Soil Compaction Studies

by

T.S.S Conlin and R. van den Driessche

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For additional copies and/or further information about the Canada–British Columbia Partnership Agreement on Forest Resource Development: FRDA II, contact:

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(250) 363-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(250) 387-6719
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1 INTRODUCTION

Growth reduction in trees due to soil compaction on skid trails has been shown to occur for as long as 32 years after harvest (Wert and Thomas 1981). The amount of compaction that occurs is related to soil moisture content, with drier soils being much less affected than moist ones (Steinbrenner and Gessel 1955; Hatchell et al. 1970; Wert and Thomas 1981). Although highly compacted, dry soils (soil strength >2500 kPa) can physically impede root growth (Greacen and Sands 1980; Nambiar and Sands 1992), limited rates of oxygen diffusion in relation to root oxygen requirements are probably more significant in moister soils with lower soil strength (Schumacher and Smucker 1981; Asady and Smucker 1989; Grant 1993).

These studies examine the effects of soil compaction on early growth of several tree species native to British Columbia. Detection of early signs of compaction-related stress will allow earlier remedial action to be taken.

The first two experiments described in this report were designed to identify early signs of compaction-related stress in lodgepole pine (Pinus contorta) (Conlin and van den Driessche 1996), Douglas-fir (Pseudotsuga menziesii), and white spruce (Picea glauca). A secondary objective was to examine the interaction of soil moisture and compaction on initial seedling growth. The third experiment was designed to examine the effects of soil compaction on the composition of the soil atmosphere, and is continuing.

2 SHORT-TERM EFFECTS OF SOIL COMPACTATION ON GROWTH OF LODGEPOLE PINE AND DOUGLAS-FIR SEEDLINGS

2.1 Methods

PVC tubes, 40 cm deep with 3464 cm³ capacity, were filled with soil (Eluviated Eutric Brunisol, 1% gravel, 45% sand, 47% silt, and 7% clay) from a site near 70 Mile House in the Interior Douglas-fir biogeoclimatic zone of Central British Columbia. The tubes were divided into five lots and their contents compacted to pressures of 0.1, (hand-compacted control) 2.0, 4.0, 6.0, and 8.0 Mpa (compacted with hydraulic press). Three watering regimes were assigned to tubes at each compaction level: no water table (NWT) (watering from above only), a 2-cm water table (2-cm WT), and a 10-cm water table (10-cm WT). One seedling was grown in each tube for 13 weeks (Conlin and van den Driessche 1996). Two experiments were conducted, one with lodgepole pine and one with Douglas-fir.

2.2 Results and Discussion

Soil used to prepare the Douglas-fir experiment was not as dry as that used in the lodgepole pine experiment, with the result that bulk densities, gravimetric water content, and penetrometer resistance values tended to be higher in the Douglas-fir study. Consequently, comparisons between experiments must be made with caution, considering the relative differences within each experiment.

Increasing soil compaction resulted in progressively higher bulk density and gravimetric moisture content (Figure 1). In the absence of a permanent water table, the soil exhibited a relatively high penetrometer resistance (Figure 1). Soil underlain by a 2-cm
water table showed a high penetrometer resistance at low compaction levels, decreasing with increasing compaction as soil moisture increased (Figure 1). Soil underlain by a 10-cm water table remained moist at all levels of compaction, and consequently showed a low (but increasing) penetrometer resistance throughout (Figure 1). In all cases, however, penetrometer resistance remained well below the 2500 kPa (25.5 kg cm⁻²) value thought to be necessary to directly cause root growth reduction in conifers (Greacen and Sands 1980).

Soil oxygen decreased with depth and with increased compaction in soils with a water table, but not in the samples with no water table. Increasing the water content of soil is known to further decrease soil oxygen content with depth (Lieffers and Rothwell 1986; Grant 1993).

Root growth in both species decreased with increasing compaction, and the root:shoot ratio of lodgepole pine also decreased as soil compaction increased, and with increasing water table depth (Figure 2). Douglas-fir showed a more complex response. There was a progressive reduction in root:shoot ratios with increasing compaction in the NWT treatment. The 10-cm WT treatment showed the lowest ratios, and the 2-cm WT the highest ratios, which declined at the two highest compaction levels. Assuming that a high root:shoot ratio was an indicator of good seedling health, it could be inferred that the moderate compaction and water treatments together provided a better environment for Douglas-fir than other treatments. However, compaction in the absence of a water table resulted in stressed plants. Lodgepole pine, on the other hand, appeared to grow better in drier, compacted soils (Figure 2).

The most apparent effect on lodgepole pine of the higher compaction levels was increased shoot height (Figure 3). This occurred independently of watering treatment. Needle length of lodgepole pine generally showed a decline with compaction level, and also showed a significant interaction between water treatment and compaction (Figure 4). Needle length in lodgepole pine was best correlated with root dry weight, so it is possible that reduced root development leads to inadequate absorption of minerals, which in turn inhibits needle development.

Douglas-fir needle length showed no interaction between watering treatment and compaction, but a tendency for longer needles at higher soil compaction levels (Figure 4). This species also attained greatest stem diameter at 4-MPa compaction (Figure 3). However, shoot dry weight at 4 MPa increased with the NWT and 10-cm WT treatments, but not with the 2-cm WT. Therefore, water table extremes led to greatest shoot weight at mid-range compactions.

Mineral nutrition is also known to influence needle length (Burdett et al. 1984). In this experiment, uptake of N, P, and K was reduced by compaction and moisture content. Other minerals that showed a significant response were Mn, B, Cu, Mg, and Zn. Iron and Ca were unaffected by compaction or water table treatments. The NWT treatment generally resulted in the highest concentrations of N in Douglas-fir foliage and lodgepole pine shoots, with higher soil moisture treatment reducing N concentration (Figure 5).
3 TWO-YEAR EFFECTS OF SOIL COMPACTION ON GROWTH OF LODGEPOLE PINE AND WHITE SPRUCE

3.1 Methods

Plots, 1.12 × 2.9 m, were prepared in raised wood-framed beds, so that 50 cm of sand was overlain by 40 cm of soil. Four treatments were applied:

1. uncompacted;
2. compacted in five alternate strips for a total of 50% of the area;
3. compacted in three wide strips for a total of 80% of the area; and
4. completely compacted.

Two rooting depths were arranged factorially with the above treatments, according to the presence or absence of a polyethylene barrier between the sand and the soil, and each treatment combination was applied to lodgepole pine and white spruce. Treatment combinations were replicated twice in 32 plots, each planted with 60 trees. The soil contained 47.7% sand, 24.8% silt, and 27.5% clay, and the underlying sand had a particle size distribution of 39% less than 0.6 mm, 53% between 0.6 and 2.8 mm, and 8% greater than 2.8 mm.

3.2 Results and Discussion

Compaction treatment significantly increased both bulk density and penetrometer resistance in all cases, both 1 and 2 years after the start of the experiment (Table 1). Pre-dawn water potentials of seedlings decreased by a small but significant amount with increased compaction, possibly as a result of restricted root growth due to the compaction (Table 1).

In the first year after planting, shoot height, diameter growth, and stem volume of both species increased by a small but significant amount with increasing compaction (Figure 6). This could be the result of inhibited root growth in compacted soil, leaving more photosynthates available for shoot growth. In the second year, however, these trends were reversed in all but the 100% compaction plots. Stem volume growth was greater in the deeper soil, especially for lodgepole pine, but there was no evidence of an interaction between soil depth and compaction treatments after 2 years.

The initial increase in shoot height associated with compaction is similar to the effect seen in the previous experiment (Section 2). It is particularly interesting in the current context, since it may create a misleading impression of the health of seedling growing in compacted soils. However, it can be expected that, as with pot-bound plants where rooting is abnormally restricted, the growth of the whole plant will eventually decrease. This decreasing trend was already becoming evident in the second year.

| TABLE 1. Mean bulk density, penetrometer measurements, and plant water potential shown by compaction treatments |
|-------------------------------------------------|-----------------|-----------------|
| Treatment                          | Bulk density | Penetrometer | Plant water potential |
|                                  | 1995 | 1996 | (kg cm⁻²) | 1995 | 1995 |
| Uncompacted                        | 1.11 | 1.11 | 0.61 | -0.75 |
| 50% compacted                      | 1.16 | 1.16 | 3.38 | -0.78 |
| 80% compacted                      | 1.17 | 1.17 | 5.91 | -0.92 |
| 100% compacted                     | 1.22 | 1.22 | 6.75 | -0.89 |
4 THE EFFECTS OF SOIL COMPACTION ON OXYGEN, CARBON DIOXIDE, AND ETHYLENE

4.1 Methods

Samples of soil gas were collected from heavily, moderately, and uncompacted soils at the Prince George Long-term Soil Productivity Site. A series of samples were obtained during the growing seasons 1 and 2 years after compaction. Samples were taken using a specially developed device (Figure 7) and sent to the Glyn Road Research Station in Victoria for analysis.

4.2 Results and Discussion

Oxygen levels remained close to ambient atmospheric levels in nearly all cases, although a few samples showed a decrease. These decreases seemed to represent very localized conditions within the plots, rather than a response to treatments.

In all cases, carbon dioxide concentrations were much higher than atmospheric levels. During the first year after treatment (1994), the compacted plots contained higher levels of CO₂ than uncompacted soil, although this difference declined during the course of the year. In year 2 (1995), the compacted plots showed higher levels only during early summer and late fall. All soil CO₂ levels were considerably lower in year 2 (Figure 8). It seems likely that CO₂ levels are related to the presence of decaying organic matter in the soil following logging. This would explain the gradual decline in CO₂ levels as the available organic matter was consumed. It has been shown that large concentrations of carbon dioxide decrease respiration in young Douglas-fir roots (Qi et al., 1994). The elevated levels of carbon dioxide seen in the earlier post-compaction period could therefore influence the early growth of replanted seedlings.

The year-2 ethylene results also showed seasonal variations. No ethylene was detected until late June, and then only in the heavy compaction treatment. Ethylene levels in the heavy compaction treatment increased relatively consistently between June and late August, dropped in September, and then rose again until October (Figure 9). Concentrations in the other two treatments varied more irregularly with time, although the highest concentrations occurred in July and October (Figure 9).

Ethylene is known to be a plant growth regulator. It has been shown to be physiologically active in lodgepole pine and Pinus serotina (Sanderson and Armstrong 1980; Topa and McLeod 1988). The soil ethylene concentrations seen in the study appear at levels that are capable of affecting plant physiology. However, it remains to be seen whether 1995 trends in ethylene concentrations are consistent from year to year, and whether they actually influence seedling growth.

5 CONCLUSIONS

Shoot height is often assumed to be an indicator of seedling health. These studies have shown that this is not necessarily the case, and that shoot height initially increased with increasing compaction in lodgepole pine in both the short-term and 2-year experiment, and in white spruce in the 2-year experiment. However, these first-year shoot measurements were not good predictors of growth on compacted soils in the second year. Although some characteristics, such as root:shoot ratios, showed a more consistent response, there were significant differences between the species. In making determinations in the field, therefore, it will be necessary to take into account the characteristics of the species involved, rather
than attempting to use one criterion, such as shoot height, for all species. Similarly the significant part played by soil moisture regime in modifying response to compaction must be considered.

From the soil atmosphere study, it can be concluded that, in the field, soil compaction causes increased levels of soil carbon dioxide. The physiological consequences of this are not yet known.

FIGURE 1. Penetrometer resistance, bulk density, and water content of soil columns for each species and each watering treatment (Pl=lodgepole pine; Fd=Douglas-fir). Ovendried soil (◇), NWT (○), 2-cm WT (♦), and 10-cm WT (▼) (n=12).
FIGURE 2. Root:shoot ratios of Douglas-fir (Fd) and lodgepole pine (Pl) grown in compacted soils.
FIGURE 3. Stem diameter and water potential of Douglas-fir (Fd), and height and water potential of lodgepole pine (Pl) plotted against compaction. Continuous lines are water potentials.
FIGURE 4. Mean needle lengths of Douglas-fir (Fd) and lodgepole pine (Pl) plotted over soil compaction. Symbols for lodgepole pine are as in Figure 1.
FIGURE 5. Douglas-fir (Fd) foliage and lodgepole pine (Pl) shoot nitrogen for each watering treatment and compaction level.
FIGURE 6. Mean height, diameter, and volume of seedlings at four increasing levels of compaction (Table 1), after 1 and 2 years, averaged for species (lodgepole pine and white spruce) and soil depths.
FIGURE 7. Soil atmosphere sampling device.
FIGURE 8. Soil carbon dioxide levels 1 and 2 years after compaction.
FIGURE 9. Soil ethylene concentrations 2 years after compaction for each of three compaction levels.
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