installed to allow recoveries at 6 time intervals: yearly for 4 years, followed by every 2nd year for another 4 years.

Initial data for the first annual recovery in 1997 indicates a large weight loss for the buried wood chips (Figure 10). Despite this apparently rapid rate of decomposition, the recovered chips maintained their size and shape, although they had noticeably softened when rubbed between the fingers in a moist state. As expected, faster weight loss rates occurred for birch vs. spruce, and for fine vs. coarse particles.

8 Litterbags are pouches, constructed of a decay-resistant mesh fabric, containing measured amounts of an organic material. The bags are either pinned to the ground or buried, and are recovered at intervals and the contents dried and re-weighed to estimate the loss due to decomposition.
Observations on Revegetation Performance

Our legume seeding treatments (Table 3) achieved their initial objectives of rapidly covering the tilled surfaces with herbaceous vegetation. High coverage was most rapidly attained on the topsoil treatment, presumably because of the higher quality seedbed. We observed that the legume root systems were well-nodulated and had effectively penetrated the surface soils on all treatments, and clearly were contributing a significant below-ground input of organic matter.

Although we did not perform quantitative measurements, red clover quickly became the dominant component of the herbaceous cover. However, longer-term observations of other rehabilitated landings in the Prince George area suggest that birdsfoot trefoil is the species most likely to persist after 5-10 years.

This rapid legume establishment and growth was not an unmixed blessing. In associated demonstration plantings established in 1996 (Table 4), widespread vegetation press of spruce seedlings occurred during the first winter. However, the 1+0 315 container stock that we had used was sufficiently robust that almost all spruce seedlings had recovered within 2 years after planting. In other demonstration plantings at Aleza Lake (Table 4), Douglas-fir seedlings appeared much less able to rebound under similar conditions. Further work would be needed to determine whether different sizes and stock types of Douglas-fir seedlings would be better able to survive this problem.

In the case of birch, considerable rodent damage occurred over the first winter after planting. Mortality averaged 25%, compared with only 2% for spruce. Although many birch seedlings reached a height of 40-50 cm during the year of planting, our inspections the following spring revealed that many had been partially or completely girdled during the winter. This damage appeared to be particularly severe in the plots with the heaviest herbaceous cover, and meadow voles were the suspected culprit (D. Seip, personal communication).

Similar problems with rodent damage occur with other deciduous species planted at Aleza Lake, based on anecdotal observations of willow and cottonwood. Fortunately, this problem does not seem to affect Sitka alder — 1997 demonstration plantings on a variety of rehabilitated soil types, and with a wide range of degrees of herbaceous cover development, showed no apparent animal damage to this species.

Soil Structural Modification

Although frost action and other natural processes have the potential to ameliorate soil compaction, results from our pre-treatment sampling suggest that the rate of natural recovery of degraded fine-textured soils is very slow.

Up to 7 years after landing construction, the pretreatment surface bulk densities reported in 1994 still require much improvement to reach the levels observed in undisturbed surface horizons (Table 2 vs. Table 1). The only visible change in the almost flat surfaces of the untreated portions of these landings was some structural modification, expressed as a somewhat finer blocky structure in the top 2-3 cm of the exposed clay-rich Bt horizon.

We observed that an almost equal degree of structural modification had occurred after only 1 or 2 years on the surfaces of large mineral soil clods created by the chip incorporation treatments of 1996. It appears that creation of a much rougher surface by tillage may accelerate the physical disintegration of either naturally dense or artificially compacted fine-textured materials. (Similar observations were reported by McNabb [1994] for sites in northern Alberta.) Although frost action may be involved, wetting and drying cycles are also likely to be important, since these soils contain a significant proportion of clay minerals known to exhibit pronounced shrink-swell activity (Arocena and Sanborn, 1999).

Conclusions

Fine-textured soils are inherently difficult to return to full productivity after construction of landings or bladed trails has removed much of the natural rooting zone, leaving behind only dense, adversely-structured B horizons at the surface. Although previous studies in the Prince George Forest Region have demonstrated that simple tillage and topsoil restoration treatments appear to be effective on coarse- and medium-textured soils, rehabilitation of fine-textured soils should be regarded as experimental at this time. Previous trials have not involved the latter soil types, so it is unclear whether rehabilitation of access structures is likely to succeed on these more challenging sites.
Studies begun at the Aleza Lake Research Forest in 1994 have attempted to address this knowledge gap, using techniques that are likely to be operationally feasible, either currently or in the future.

The ultimate test of these treatments will be the long-term performance of the planted trees and the alteration of soil properties (e.g., bulk density, nutrient availability, organic matter content). Some interim observations may point toward these long-term results:

- wood chips appear to maintain favourable soil bulk densities for 2 years after incorporation, and the accompanying fertilization has prevented any obvious symptoms of N starvation in planted seedlings;
- topsoil recovery and replacement was the most successful of the 3 treatments in restoring surface soil fertility;
- use of paper birch in rehabilitation treatments may be limited by high rates of rodent damage, particularly where revegetation treatments have resulted in dense herbaceous cover.

**Disclaimer**

Any mention of product or commercial names is purely for descriptive purposes and is not intended as an endorsement or approval by the Ministry of Forests of any product or service to the exclusion of others than may be suitable.

**Acknowledgements**

Financial support for this study has been provided by Forest Renewal BC (Project OP97075-RE), the Prince George Forest Region, and the Ministry of Forests Research Branch. In his capacity as Manager of the Aleza Research Forest, Mike Jull, formerly of Prince George Forest Region, assisted us in gaining the necessary approvals for securing our study sites. We thank our contractors, collaborators, student field assistants, and the Prince George Forest District for their indispensable roles in establishing these installations.

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