

**Modeling Soil Compaction, Decompaction and Tree Growth  
on Alberta Soils Following Forest Harvesting  
1994-1997**

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## **Executive Summary**

The soil compaction project originated from discussions with government and industry foresters during a series of workshops on the topic that were conducted across Alberta in 1993. A number of unanswered questions regarding the compaction of boreal forest soils and its effect on tree performance were discussed but could only be answered if several assumptions were first made. This research project was designed to answer the most important questions.

The objective of the project was to model the compaction of Alberta soils from skidder traffic following forest harvesting, the natural rate of soil decompaction, and the effects that soil compaction had on conifer performance. The specific objectives were to determine:

- the changes in soil physical properties resulting from summer logging on moist soil at four levels of skidding activity;
- the natural rate that compacted forest soils recover as a function of severity of compaction, soil type, and climate; and
- the effect of soil compaction on seedling performance, including the effect on seedlings growing adjacent to areas of contrasting amounts of compacted soil, i.e., seedlings planted in undisturbed soil adjacent to severely compacted skid trails.

Quantifying the changes in the soil physical properties was emphasized during this time period. Because decompaction by natural processes depends on climate and results of other studies suggest that it could be rapid, soils were remeasured on an annual basis.

However, periodic remeasurement for a longer time period will probably be required to fully document decompaction. Similarly, any potential deleterious effects of soil compaction on seedling performance are not likely to be evident after only one or two years. Therefore, the experimental design and plot layout were developed to allow these questions to be answered over a longer time period. The results of the initial research and experience gained from monitoring these sites in the initial work will determine the amount and type of continued monitoring necessary to fully answer all the questions and objectives.

### **Organisation of the Report**

The results of the research are organised into six manuscripts and one progress report, depending on their anticipated suitability for publication in the scientific literature. Insufficient data on seedling performance have been collected for publication, hence, the initial measurements are included as a progress report. Because the foci of these papers are on soil and soil processes, most, if not all the papers, will be submitted to the Soil Science Society of America Journal (US) and Canadian Journal of Soil Science. The current title and authors of the seven papers are as follows (Papers are numbered to facilitate links to this summary):

1. Bulk density and air-filled porosity of compacted boreal forest soils. D.H. McNabb, A.D. Startsev, and H.V. Nguyen
2. Effects of skidding on soil infiltration in west-central Alberta. A.D. Startsev and D.H. McNabb

3. Effects of skidder traffic on soil retention and pore size distribution of medium-textured soils in the boreal forest of Alberta. D. H. McNabb and A. D. Startsev
4. Soil water retention as a function of particle size distribution and void ratio. A.D. Startsev and D.H. McNabb
5. Short-term changes in soil bulk density following skidding in the boreal forest of west-central Alberta. A.D. Startsev and D.H. McNabb
6. Soil biological activity in recent clearcuts in west central Alberta. N.A. Startsev, D.H. McNabb, and A.D. Startsev
7. Effects of soil compaction on conifer performance in the boreal forests of Alberta: A progress report. A.D. Startsev.

The weather data collected between 1995-97 was not intended to be developed into an independent report but was incorporated into Papers 2, 5, and 6 to support the interpretation, which is the primary role of these data.

### **Methods**

A total of 14 research sites representing a range of soil and climatic conditions were selected from across west-central Alberta where summer logging is common (P1-Fig 1, ie., Paper 1, Figure 1). Eleven sites were harvested with large, wide-tired skidders; tire width was 0.8 to 1.2 m (P1-Table 2). Two sites were logged with short-wood harvesting equipment, and one site with a wide-tracked crawler tractor. Nine sites were logged in 1994 and five sites in 1995.

The experimental design at each site included four identical blocks containing four levels of skidding: a control (no skidding the full length of the corridor); and 3, 7, and 12 cycles of skidding (a cycle is one empty and one loaded trip) (P1-Fig 2). Soil cores for determination of bulk density, air-filled porosity, water content and water retention were collected from skidded blocks as soon after skidding as feasible, generally from one day to a week. All treatments and blocks were remeasured to determine recovery of bulk density and infiltration rate one and two years after establishment of the installation. Soil respiration, decomposition of cellulose, organic matter content and the humic to fulvic carbon ratio were measured at four sites on soil collected in 1994, 1995, and 1996.

Each site was instrumented to measure soil temperature, water potential, and RedOx potential in the control soil and adjacent 7-cycle compaction treatment in one block per site. Air temperature, snow depth, and precipitation were also recorded on the control.

Lodgepole pine or white spruce was planted after site preparation in the following micro-sites created in each block: control, wheel track, centre of track, and outside edge of track. Each seedling was tagged and measured annually for diameter (at 2 cm) and height.

### **Change in Soil Physical Properties Following Skidding**

Changes in soil physical properties are presented in Papers 1, 2, and 3.

## Results:

- Most compaction occurred in the first few passes and increases in bulk density became asymptotic between 7 and 12 cycles (P1-Fig 3).
- The increase in bulk density after 3 cycles was statistically significant at 8 of the 14 sites, but the increase in bulk density between 3 cycles and 7 or 12 cycles was not significant (P1-Table 3).
- The significant increase in bulk density generally occurred to a depth of at least 22 cm.
- Decreases in air-filled porosity were the reverse image of bulk density; porosity decreased significantly after 3 cycles but the continued decrease was not significant (P1-Fig 5).
- Probability of significant increases in bulk density and decreases in air-filled porosity depended on soil water potential at the time of skidding (P1-Fig 4).
- Significant compaction occurred if soil water potential was lower than  $-15$  kPa (soils were wetter than field capacity).
- Soil compaction reduced air-filled porosity, but had no other obvious effect on pore size distribution at a soil water potential less than  $-20$  kPa (P3-Fig1 and 2).
- Change in pore size distribution was not significant if the increase in bulk density was not significant (P3-Fig 2).
- Infiltration rate of surface soil decreased by 50 percent following 3 cycles of skidding (P2-Fig. 2).
- An improved model to predict soil water retention of soil based on texture and void ratio was developed using data from these sites (P4-Eqn 16).



**Implications:**

- Wide-tired skidders and short-wood forwarders only cause significant compaction when the soil is wetter than field capacity (about  $-15$  kPa).
- Effects of significant compaction on soil structure are limited to the air-filled pores, which suggests that damage to soil structure is lessened and integrity of the aggregates was maintained despite the compaction.
- Wide tires probably allow skidders to operate on much wetter soils than skidders with standard tires without causing rutting.
- While wide-tired skidders did not cause significant compaction when soils were drier than about  $-15$  kPa, skidders with standard tires are expected to compact soil to a higher bulk density and cause more changes in pore size distribution when air-filled pore space is not limiting compaction. The increase in bulk density will likely remain statistically significant to a lower water potential (drier soil) if the soil was trafficked by skidders operating with standard tires.
- Wide tires reduce the risk of significant soil compaction over part of the range of soil wetness commonly encountered in the boreal forest.
- Soil wetness can be easily used to estimate when soils are susceptible to compaction by wide-tired skidders using a hand-held tensiometer, or estimated from soil consistence in the field with calibration to tensiometer measurements.
- Results validate the soil wetness criteria in the soil rating system in the Alberta Forest Soil Conservation Guidelines for skidders with wide tires: wet soils have

water potentials less than  $-15$  kPa; moist soils have water potentials between  $-15$  and about  $-70$  kPa; and dry soils have water potentials lower than  $-70$  kPa.

- Managing soil wetness is the primary method that can be used to reduce the risk of significant soil compaction by these types of equipment.

### **Soil Recovery**

Soil recovery is discussed in Papers 2 and 5.

#### **Results:**

- Bulk density increased significantly ( $0.05 \text{ Mg m}^{-3}$ ) across all treatments after one year; probably as a result of natural compaction following the termination of root growth and increased decomposition (P5-Fig 1).
- Two years after harvesting, bulk density of compacted soil remains significantly higher than in the non-trafficked control regardless of the number of skidding cycles (P5- Fig 1).
- After two years, bulk density of soil in the compacted treatments decreased, and the decrease was slightly more in the higher trafficked soil.
- The failure of the soil to decompact rapidly is attributed to the heavy snowpack that has prevented the soil from freezing the past two winters (P5-Fig 2).
- The infiltration rate of the surface soil has partly recovered, more in the 3-cycle treatment than in the 7- or 12 cycle treatment (P2-Fig 2). Faster recovery of less trafficked soil may have occurred because it was better protected by the organic

debris that may keep soil water content higher in fall prior to freezing, which would enhance the freeze-thaw process.

#### **Implications:**

- Although the soil did not decompact at depth, the recovery of surface infiltration should improve soil water retention.
- More intensively trafficked soil will probably require a long period of time for recovery from compaction.
- Under heavy winter snow covers, soils in the boreal forests of west-central Alberta normally do not freeze to an appreciable extent, which reduces the efficacy of the freeze-thaw process for decompacting soil.

### **Post-Harvest Soil Environment**

Changes in soil biological activity as affected by forest harvesting and soil compaction are covered in Paper 6.

#### **Results:**

- Soil respiration increased across all compaction treatments, probably because of higher soil temperatures following canopy removal (P6-Fig 4).
- RedOx potential in compacted soil at hygric sites decreased to values typical of anaerobic environment due to reduced aeration and periodic waterlogging (P6-Fig 3).

- Compaction had the most obvious effect on the anaerobic decomposition of cellulose (P6-Fig 6).
- The rapid response of soil microflora to an anaerobic soil environment suggests that some of the soil organisms in the mature boreal forest is well adapted to periodic anaerobiosis (P6-Fig 5).
- The changes in soil biological activity affected the type of soil organic matter. Over the 2-year period, the humic to fulvic carbon ratio decreased, particularly in the heavily trafficked skid trails (P6-Fig 8). Although changes in the rate of decomposition are occurring, no significant change could be found in the total organic carbon content of the soil at this point in time.

#### **Implications:**

- Compaction of more poorly drained soils is likely to increase anaerobiosis and contribute to a faster rate of soil organic matter decomposition than in better drained soils. These changes in soil processes could shift the soil to a lower drainage class if the soil does not decompact.
- Site preparation that improves soil aeration should alleviate some of the adverse effects of poor aeration resulting from soil compaction.

#### **Conifer Seedling Performance**

The progress report on the study of effects of compaction on conifer performance is referred in this summary as paper 7.

**Results:**

- First year survival did not show an obvious effect of compaction at four sites planted in 1995 (P7- Table 2).
- First year growth was not affected by compaction although seedling size differed markedly among sites.

**Implications:**

- Difference in soil aeration had no obvious effect on seedling survival or may have been mitigated by site preparation.
- It is too soon to make statements regarding the potential impacts of compaction on conifer growth.

**Questions Remaining to be Answered**

Freezing of forest soils was expected to occur annually, and has been effective in decompacting forest roads in the region in as little as two years. But, heavy snow is an important unknown that prevents the soil from freezing in some years. The effects of soil compaction on the aeration of particularly poorly drained soils raises questions regarding the effects of soil compaction on the drainage classification of the soil if decompaction does not occur. Remeasurement of bulk density following a winter with little snow, or the physical removal of snow, should establish the role of the freeze-thaw process in the initial decompaction of these soils.

Early effects of poor soil aeration probably should have an immediate effect on seedling survival but not necessarily growth. First year survival was not affected on these sites by soil compaction. Seedlings should be measured for at least five years to establish whether soil compaction will affect growth. It is less likely for soil compaction to affect the growth of young trees at a later date if it did not have such an effect when the trees when they were seedlings.

The next phase of this research should concentrate on measuring decompaction on only the sites where the increase in bulk density was statistically significant. Soil freezing could be encouraged, if it does not occur naturally, by removing the soil on part of the plots. Seedlings need to be measured until they are at least five years old to determine whether soil compaction is having any affect on their growth.