The Long Term Soil Productivity Study in British Columbia

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Abstract

In the LTSP, we recognize that a leading edge reputation in forest management is based on environmental sustainability as well as on high-quality, reasonably priced product. In BC, LTSP sites have been installed in 4 biogeoclimatic zones, with 5 timber species, and on calcareous and non-calcareous soils. Throughout North America, there are 62 similar installations, all designed to investigate the impacts of soil disturbance on near-term and long-term soil and forest productivity. Plots have had three levels of compaction (none, intermediate and heavy) and three levels of organic matter removal (stem only harvest; whole tree harvest; forest floor removal and whole tree harvest) before being regenerated with commercial tree species. Measurement of soil properties, understory vegetation, microclimate, and tree productivity occur at scheduled periods throughout the full rotation. Findings from this research contribute to the development of our knowledge base and to ongoing development of forest practice regulations and guidelines.

Introduction

Maintenance of near- and long-term forest productivity and the sustainability of forest management are of concern to forest managers and the international marketplace. Forest productivity depends on maintaining the diversity and function of soil as much as the aboveground ecosystem. Inherent site productivity is a function of off-site factors such as climate and ecological diversity (Franklin et al. 1989) and on-site factors such as soil productivity. Some soil properties that affect productivity are fixed, including soil texture and soil mineralogy. Forest management can, however, alter many soil properties. Powers et al. (1990) proposed a model of soil productivity that relates alterable soil properties to two factors - soil porosity and organic matter. Both total porosity and pore size distribution are altered by soil compaction. Soil organic matter directly influences soil nutrient reserves and supply and water storage capacity. Nitrogen, the nutrient most commonly limiting to forest growth (Binkley 1986) is present in forest soils almost exclusively in organic forms. Soil nutrient availability is largely a function of the level of biological activity in the soil, which depends directly on organic matter quantity and quality. Soil organic matter also influences soil structure and porosity, thermal properties, and susceptibility to erosion. There are numerous indirect and interactive effects of organic matter and soil porosity. For example, de-compacted landings may re-compact without organic matter additions and removal of soil organic matter affects biological activity, which may alter soil structure.

Timber harvesting and site preparation affect soil porosity and site organic matter. Harvesting removes organic matter and nutrients in trees and may displace forest floor organic matter during road and landing construction (Carr and Mitchell 1989). Site preparation may lead to a loss of organic matter (burning, scalping) or its displacement away from growing trees. Ground-based harvesting causes soil compaction to some extent, depending on the harvesting or silvicultural system used. Site preparation may also cause compaction if carried out under adverse conditions on sensitive sites. Strategies for minimizing site degradation during timber harvesting (Lewis et al. 1989) and site preparation have been developed, but we need solid research results to back up these strategies. The FRPA will be refined and modified as research results emerge. Although it is clear that soil productivity must be conserved, it is also clear that each additional requirement imposed on the forestry industry add costs, so it is important that guidelines be relevant to specific forests and soils.

Objectives

1. Determine the effects of different levels of organic matter (above-ground biomass and forest floor) retention and soil compaction on long-term forest soil productivity on a range of species, sites and ecological conditions.
2. Study the long-term effects of organic matter removal and soil compaction on soil nutrient status, soil physical properties, soil microclimate, soil biological activity, biodiversity of soil organisms, and nutrient cycling.
3. Identify causal relationships between soil properties that are altered by soil disturbance and long-term forest productivity.
4. Investigate the influence of ecosystem unit on the effects of soil disturbance on long-term soil productivity.

Materials and methods

Experimental design

Four fully replicated installations now exist in the province (SBS, BWBS, IDF, IDF on calcareous soil). Sites are representative of the zonal ecosystem (medium moisture and nutrient conditions). Replicates have similar soil and site features. Each installation is treated as a block in a randomized block design. Within each study site a minimum of nine core treatment plots has been established, representing a factorial combination of three organic matter removal treatments (OM1 = Stem (boles) only removed; OM2 = Stems and crowns removed (whole-tree harvesting); OM3 = Stems, crown and forest floor removed) and three soil compaction treatments (C0 = No compaction; C1 = Intermediate compaction; C2 = Heavy compaction). This results in nine experimental units per study site (OM1C0, OM1C2, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1, and OM3C2). Treatments have been randomly assigned to plots. Two tree species are being grown in each plot. The final design is a split plot design.

Completion of BC LTSP installation phase

There currently exists one LTSP replicate in the Interior Cedar Hemlock (ICH) biogeoclimatic zone in Idaho and a second in BC near Nelson, installed by our project team last year. In 2003/4, we began the establishment of the final replicate in this forest type in British Columbia. Selkirk College collaborated on the assessment of the BC ICH installations.

Re-measurement of existing installations

There are three replicate LTSP sites in the Sub-boreal Spruce (SBS) biogeoclimatic zone in the Northern Interior Forest Region (one replicate in each of the former Prince Rupert, Prince George, and Cariboo Forest Regions). The site in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone is in the Peace Forest District, Northern Interior Forest Region (former Prince George Forest Region). Fully installed Interior Douglas-fir (IDF) sites are in the Southern

Interior Forest Region, Kamloops and on calcareous soil in the Rocky Mountain Forest District, Southern Interior Forest Region, Nelson.

In 2003/4, certain established installations were fully re-measured because they had reached Years 5 (BWBS-3, IDF-1) and 10 (SBS-1, -2). Samples were analyzed for pH, total C, total N, mineralizable N, total S, available P, CEC and exchangeable cations. Particle size distribution was determined on two of the composite samples. Five-point moisture curves and saturated hydraulic conductivity were determined. Whole soil and fine fraction (< 2 mm) bulk densities were calculated. Coarse fragment contents were determined through 1 m x 1 m x 0.20 m excavations at 4 locations outside the treatment plots. Forest floor mass was determined by excavating 10 samples, approx. 20 x 20 cm, per plot. Survival and condition of planted seedlings were measured at the end of the first, third, fifth, tenth growing season after planting, and at intervals thereafter. Height and diameter were measured immediately after planting and from the third growing season at the same intervals described above. For sites in re-measurement years, current year foliage was sampled for nutrient content.

Maintenance of existing installations

As needed, competing vegetation was clipped within a 1m radius of planted conifers. Annual maintenance of the plots (corner posts, signs, and microclimate equipment) and of access to the plots (roads and trails) was carried out.

Wood decomposition studies

In co-operation with Dr. Martin Jurgensen, School of Forestry and Wood Products, Michigan Technological University, and Dr. Deborah Page-Dumroese, USFS Rocky Mountain Research Station, Moscow, ID, a wood stake decomposition study is being conducted at the IDF-calcareous and ICH LTSP installations. Four LTSP treatment plots are being used: 1) OM0C0, 2) OM0C2, 3) OM2C0, 4) OM2C2. Plots were also set up in an uncut stand adjacent to the treatment area and in the rehab plots. Two standard types of wood stakes were used: loblolly pine sapwood and aspen sapwood. Three penetrometer readings were taken within 5 cm of the stakes just prior to stake extraction to determine soil strength. The stakes were sent to the Institute of Wood Research at Michigan Technological University for mechanical testing, and the USFS Forestry Sciences Laboratory, Moscow, Idaho for chemical analysis.

Dr. Brian Titus, Canadian Forest Service – Pacific Forestry Centre, also carried out a decomposition study at the ICH and IDF-calcareous sites in the same treatments as the mini-plot study (see below). White birch tongue depressors were inserted horizontally at different depths in the humus (just under surface, mid-way down humus and at humus-mineral soil interface).

Mini-plot study

At the BC ICH and IDF-calcareous sites, Dr. Doug Maynard, CFS-PFC, is studying mini-plots that approximate the LTSP treatments but on a more operationally relevant scale. The mini-plot design is completely randomized with eight treatments. The treatments include undisturbed no compaction (OM1C0), undisturbed light compaction (OM1C1), undisturbed heavy compaction (OM1C3), deposit no compaction, shallow gouge no compaction, shallow gouge light compaction, deep gouge no compaction, and deep gouge light compaction. Douglas-fir and lodgepole pine were planted. Competition from woody species (e.g., aspen suckers), advanced regeneration, and grasses was controlled manually as needed.

Soil moisture and bulk density were determined and soil cores taken to determine aeration porosity. Foliage chemistry was done at the end of the 2nd growing season. PRS Probes@ (Western Ag Innovations Inc., Saskatoon SK) were used to estimate nutrient availability. Tree heights and basal diameter were measured in September.

Rehabilitation study

Because of the operational relevance of the rehabilitation of disturbed sites and its impacts on site productivity, we installed rehabilitation trials at the IDF-calcareous sites and the ICH sites. The rehab trial consists of a 40x70m plot that received heavy compaction and complete removal of forest floor (OM3C2). The site was left fallow over winter and rehabilitated the following spring. On half of the plot, forest floor was replaced and then mixed into the top 20 cm of mineral soil. On the other half of the plot, the mineral soil was dug up to 20 cm but no organic matter was added. The two split plots were split again and Fd or Pl planted.

Soil fauna responses 10 years after disturbance

We collected 4-cm diam cores of forest floor and upper mineral soil from LTSP sites in the SBS, two of which were in their 10th year, including the uncut forest controls. We extracted soil mesofauna in a high gradient extractor. We began to sort and count soil mesofauna by taxonomic group and will complete this as time and funds permit. This data will be compared to similar data collected just after treatment to determine the changes in the soil fauna community in the 10 years since disturbance.

<u>Progress, results and discussion</u>

Core LTSP study

a) BWBS

Results

<u>Soil Properties</u>

Interactions between the soil compaction and organic matter removal treatments were not significant for the soil properties measured up to the fifth year post treatment.

Compaction

The intermediate and heavy compaction treatments had significantly greater mineral soil bulk density in the 0 to 10 cm depth in Year 1 (Figure 1). By year 5, the no compaction treatment had the lowest bulk density, however differences between treatments were not significant.

At the 10 to 20 cm depth, there were no significant differences between treatments in Year 1 (Figure 2). The no compaction treatment had the lowest bulk density at year 5 (1.365 g/cm3), which was significantly lower than the heavy treatment (1.534 g/cm3).

Aeration porosity at the 0-2 cm depth in mineral soil declined for all treatments in the year of treatment (Figure 3). The no compaction treatment had the greatest value for aeration porosity in both Year 1 and year 5. In Year 1 the heavy compaction treatment had significantly lower aeration porosity values, and in Year 5 the intermediate treatment was significantly lower.

Aeration porosity at the 10 cm depth in mineral soil indicated a trend of increasing values over time for the no compaction treatment, while the compacted treatments decreased at year one and increased slightly between years 1 and 5 (Figure 4). At year 5, the no compaction treatment

(11.9%) had significantly greater aeration porosity than both the intermediate (5.7%) and heavy (6.9%) treatments (Figure 4).

Organic matter removal

The scalping treatment which removed the forest floor increased mineral soil bulk density in the 0 to 10 cm layer in Years 1 and 5 compared to pre-harvest levels (Figure 5). By year 5, the differences between the stem only and whole tree treatments were statistically significant, both being lower than the scalping treatment.

At the 10 to 20 cm depth, there were no significantly differences in mineral soil bulk density in year 1 (Figure 6). At year 5 the whole tree treatment had significantly lower mineral soil bulk density (1.331 g/cm3) than the other two treatments.

Aeration porosity at the 0-2 cm depth in mineral soil declined for all treatments in Year 1 (Figure 7). The scalping treatment continued to decline between Years 1 and 5. The aeration porosity values of the scalping treatment at 8.8% was significantly lower than the stem only and whole tree treatments with 19.6% and 20.4% aeration porosity, respectively.

At the 10 cm depth in mineral soil the stem only treatment was significantly lower than the other treatments in year 1 (Figure 8). However, by year 5, the scalping treatment had significantly lower aeration porosity than the whole tree and stem only treatments (Figure 8).

Aspen and white spruce regeneration

Compaction

Aspen density was not significantly different between compaction treatments during the first 5 years (Figure 9). The no compaction treatment had significantly greater maximum height for aspen regeneration at years 4 and 5, compared to the intermediate and heavy compaction treatments (Figure 10).

Total height of white spruce regeneration was not significantly different between compaction treatments during the first 5 years (Figure 11). Mean height of the no compaction treatment spruce was 62.2 cm, compared to 52.3 and 53.2 for the intermediate and heavy compaction treatments, respectively.

Height increment of the white spruce was not significant overall (Figure 12). White spruce height increments show a pattern of decreasing from the year of planting on site, then a recovery in height increments for all treatments. The no compaction treatment has the greatest mean height increments in years 3, 4 and 5. Only in year 3 was the difference between the no compaction treatment and the compaction treatments statistically significant (Figure 12).

Organic matter removal

The scalping treatment stimulated the amount of aspen regeneration, with aspen density being significantly greater in Years 1 and 2 (Figure 13). By year 5, there was no significant difference between the scalping and whole tree treatments, which were both significantly greater than the stem only treatment.

The maximum height of the aspen regeneration on the scalped treatment was significantly shorter than the other organic matter treatments by year 2 (Figure 14). The differences between the scalped treatment and those where organic matter was retained increased by years 4 and 5.

By years 4 and 5, the stem only treatment had significantly greater total white spruce height than the whole tree and scalping treatments (Figure 15). Winter desiccation of spruce seedlings in some years resulted in damage to the upper portions of the stem, killing buds and upper stem tissue. This reduced total height of some plots, particularly in Years 2 and 3.

Height increment of white spruce began to clearly diverge between treatments at year 4 (Figure 16). The stem only and whole tree treatments had spruce increments greater than 10 cm in years 4 and 5, while increment of the scalping treatment remained less than 5 cm per year.

Aspen regeneration

All treatments had abundant aspen regeneration. Five years after harvesting aspen regeneration ranged from 27,000 to 46,000 st/ha among all the treatments. The 2 and 5 cm mineral soil compression treatments applied in this study did not result in significant reductions in aspen density found by Stone and Eliof (1998) or under operational conditions (Shepherd 1993, Navratil 1996, Kabzems 1996).

The greatest differences between the treatments were in the height of the tallest aspen trees (Table 1). The most disruptive treatment (scalping) had significantly shorter aspen regeneration by Year 2, while the effects of the compaction treatments became statistically significant by Year 4.

Even though the compaction treatments applied here were not severe, these initial estimates indicate a loss of 25 to 31% of productivity, based on estimated site index (Table 1).

Discussion

The changes in soil properties one and five years after harvesting are a combination of experimental treatment (deliberate compaction treatment, organic matter removal) which was most apparent immediately after treatment, and plant community responses (organic matter inputs, root expansion) which had greater influence in year 5.

Compaction

Pre-treatment, mineral soil bulk densities and aeration porosity values were similar for all treatments. The no compaction treatment had the lowest bulk density and highest aeration porosity values in Year 1. Forest harvesting when soils were frozen did not appear to change these soil properties, similar to the results of Stone and Eliof (1998).

Shortly after applying the experimental treatments, the intermediate and heavy compaction treatments tended to have significantly greater bulk densities and lower aeration porosity values than the no compaction treatment. Of the two variables, aeration porosity appears to be a more sensitive indicator of changes in soil properties than bulk density (Kabzems 1996)

The 0-2 cm aeration porosity and 0 to 10 cm mineral soil bulk density samples are from the mineral soil zones with the greatest amount of organic matter inputs from plants. Between years 1 and 5, 0-10 cm mineral soil bulk density values declined for both the intermediate and heavy compaction treatments, and aeration porosity values increased.

Mineral soil bulk density in the 10 – 20 cm layer did not indicate an immediate response to the bulk density treatments. The no compaction treatment had a slight declining trend for mineral soil bulk density, while the heavy compaction treatment was significantly greater by year 5.

Aeration porosity declined slightly in Year 1 for the intermediate and heavy compaction treatments, and by Year 5 had only recovered to near pre-disturbance levels. In contrast, the no compaction treatment has shown a consistent increase for aeration porosity in the two sampling periods after harvest.

The 16 to 22% increases in upper mineral soil bulk density at this site is similar to that reported by Stone and Elioff (1998), who noted that this increase is not large compared to values found on operational sites. The changes in mineral soil bulk density are not as dramatic as those found on operational sites where repeated machine traffic has occurred. In a heavily used skid trail on a sandy loam textured soil, bulk density changes at the 8 cm depth ranged from 22 to 34% increases (Kabzems 1996).

Organic matter removals

In the first five years after treatment, the scalping treatments also resulted in greater mineral soil bulk density, particularly in the 0-10 cm surface layer of mineral soil. Aeration porosity values at the 0-2 cm depth of the mineral soil declined for all treatments in Year 1, however the stem only and whole tree treatments had risen to near pre-harvest values for aeration porosity by year 5. In contrast, aeration porosity values for the scalped treatment had continued to decline from 11.1% in Year 1 to 8.8% in year 5.

At the 10 cm depth, aeration porosity did not show a consistent decline in all treatments from pre-harvest to year 1. Aeration porosity values for the scalped treatment declined between year 1 and 5, while in contrast, the stem only and whole tree treatments increased aeration porosity values in that time period.

In contrast to Stone and Eliof (1998), the results from the BWBS site indicate that there was a degree of recovery of mineral soil bulk density. The lack of recovery in the scalping treatments indicate that biological activity and organic matter inputs are the critical factor for recovery of soil physical properties.

b) Sub-Boreal Spruce (SBS) installations

SBS-1 and SBS-2 were re-measured in their 10th years in 2003/4. SBS-3 will be re-measured in its 10th year in 2004/5. Therefore results presented here are trends only based on 2 of 3 SBS replicates.

The 10 year tree height and diameter measurements for the two replicate SBS sites thus far measured demonstrated a 25% reduction in growth for spruce on scalped soils (Figure 17).

No growth trends were observed for lodgepole pine, and some additional work done by Marty Kranabetter may help explain why. Tuberculate ectomycorrhizae are formed on lodgepole pine by fungi in the genus *Suillus*. Tuberculate ectomycorrhizae associate with nitrogen fixing bacteria which may provide an additional source of N to the pine. By counting fruiting bodies of different *Suillus* species on treatment plots, it was determined that *Suillus brevipes* was particularly abundant on the scalped plots (Figure 18). The natural abundance of N^{15} isotope in *Suillus brevipes* fruiting bodies was higher than 2 other Suillus species (Table 2) and much higher than in *C. rutilans*, which indicates that more of the *Suillus* N was fixed from the atmosphere.

A comparison across organic matter treatments indicated a drop in foliar N from year 5 to year 10 in spruce but not in lodgepole pine (Figure 19).

Trends in bulk density across compaction treatments, from post-harvest to year 10 (Figure 20, Topley only) suggest that there may be some recovery of porosity in year 10 for the uncompacted soils.

SBS plant communities

Effects of site conditions and organic matter removal on plant community diversity, structure and composition were still evident five years after treatment. Differences in plant composition due to site differences such as disturbance history, climate and geography overrode differences due to organic matter removal treatments, except for non-vascular species and functional guilds. For these two groups, the scalping treatment (all organic matter removed) had a greater impact on structuring plant communities than site conditions. The strong response of functional guilds, which were species grouped into similar life history traits, suggests that the soil disturbance interacts with life history traits to determine guild composition. The removal of disturbance-sensitive cryptogam species and the invasion of pioneering cryptogams explained the strong response of non-vascular composition to organic matter removal. When we controlled for the effect of site in RDA ordinations, scalped plots generally had plant assemblages distinct from whole-tree and stem-only removal treatments for all species, functional guilds and non-vascular species. Scalped treatments had higher cover of early successional species and lower diversity than other organic matter removal treatments.

Soil compaction treatments, which were intended to be at the upper range of severity in logging practices, showed little effect on plant community response. Only non-native species richness and herb diversity were influenced by soil compaction treatments. Chemical and physical soil properties did not explain differences in treatments. Site differences were much more important in determining soil quality than treatment differences.

c) Interior Douglas-fir (IDF) installations near Kamloops

Three sites are established in the IDFdk subzone near Kamloops. All sites are located within 50 km, in a northwest direction, from the city. Site 1, Dairy Creek, is within the Isobel Lake demonstration forest. Site 2, Black Pines, is within the Kamloops District Small Business operating area, and site 3, O'Connor Lake, is within Weyerhaeuser Canada's operating area.

In 2003, 3-year post-treatment seedling growth measurements were completed at the third site, O'Connor Lake. At the Dairy Creek site, all the dead Douglas-fir on the non-scalped plots were replaced with seedlings from a new seedlot and stocktype. Although these seedlings will be 5 years younger than some of the original plantings, the long-term nature of the study will still allow examination of growth rate differences of different aged seedlings. Immediate post-treatment and first growing season measures were completed on all replanted seedlings.

Five-year post-treatment measures of soil chemistry, soil bulk density, soil aeration properties, vegetation, and seedling growth were also completed at Dairy Creek. The climate stations at the Dairy Creek and Black Pines site were maintained. The data have been checked and archived. Preliminary analysis of all year 5 data is in progress.

Results and Discussion

Microclimate

Soil temperatures during the growing season at 2, 10, and 30 cm, illustrated in Table 3 by cumulative degree days at 10 cm depth, all decreased in the order: OM3>OM2>OM1. Compaction exhibited little effect on soil temperature. In the first two years after treatment, the OM3 treatment appeared to result in increased drying of the soil during the growing season. However, by four years after treatment and planting, these treatment differences have disappeared (Table 3). Compaction appeared to have little or no effect on the number of days with dry soil. Freeze thaw cycles were more common in the OM3 treatments; with again no pattern related to compaction (Table 3). It is noteworthy that very similar results for both temperature and moisture relationships have been observed at the LTSP sites in the Sub-boreal Spruce zone.

Change in physical properties

Aeration porosity is a measure of the volume of soil occupied by relatively large pores (greater than 15μm). Any harvesting caused a decrease in aeration porosity (Figure 21), presumably from loss of the fine roots and fungal biomass that are important in maintaining forest soil structure. Compaction, but not organic matter removal, caused a further significant decrease in porosity (Figure 21). None of the porosities, however, were decreased below 10%, often assumed to be a threshold below which root growth may be limited.

Mineral soil bulk densities in both the 0 – 20 cm (Figure 22) and 20 – 40 cm (not shown) soil depths were generally increased by compaction. However, there were no significant differences in the post-treatment bulk densities between the C1 and C2 treatments. The increases in bulk density with compaction were greater on the OM3 treatment (bare mineral soil) than on the OM1 and OM2 treatments. Similarly, bulk densities relative to the maximum achievable with the Proctor test also only exceeded the 85% figure considered to possibly indicate a "degraded" soil on the scalped (OM3) – compacted plots (Krzic and Bulmer FII project 2003-0219). Removal of the forest floor without compaction increased soil density in the 0 – 20 cm layer, but not in the 20 – 40 cm layer at Black Pines and O'Connor Lake.

Year 3 seedling performance

Pine seedling survival was very high (90-99%) at all sites. Survival of Fd was generally high (85-97%) on scalped plots, however, Douglas-fir seedlings had variable survival (35-95%) on unscalped plots, depending on grass cover and adverse frost or drought conditions. After 3 growing seasons there were no significant treatment effects on lodgepole pine height (Figure 23) or diameter (data not shown). Both total height and diameter of Douglas-fir were significantly increased by the scalping (OM3) treatment, probably through both improvement of soil temperature regime and reduction of vegetation competition. Because the compaction treatments interacted with organic matter treatments, compaction effects must be considered for individual organic matter treatments. For the treatments with forest floor intact (OM1 and OM2), there were no significant effects of treatment on fir height or diameter. For the scalped treatment, both total height and diameter of Douglas-fir were greater on the non-compacted treatment than on either compaction treatment.

d) Interior Douglas-fir (IDF) installations on calcareous soil near Nelson

All sites had netting removed from seedlings.

Mud Creek

Year 3 measurements of trees were completed in the spring due to delay by early winter the previous year. Brushing of hardwoods was completed on a couple plots as needed. Microclimate and weather monitoring were maintained and downloaded. Seedling survival and vigour were recorded in the fall.

Emily Creek

Year 3 seedling growth was measured on lodgepole pine, and survival and vigour were described for Douglas-fir. Wood stakes were installed on some plots but the rest was delayed due to severe fire season and later due to early frost. Litterbags were successfully installed on all plots.

Kootenay East

Vegetation was described for year 2 at Kootenay East. Survival and vigour were described for seedlings. Wood stakes and litterbags were successfully installed on all representative plots.

e) Interior Cedar Hemlock (ICH) installations

McPhee Creek

Harvesting was completed in the spring and plot corners were re-established. Treatments were delayed due to the bad fire season and started in the fall but progress was hampered due to early frost and then snow. A similar situation occurred with the elk fence construction. *Hypholoma* was installed on that plot. Elk fence installation was restarted in March but soil became too wet due to heavy rains during snowmelt. Completion of this work is now scheduled in April.

Rover Creek

Rehabilitation plot were treated and then all plots planted. A weather station was installed, along with microclimate monitoring on representative treatments. Soil chemistry and physical properties were determined and vegetation sampled on all plots during the growing season. Manual brushing occurred on half of each treatment plot. Seedlings were numbered and measured in the fall. *Hypholoma* was installed on that plot and litterbags and wood stakes were installed in representative plots. Fence received annual maintenance by contractor.

Linked studies

Wood stake decomposition study (Deb Dumroese, USDA-FS, Marty Jurgensen, MTU)

A key part of this study is having study sites that encompass a wide range of soil conditions. Study areas are located throughout the U.S., Canada, and Europe. These sites represent a wide variety of soil types and climatic conditions, which are being monitored for soil moisture and temperature. Soil chemical and physical properties have also been characterized on each of these sites.

Samples are collected once every year, since decomposition rates are thought to be relatively slow. To date, we have collected temperature and moisture data (recorded every 4 hrs) and two "sets" of standard wood stakes (five sample dates are planned) on the Mud Creek LTSP site. In 2003, additional wood stakes were installed in the "new" LTSP sites in BC (site manager: Dr. Mike Curran). Summer 2004 will be the first sample period for these stakes.

Decomposition of standard wood materials in the forest floor (Brian Titus, CFS-PFC)

Decomposition rates of birch tongue depressors buried at 3 depths were determined in 8 disturbance treatments. Decomposition increased significantly with depth in 6 treatments at Emily Creek, but in only one (deposit) at Mud Creek. At both sites, decomposition tended to be greatest in the mixed humus-mineral soil of deposits. Does mixing of humus with mineral soil stimulate microbial activity? Decomposition tended to increase with compaction of mineral soil at Mud Creek but decrease at Emily Creek.

N availability (ion exchange membranes; PRSTM-probes) was not related to decomposition rate, except at Mud Creek. Undisturbed treatments had more plant uptake than bare gouges. Mixed humus-mineral soil deposits at Mud Creek had high N availability and decomposition rates. On a LTSP trial at Mud Creek, decomposition also tended to increase with depth, especially in upper horizons. Decomposition was greatest in a rehabilitation treatment that mixed humus and mineral soil, similar to the deposits in the adjacent trial.

Mini-plot study (Doug Maynard, CFS-PFC)

Survival at Mud Creek was affected by drought in the first two growing seasons. Survival was the lowest in deposits and highest in gouges. Higher soil moisture at the other two sites resulted in >95% survival (except lodgepole pine on the deposits at Emily Creek with 75% survival).

At Mud Creek, growth was the poorest in the undisturbed treatments. At Emily Creek, the poorest growth was in the displaced treatments. Growth on the deposits was intermediate at both sites. The different growth response to disturbance between sites was probably related to differences in soil chemical and physical properties (e.g., pH, depth to carbonates, texture and % coarse fragments).

There was a flush of available N for 2 – 3 years following treatment. The majority of the total N supply rate was nitrate. The highest N supply rates at Mud Creek and Emily Creek were measured in the deposits. However, at Mud Creek there were significant differences among disturbance treatments. In contrast, there were no differences among treatments at Emily Creek.

Different responses to disturbance between the two sites were probably related to differences in vegetation competition (although clipped yearly), as well as pH, LFH depth, and possibly C:N ratios. In contrast to N, the highest P (and K) supply rates were measured in the undisturbed treatments. There was a significant correlation between N supply rate and N uptake in lodgepole pine at Mud Creek. Soil moisture (and possibly temperature) were the most limiting factors in the deposits so no correlation with N and uptake would be expected.

Soil fauna responses 10 years after disturbance (Shannon Berch, MoF)

Forest floor samples were collected from SBS-1 and SBS-2 as planned for macrofauna extraction. Forest floor and mineral soils were collected from SBS-1 and SBS-2 for mesofauna extraction. In all cases, as in year 5, samples were collected separately from pine and spruce split-plots. The third SBS replicate will be sampled in 2004/5.

Macrofauna were extracted in Berlese funnels and mesofauna in high gradient extractors and samples stored in the Research Branch Lab until sorted and counted. Sorting and counting will be carried out in 2004/5.

Initial analysis of year 5 data indicates a trend toward increased density of mesofauna in forest floor and mineral soil horizons compared to year 1 (Figure 24).

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Table 1. Mean maximum aspen heights and estimated site index for the organic matter removal and soil compaction treatments at the BWBS sites.

Treatment	Aspen maximum height at Year 5 (m)	Estimated Site Index* (m, bh age 50)
Stem only	2.21	15
Whole tree	2.41	17
Scalping	1.18	< 6
No compaction	2.30	16
Intermediate compaction	1.77	12
Heavy compaction	1.72	11

* from Huang 1997

Table 2. Fruiting body nutrient concentrations and natural abundance of N^{15} isotope at Topley SBS site.

	(n)	N (%)	N^{15} (‰)	C:N ratio	N:S ratio
C. rutilus	18	2.01a (0.06)	0.81a (0.35)	25.3a (0.64)	15.9a (0.27)
S. brevipes	16	3.24b (0.13)	11.1b (0.49)	14.7b (0.63)	18.0ab (0.48)
S. flavidus	16	3.42b (0.10)	8.51c (0.33)	13.8b (0.44)	19.0ab (0.39)
S. tomentosus	11	3.93b (0.18)	8.60c (0.52)	12.0b (0.52)	20.1b (0.34)
$p > F$		*0.009*	*0.001*	*0.001*	*0.047*

Table 3. Mean annual growing degree days, mean number of very dry days, and mean number of days with soil freeze – thaw cycles at the Dairy Creek IDF site for the period 2001-03

Treatment	GDD[1] > 5°C at 10 cm during May 15 – Sept 15	Days during May 15 – Sept 15, 2000 and 2001 when soil drier than –1.5 MPa	Days during May 15 – Sept 15, 2002 and 2003 when soil drier than –1.5 MPa	Days < 0 >[2] at 2 cm	Days < 0 >[2] at 10 cm	Days < 0 >[2] at 30 cm
OM1 C0	743	0	36	12	1	1
OM2 C0	845	5	65	10	7	2
OM3 C0	1130	13	59	24	25	16
OM1 C2	732	0	56	3	4	0
OM2 C2	902	0	37	14	5	1
OM3 C2	1012	20	69	15	25	9

1: growing degree days
2: freeze-thaw events (fluctuations above and below 0°C)

Figure 1. Upper (0-10 cm) mineral soil bulk density for the compaction treatments at the three BWBS sites. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

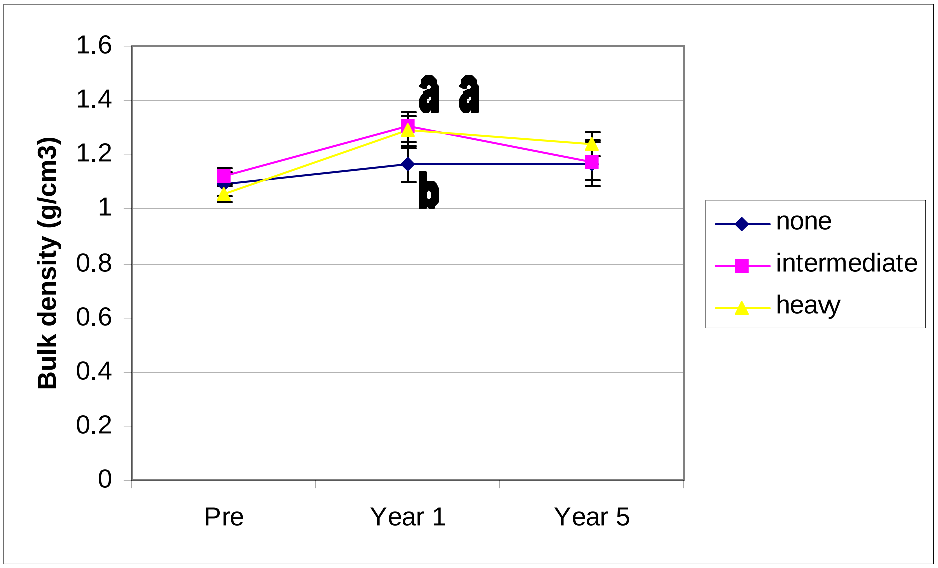


Figure 2. Lower (10-20 cm) mineral soil bulk density for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

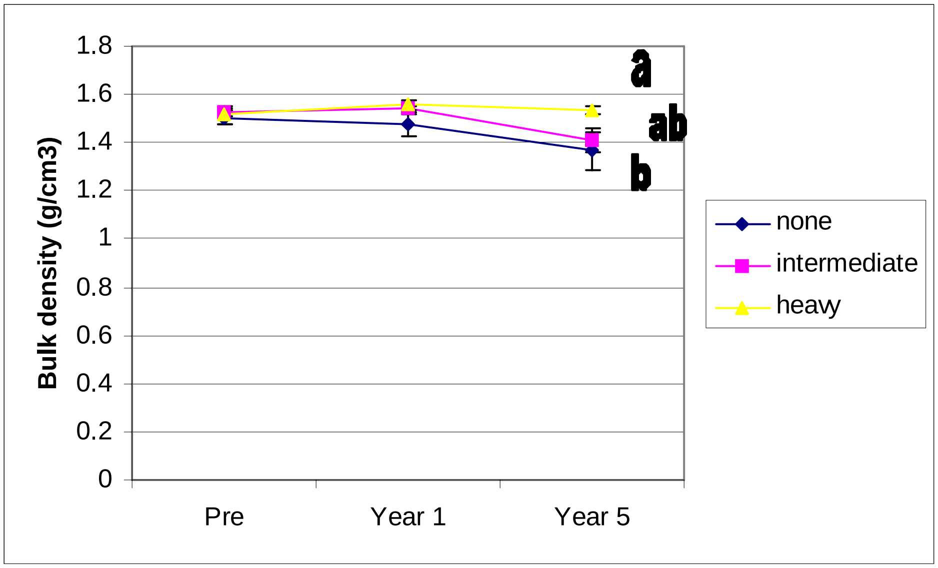


Figure 3. Aeration porosity (0-2cm depth) values for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at p ≤ 0.05.

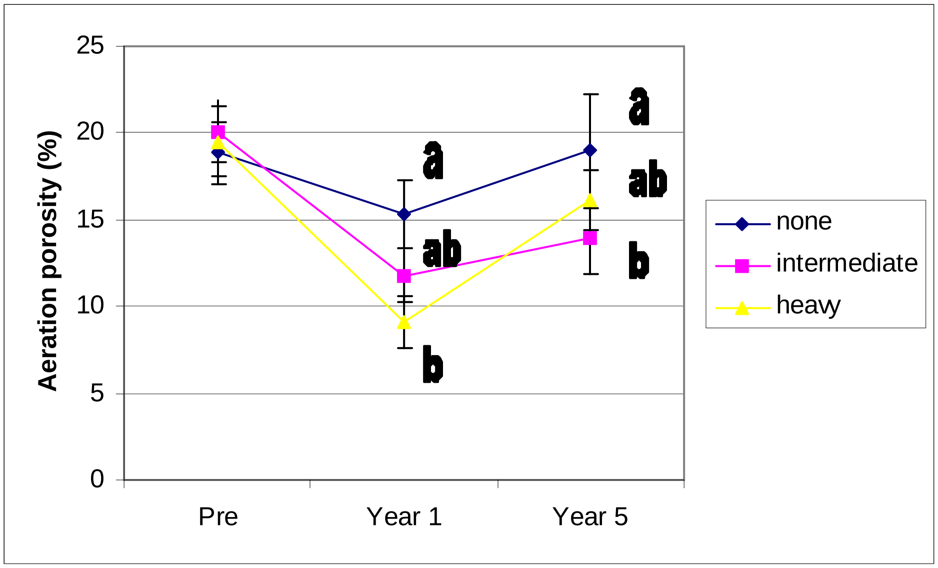


Figure 4. Aeration porosity (10-12 cm depth) values for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

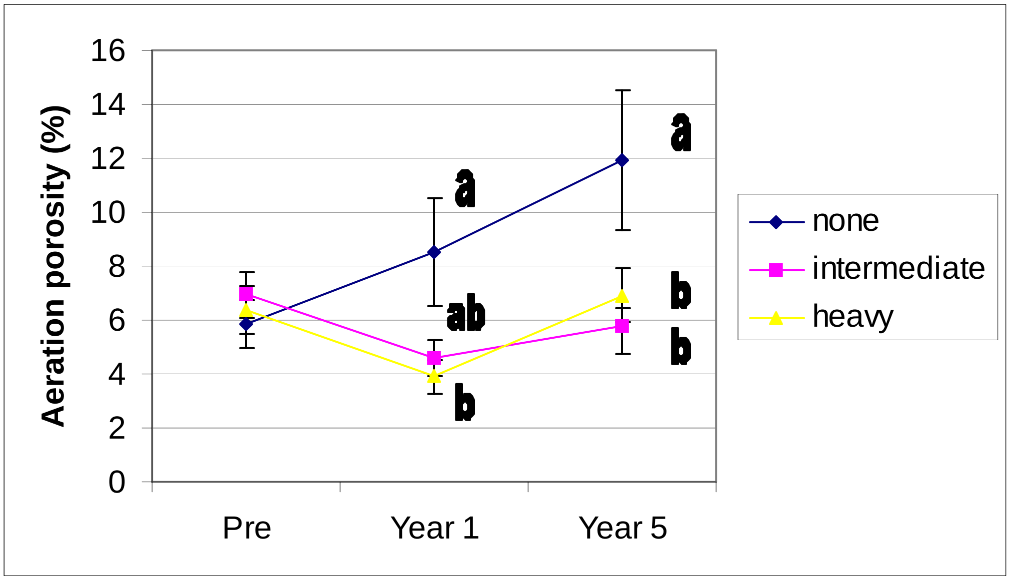


Figure 5. Upper (0-10 cm) mineral soil bulk density for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

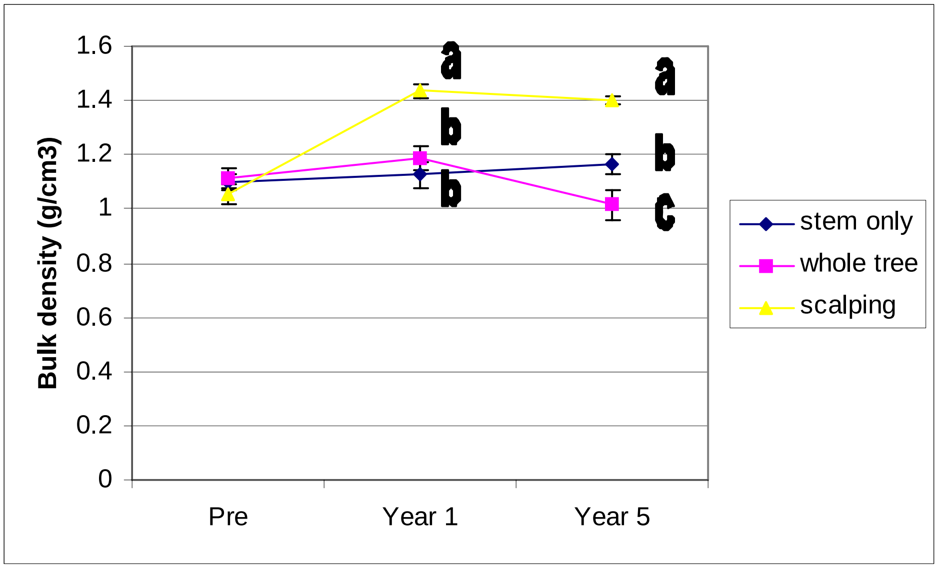


Figure 6. Lower (10-20 cm) mineral soil bulk density for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at p ≤ 0.05.

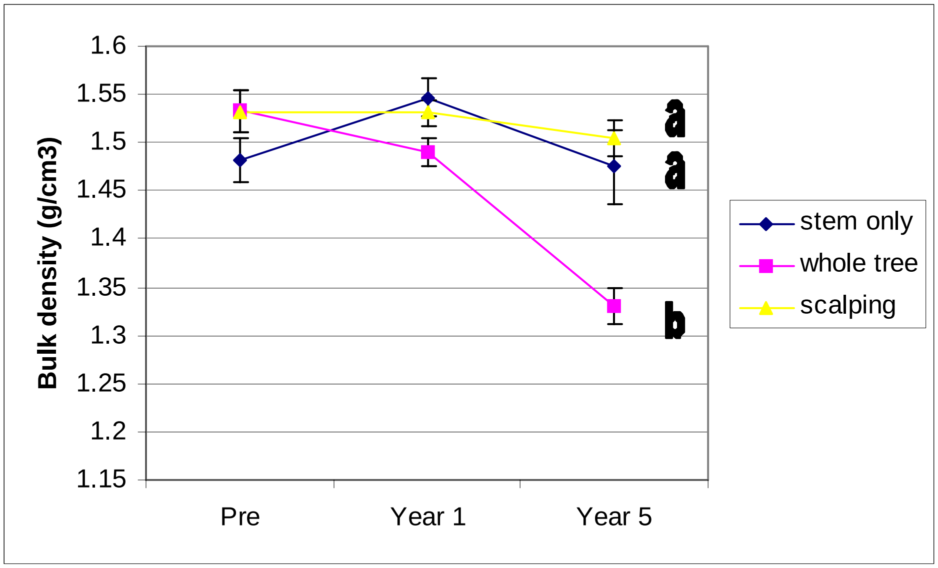


Figure 7. Aeration porosity (0-2cm depth) values for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

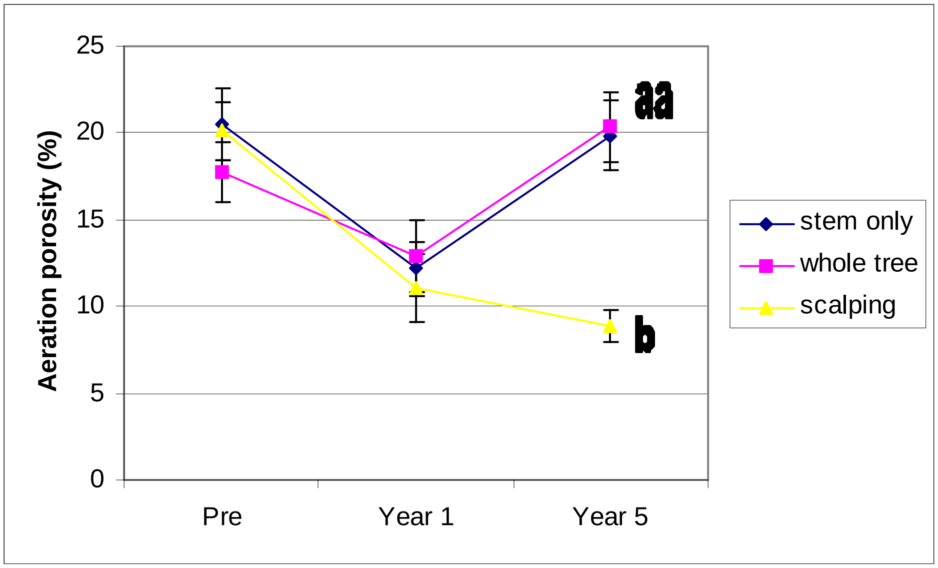


Figure 8. Aeration porosity (10-12 cm depth) values for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

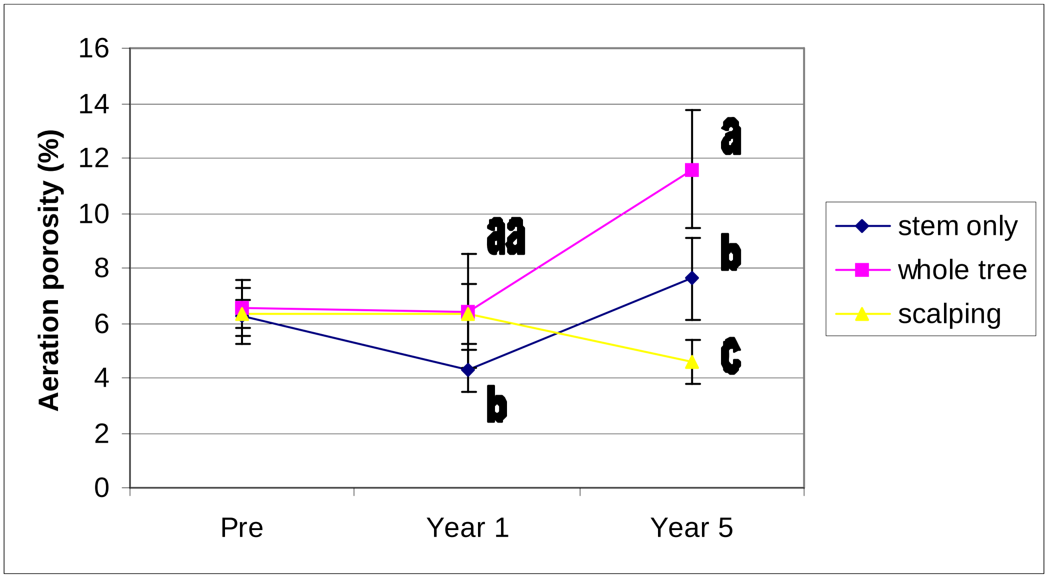


Figure 9. Density of aspen regeneration years 1 to 5 after harvesting for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

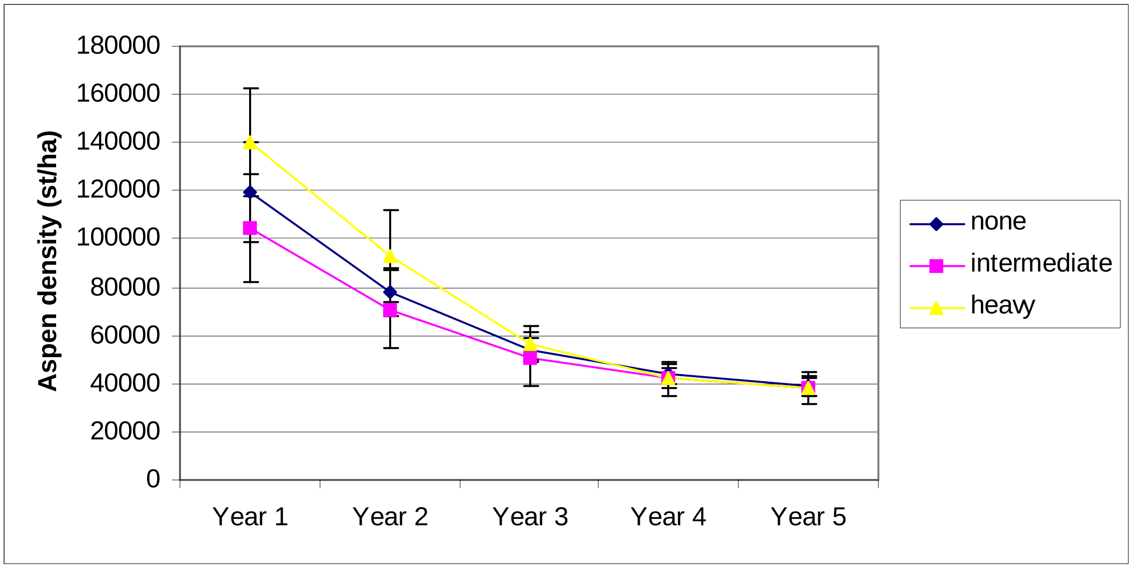


Figure 10. Mean maximum height of aspen regeneration years 1 to 5 after harvesting for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

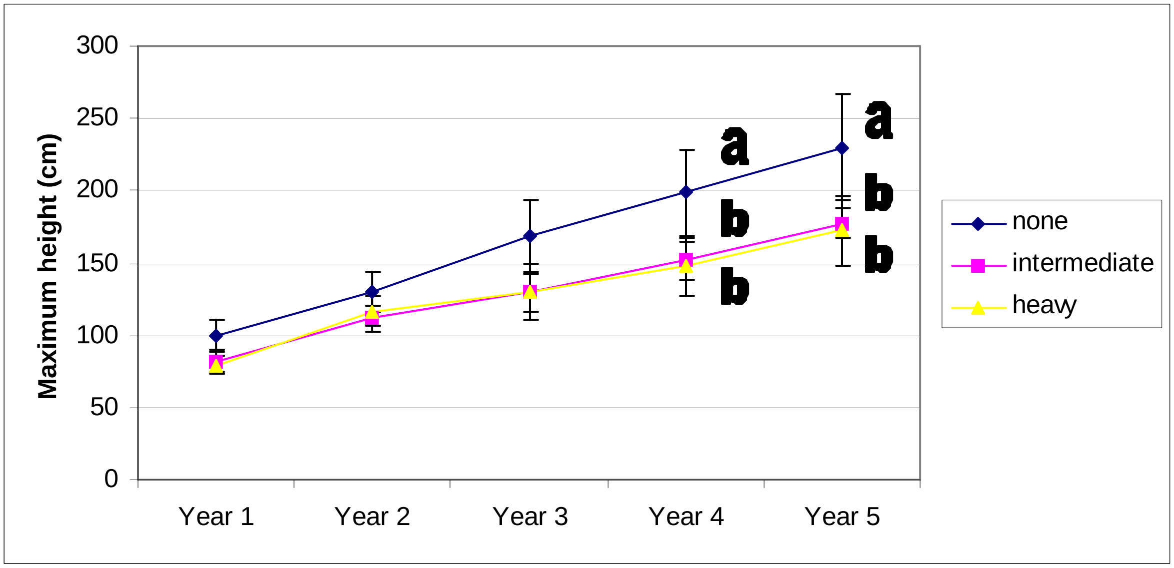


Figure 11. Mean total height of white spruce regeneration years 1 to 5 after harvesting for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

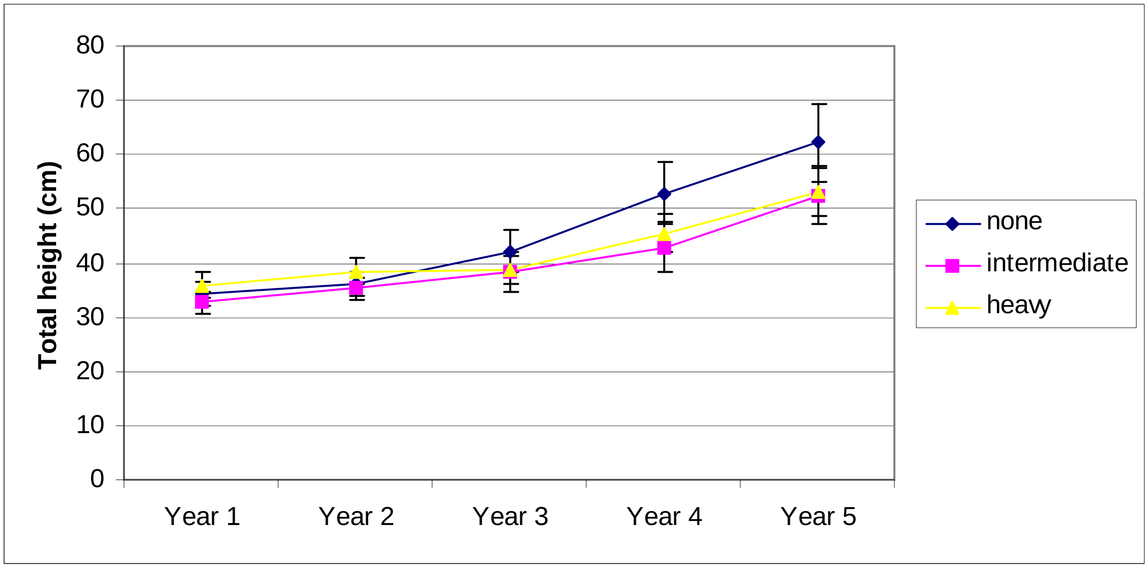


Figure 12. Mean annual height increment of white spruce regeneration years 1 to 5 after harvesting for the BWBS compaction treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

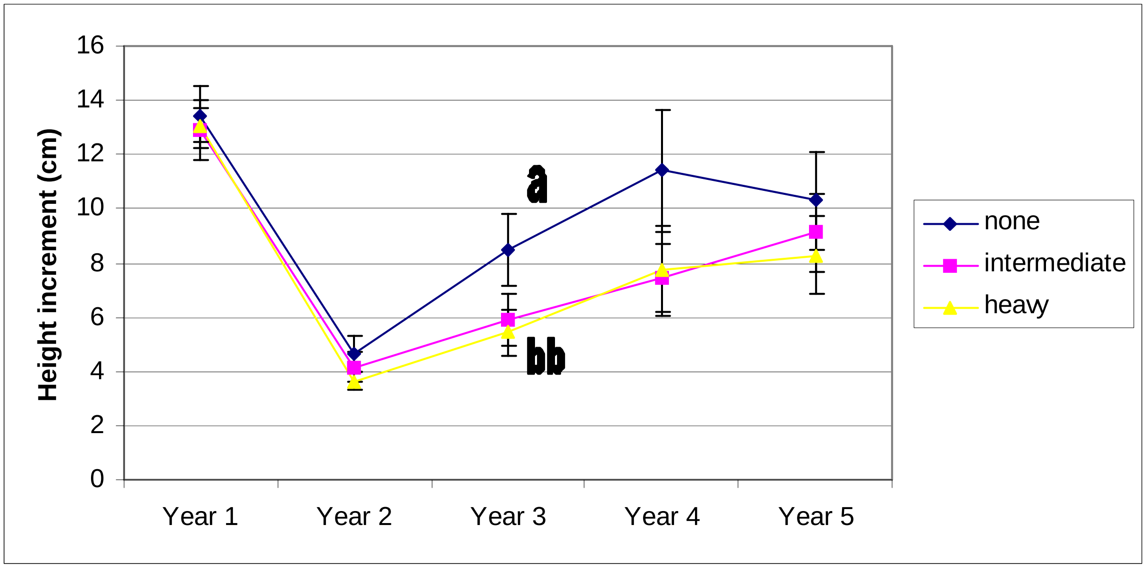


Figure 13. Density of aspen regeneration years 1 to 5 after harvesting for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

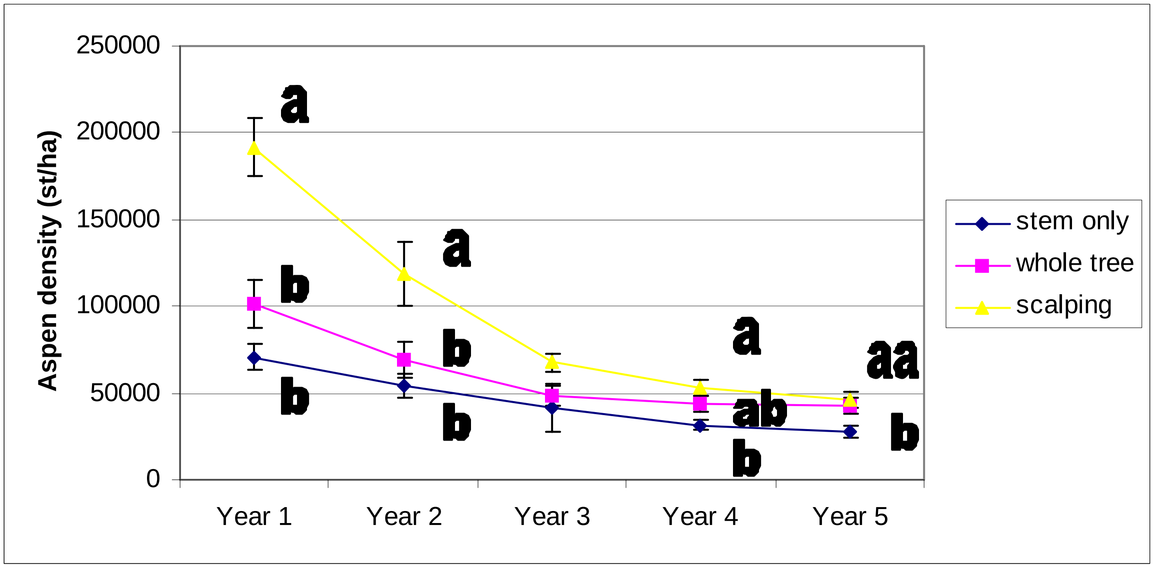


Figure 14. Mean maximum height of aspen regeneration years 1 to 5 after harvesting for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

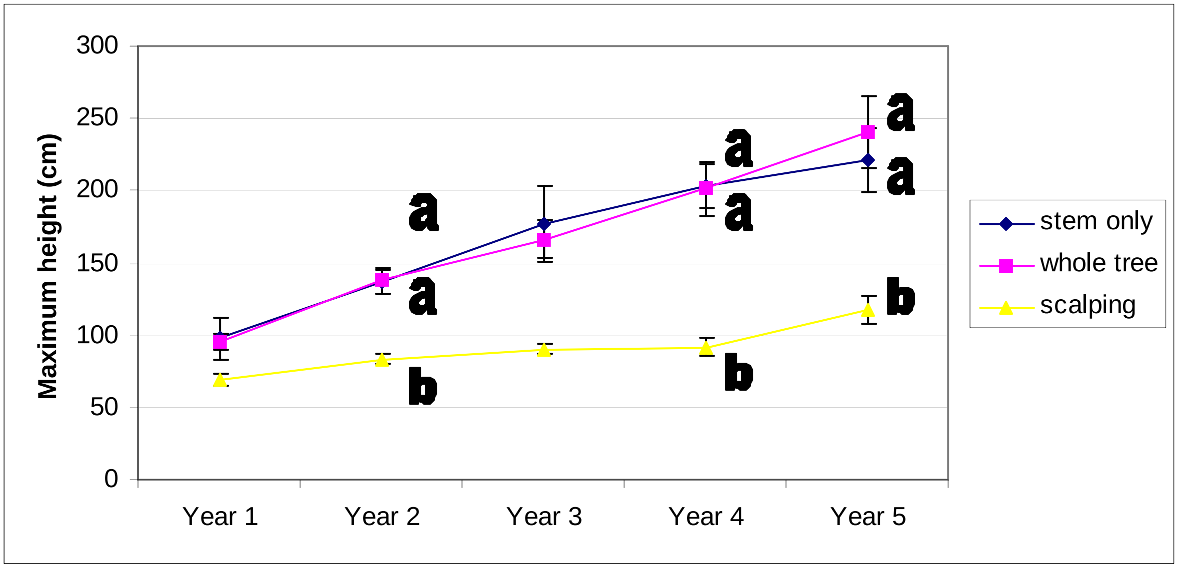


Figure 15. Mean total height of white spruce regeneration years 1 to 5 after harvesting for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

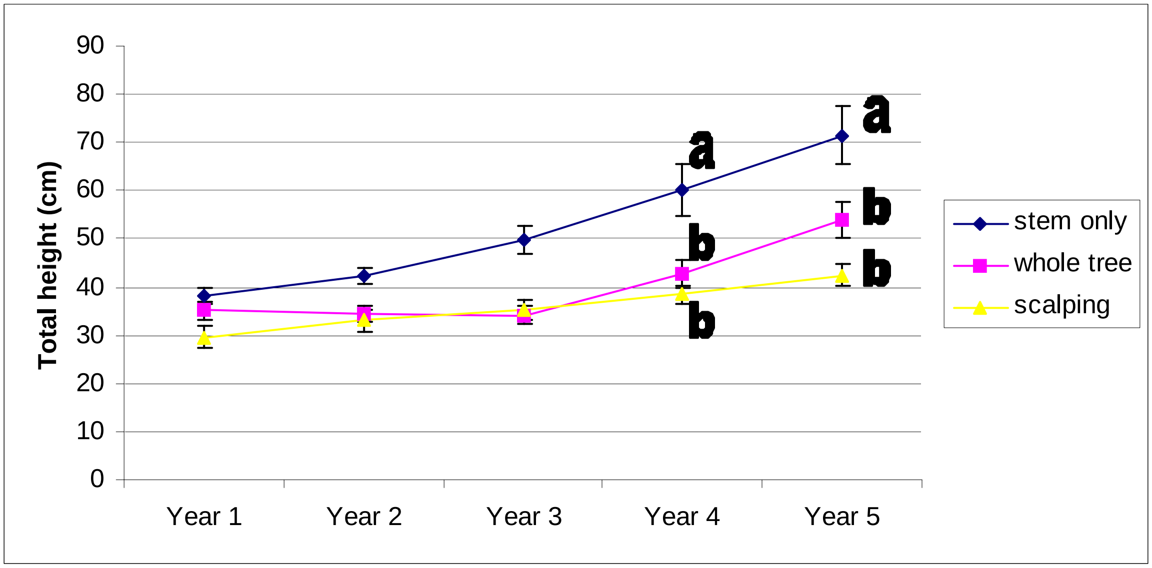


Figure 16. Mean annual height increment of white spruce regeneration years 1 to 5 after harvesting for the BWBS organic matter removal treatments. Treatment means followed by the same letter do not differ significantly at $p \leq 0.05$.

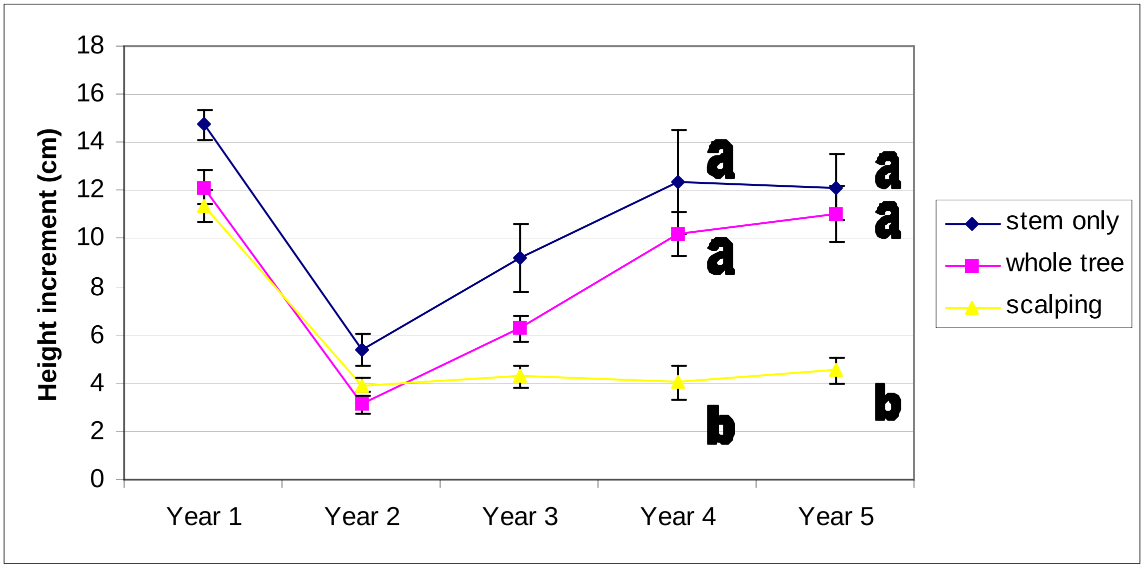
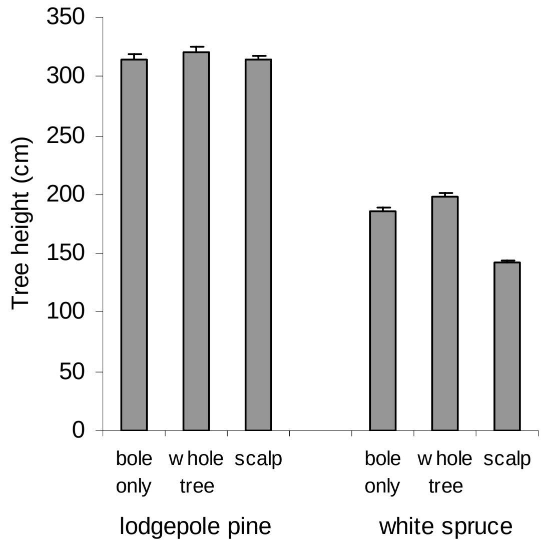


Figure 17. 10 year tree height and diameter, demonstrating 25% reduction in growth for spruce on scalped SBS soils.



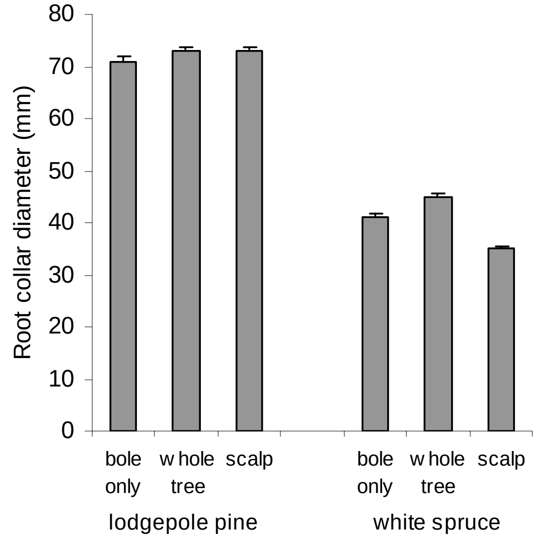


Figure 18. Number of *Suillus* fruiting bodies associated with lodgepole pine on SBS treatment plots.

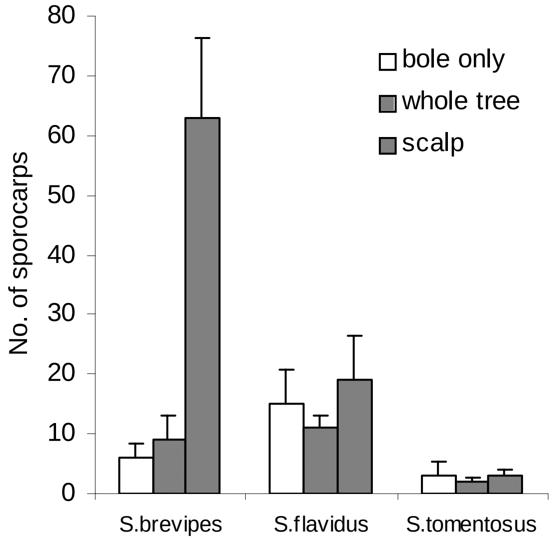


Figure 19. A comparison of year 5 and year 10 foliar nitrogen across SBS organic matter treatments

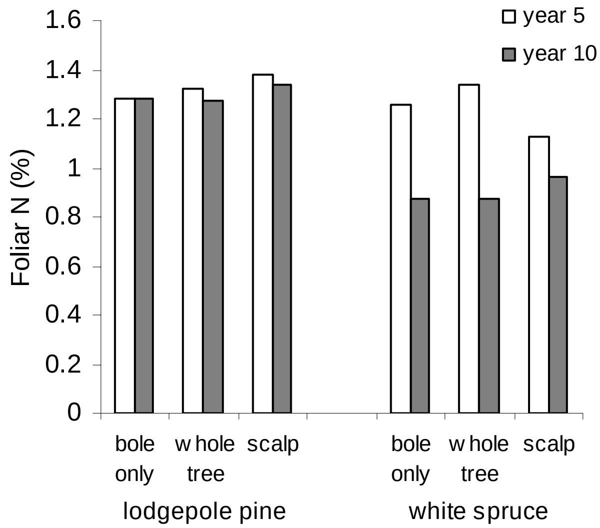
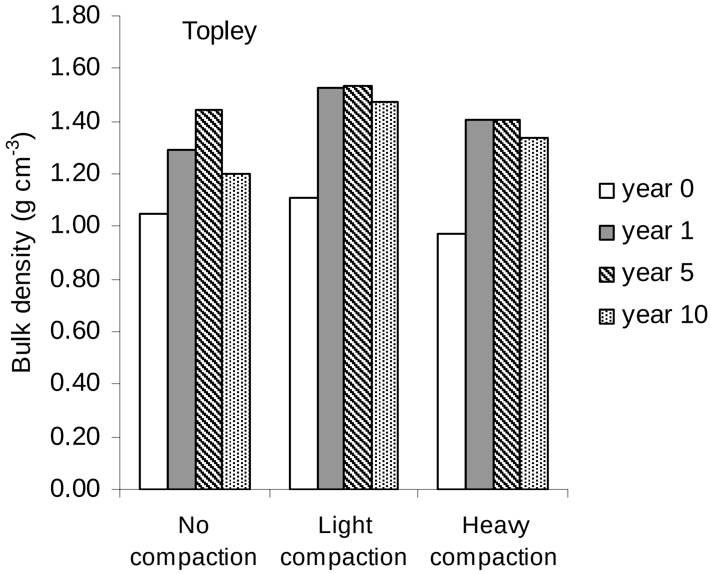


Figure 20. Trends in bulk density across compaction treatments, post-harvest to year 10 (Topley only)



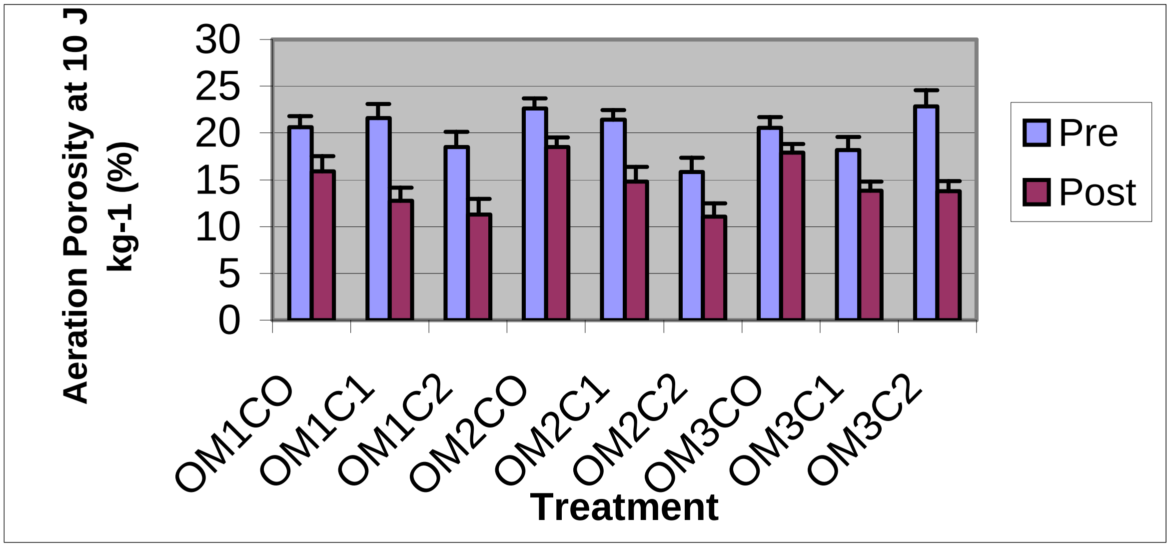


Figure 21. Mean pre- and 1-year post-treatment aeration porosities in the 0 – 20 cm soil depth for each treatment at the three Kamloops IDF sites. Error bars are standard error of the mean.

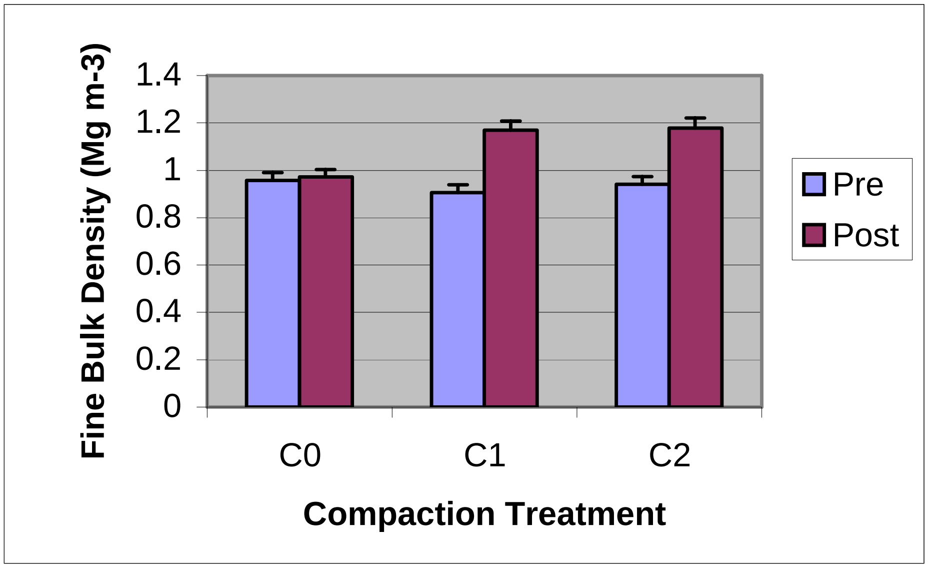


Figure 22. Mean pre- and post-treatment fine soil (<2mm) bulk density of the 0 – 20 cm soil layer for compaction treatments at the three Kamloops LTSP sites. Error bars are standard error of the mean.

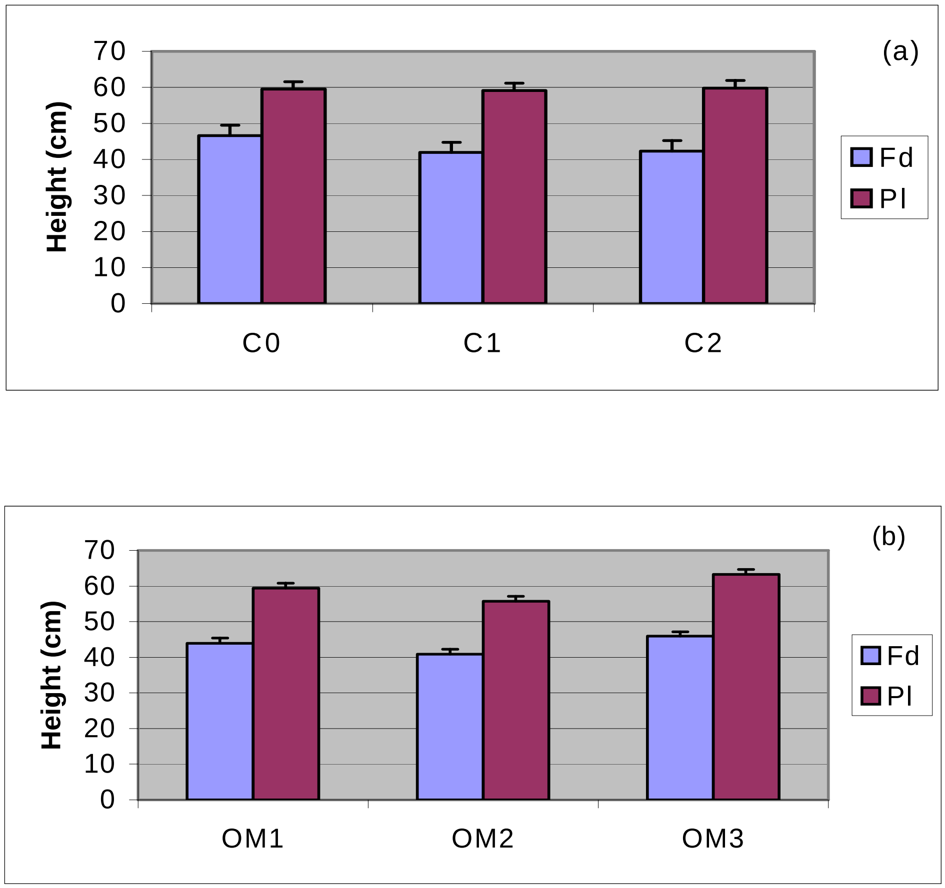
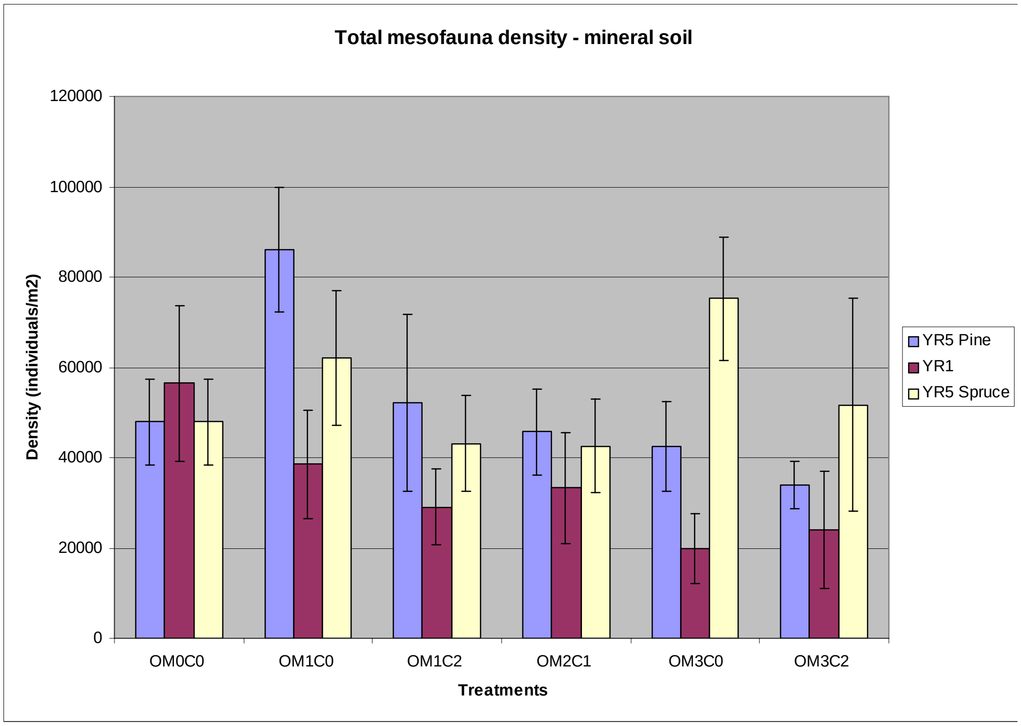


Figure 23. Mean tree height at year 3 in response to (a) compaction and (b) organic matter removal at the 3 Kamloops IDF sites. Error bars are standard error of the mean.

Figure 24. Comparison of soil mesofauna density in a) forest floor and b) mineral soil one and five years after treatment application.

a) Mineral soil



b) Forest floor