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Compaction of boreal forest soils

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Highlights

- Compaction due to harvesting equipment in dry soil conditions is unlikely to have long-term negative effects on soil nutrients, tree growth and site productivity.
- Reduced initial tree growth and decreases in some soil nutrients can be expected when harvesting occurs in wet soil conditions.
- Wide-tired harvesting equipment and minimal passes are recommended in moist and wet soil conditions to avoid soil compaction.
- Winter harvesting is advocated wherever and whenever feasible in order to limit the negative impacts of compaction.

Each skidder pass deepens the ruts on the trail. It seems unlikely that anything could grow there post-harvest. The same goes for the heavily trafficked landings and haul roads. Yet, merely a year later aspen suckers emerge from the sandy loam soil that previously resembled pavement. So, what's the concern over compaction? It doesn't appear to be an issue here. Or is it? With ever increasing mechanization of forestry operations and the resultant increase in traffic on the soil, concerns over soil compaction have been raised. Soil compaction, in turn, is of concern because of its potential to reduce site productivity. This note looks at research results, summarizes the observed impacts on soil nutrients and subsequent tree growth, and suggests how the research results could be implemented in forestry practice.

Defining compaction and its effects

Soil compaction is generally defined in physical terms. An increase of more than 15% in the pre-harvest bulk density of the soil indicates compaction.[6] It can be caused by as little as one skidder pass or only after repeated passes. Compaction is most commonly associated with skid trails and landings, which together can represent a considerable portion of a cut block. This could translate into reduced overall site productivity.

While compaction is readily definable, its effects are less so. Studies of the physical impacts of compaction on soil are numerous yet only a handful has investigated the effects of compaction on chemical and biological soil processes. A look at the current research shows that, while effects of compaction are somewhat varied and ecosystem specific, some generalizations are possible.

Let's get physical

Most compaction studies to date have focused on soil physical parameters and their relationship to tree growth. There is agreement that compaction leads to a loss of soil air space--particularly large air pores (macroporosity). When air pore loss reaches a critical level, serious consequences to soil processes and the root environment may occur.[13] When oxygen levels drop below 6 to 10% plant root growth becomes limited.[7] Compacted soils can lead to surface water logging.[6] Compacted wheel ruts with standing water are a common sight on logged sites. Here water is unable to move into the soil. This reduced water infiltration capacity can also reduce lateral water flow, which can exacerbate growth problems on low productivity or poorly drained sites.[5]

Wheel ruts can cause soil compaction which, in turn, reduces water infiltration and can result in reduced growth and productivity. Photo courtesy of Fisheries and Oceans Canada.

Compaction and nutrients

Direct effects

Compaction is thought to affect nutrient availability and uptake through various mechanisms including a change or decrease in water flow and infiltration. For instance, erosion of compacted soils can lead to nutrients being washed away with soil particles. This would be of particular concern on sloping land where such nutrient losses could not only affect the future productivity of the site but may also have implications for watercourses (e.g. excess sediments in fish spawning habitat).[6]

Nutrient cycling is also affected by reduced pore space and oxygen exchange, as mentioned above. Resultant anaerobic conditions are linked to increased conversion of nitrate to nitrogen gas (denitrification).[6] It has been suggested that such losses could add up to 10-40 kg of nitrogen (N)/ha compared to the 1-3 kg of N/ha lost to normal 'background' denitrification.[9] Anaerobic conditions may also cause increases in pH (as more CO_2 dissolves in water), which affects the release of micronutrients.[12] Molybdenum, for example would be more available while manganese less so. Anaerobic conditions can be ameliorated or exacerbated by the amount of soil organic matter, soil wetness, temperature and the amount of precipitation vs. the amount that plants transpire.[16]

Indirect effect on nutrients via the soil biota

Compaction can impact site productivity via its effects on soil organisms. Since the soil biological cycle, in large part, mediates nutrient availability, any effect of compaction here is key. While it is generally believed that compaction reduces the abundance and possibly diversity of soil fauna and microflora, evidence suggests that such generalizations may not always apply.

The effects of compaction on the process of decomposition, has been studied to some extent. In the mixedwoods of Alberta, researchers found that soil microbial activity generally decreased with increasing compaction yet decomposition increased, particularly where water logging was evident.[15] Does this have long term consequences for nutrient cycling? It does not appear so in the case of these Albertan sites or other boreal forest sites.[11,15] Soil organisms seem to be 'pre-adapted' to difficult conditions in soils that are characteristically low in organic matter, become waterlogged from time to time and have compacted subsoils. As soil flora and fauna quickly colonize environments created by forest harvesting, researchers have observed only a minor interruption in 'services'. Could this accelerated rate of decomposition in waterlogged, compacted soils lead to an eventual decline in soil organic matter? No one knows for sure.

In the short-term, the interruption in nutrient cycling processes due to compaction appears to be sufficiently small that there are no significant changes in nutrient availability. Indeed, after patch clearcutting an aspen stand on a coarse-textured luvisol in Saskatchewan, no change was found in nutrient concentration in the soil or the LFH horizons. Here, the annual variation in nutrients was by far greater than any impact of compaction on their site.[14] Similarly, no effect of compaction was found on the nutrient contents of the organic or mineral soil horizons of a relatively dry fine-textured soil after aspen harvest.[8]

Studies of moist or wet soils however, paint a less positive picture of the impacts of compaction on soil nutrients. In boreal British Columbia, decreases (of about 50% compared to plots not compacted) in calcium (Ca) and magnesium (Mg) in fine-textured soils were found post-harvest, which could have been attributed to soil moisture at the time of harvest.[1] Results from the Long Term Site Productivity trials in northern B.C. point to an increase in soil CO_2 with compaction, which may, in turn, lead to poor root growth, impede the N cycle and raise soil pH.[7]

Impacts on tree growth

Some studies show negative effects of compaction on seedling growth. Plant growth is much more susceptible and more negatively affected by the anaerobic conditions (i.e. waterlogging) that can result from compaction than soil organisms. It's simple - roots require oxygen. For example, on a site with moderate compaction, significant reductions in the abundance of aspen suckers were found on moist fine-textured soils in northern B.C.[2] Similarly, on the fine-textured gray luvisols of the Abitibi region, black spruce and balsam fir regeneration was reduced by up to 95% on heavily trafficked skid trails.[10] In compacted sites in Maine, on coarse loamy soil, spruce and balsam fir regeneration was dramatically reduced with a noticeable decline in growth and vigour.[5] And although compaction decreased growth and density of young aspen, some researchers suggest that site preparation may negate compaction effects in boreal mixedwoods.[12]

Soil compaction at a site of the Long Term Soil Productivity study in northern British Columbia. Increases in soil CO_2 as a result of soil compaction at these sites may lead to poor root growth in the future. Photo courtesy of the Long Term Soil Productivity Research Team.

How wet is the soil?

The susceptibility of soil to compaction is clearly related to soil moisture. There is little doubt that saturated soils, regardless of texture, are more likely to be negatively affected by compaction compared to dry soils. There is also agreement that damage to soils and thus site productivity, is reduced or even negligible when harvesting occurs on soils below field capacity.[14] Gleysols, for instance, are thought to be much more susceptible than soils that are not periodically saturated. In Alberta, compaction is only considered a hazard in wet forest soils and in soils derived from till and volcanic ash with high clay content horizons.[6] In boreal Alberta's medium-textured soils, it was found that skidders with wide tires did not affect soil physical properties significantly at water potentials below –15kPa.[16]

Frozen soils

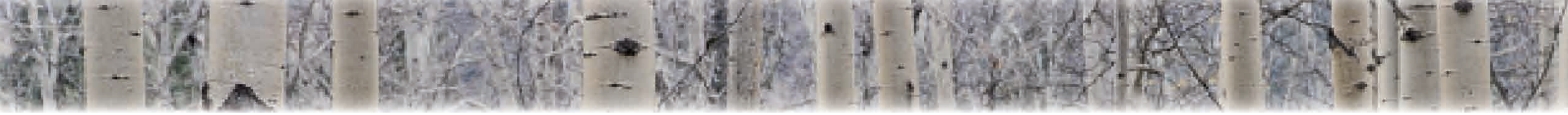
Winter harvesting is recommended whenever feasible since compaction is limited on frozen soils.[1,4] For example, winter harvest is advocated for forests in Northern B.C. on fine- to medium-textured soils to avoid compaction and reductions in soil productivity.[2] In the boreal mixedwoods of the Northwest Territories, mechanical harvesting and site preparation on frozen, fine-textured soils results in minimal physical disturbance and does not significantly alter the nutrient status of the soil either.[4] In terms of regeneration success, one study showed that winter harvesting of black spruce in northern Quebec resulted in a 23% gain in stocking compared to summer harvesting.[15]

Winter harvesting at a Long Term Soil Productivity study site in Northern B.C. Winter harvesting can limit compaction, especially on fine and medium-textured soils. Photo courtesy of the Long Term Soil Productivity Research Team.

Logging equipment can make a difference

Harvesting with feller bunchers such as this one has been shown to increase soil compaction, thereby reducing regeneration growth and soil microbial abundance. Photo courtesy of Chris Schnepf, University of Idaho

Not only do soil texture and moisture affect the susceptibility of a soil to compaction but so do the type and intensity of use of machinery. For example, there were no negative effects on aspen growth on an unfrozen clay soil winter logged by chain saw and then cable winched. When an adjacent site on the same soil was logged with a feller buncher and grapple skidder, however, the disturbance was significant and reduced regenerating aspen growth. Yet the same equipment will be much less destructive in drier conditions. Wide-tired grapple skidders and forwarders did not seriously compact a fine-textured boreal soil when harvesting occurred under dry conditions.[14] In another study, it was found that a Timberjack Harvester 1270 caused negligible impact on mites and collembolans although harvesting with a feller buncher significantly reduced their numbers, which could have consequences for the nutrient cycle and thus, site productivity.[13]



Recovery?

Recovery of compacted soils depends on the degree of compaction in the first place. Here, research results and opinions vary. Some studies suggest that in Alberta, compacted soils of a range of textures could take between 10 and 21 years to return to pre-disturbance conditions.[17] Other results suggest that the damage may be irreversible with long lasting consequences for water infiltration, which in turn would affect tree growth.[5] In both fine- and coarse- textured soils, compaction remains quite noticeable for 3-5 years after logging, in the upper soil layers.[17,18] Traffic intensity does make a difference though. One year after harvesting with three skidding cycles, Albertan fine- to medium-textured luvisols showed significant recovery in water infiltration. On the other hand, intensely skidded trails did not recover three years after harvest.[16]

Can soils naturally 'decompact'? Some research suggests that frost penetration can accelerate the recovery of compacted soils. Other research from boreal Saskatchewan indicates that the reversal of effects of compaction through the freeze/thaw cycle is very slow.[3] Certain clays found in the B horizon of luvisols (commonly found under aspen mixedwoods) may help promote recovery from compaction through their ability to shrink and swell.[2] This could loosen compacted layers over time.

Summary

Short-term effects of compaction on soil nutrients appear to be minimal when harvest traffic occurs in dry soil conditions. Under wet conditions, a decrease in soil nutrients is likely as is reduced initial tree growth. Clearly, soil moisture is key in avoiding any negative site productivity effects of compaction; thus traffic on soils at field capacity or wetter should be avoided. If harvesting must occur in wet soil conditions, then wide-tired equipment is recommended with a limited number of passes. Winter harvesting is also advocated where feasible since frozen soils are much more resistant to compaction.

References

1) Arocena, J.M. 2000. *Cations in solution from forest soils subjected to forest floor removal and compaction treatments.* For. Ecol. and Mgmt. 133: 71-80.

2) Arocena, J.M. and P. Sanborn. 1999. *Mineralogy and genesis of selected soils and their implications for forest management in central and northeastern British Columbia.* Can. J. Soil Sci. 79: 571-592.

3) Block, R., Van Rees, K.C.J. and D.J. Pennock. 2002. *Quantifying harvesting impacts using soil compaction and disturbance regimes at a landscape scale.* Soil Sci. Soc. of Amer. J. 66: 1669-1676.

4) Bock, M.D. and K.C.J. Van Rees. 2002. *Forest harvesting impacts on soil properties and vegetation communities in the Northwest Territories.* Can. J.For. Res. 32: 713-724.

5) Briggs, R.D., Hornbeck, J.W., Smith, C.T., Lemin Jr., R.C. and M.L. McCormack Jr. 2000. *Long-terms effects of forest management on nutrient cycling in spruce-fir forests.* For. Ecol. and Mgmt. 138: 285-299.

6) Chanasyk, D.S., Whitson, I.R., Mapfuma, E., Burke, J.M. and E.E. Prepas. 2003. *The impacts of forest harvest and wildfire on soils and hydrology in temperate forests: A baseline to develop hypotheses for the Boreal Plain.* J. Env. Eng. 2: S51-S62.

7) Conlin, T.S.S. and R. van den Driessche. *Response of soil CO_2 and O_2 concentrations to forest soil compaction at the Long-term Soil Productivity Sites in central British Columbia*. Can. J. Soil Sci. 80: 625-632.

8) Corns, I.G.W. and D.G. Maynard. 1998. *Effects of soil compaction and chipped aspen residue on aspen regeneration and soil nutrients.* Can. J. Soil Sci. 78: 85-92.

9) Dutch, J. and P. Ineson. 1990. *Denitrification of an upland forest site.* For. Chron. 63: 303-317.

10) Harvey, B. and S. Brais. 2002. *Effects of mechanized careful logging on natural regeneration and vegetation competition in the southeastern Canadian boreal forest.* Can. J. For. Res. 32: 653-666.

11) Kranabetter, J.M. and B.K. Chapman. 1999. *Effects of forest soil compaction and organic matter removal on leaf litter decomposition in central British Columbia.* Can. J. Soil Sci. 79: 543-550.

12) McNabb, D.H., A.D. Startsev and H. Nguyen. 2001. *Soil wetness and traffic level effects on bulk density and air-filled porosity of compacted boreal forest soils.* Soil Sci. Soc. Amer. J. 65: 1238-1247.

13) Marshall, V.G. 2000. *Impacts of forest harvesting on biological processes in northern forest soils.* For. Ecol. and Mgmt. 133: 43-60.

14) Maynard, D.G. and D.A. MacIsaac. 1998. *Soil nutrient and vegetation response to patch clear-cutting of an aspen forest near Meadow Lake, Saskatchewan.* Can. J. Soil Sci. 78: 59-68.

15) Pothier, D. 2000. *Ten-year results of strip clear-cutting in Quebec black spruce stands.* Can. J. For. Res. 30: 59-66.

16) Startsev, A.D. and D.H. McNabb. 2000. *Effects of skidding on forest soil infiltration in west-central Alberta.* Can. J. Soil Sci. 80: 617-624.

17) Startsev, N.A., McNabb, D.H. and A.D. Startsev. 1998. *Soil biological activity in recent clearcuts in west-central Alberta.* Can. J. Soil Sci. 78: 69-76.

18) Stone, D.M. and J.D. Elioff. 1998. *Soil properties and aspen development five years after compaction and forest floor removal.* Can. J. Soil Sci. 78: 51-58.

Management Recommendations

- Managing soil wetness is key to minimizing compaction. If possible, one should: a) schedule harvest on poorly drained soils for drier periods or when they are frozen, b) minimize the period between felling and skidding since this allows for minimal recharge of soil water and maximum transpiration thus reducing soil moisture.
- The wider the skidder tires the better. The less equipment the better. Chain saw followed by cable winching is by far less hazardous to the soil than feller bunchers and grapple skidders.
- Organic matter (i.e. retention of some coarse woody debris on site or minimal removal/displacement of the forest floor) can minimize the impacts of com paction.
- Machine traffic in depressions should be avoided as they are generally more waterlogged and thus, more susceptible to compaction.

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