Soil compaction and its effect on surface runoff and nutrient changes

Justification/Background

Intensive forest management of younger stands and stand condition improvement treatments often involve removing small-diameter trees in partial cuts such as single tree selection, leaving more space between trees. With increased demand of fire hazard reduction and ecosystem restoration treatments in the Inland-Northwest region, multiple entries into the forest stands over a certain time period are often considered to achieve desired objectives of managing our forest resources. This means that the impacts of harvesting operations on soils become cumulative, since those impacts tend to remain a longer time period up to several decades (Froehlich 1979; Geist et al.1989; Ryder et al.1994).

Soils in northern Idaho are primarily volcanic ash capped or mixed soils, principally from the Mazama volcanic eruption 6700 years ago. These soils have low bulk density, high porosity and low shear strength and are prone to severe vibrational and compressional compaction (Page-Dumroese et al. 1998). It is difficult to uncompact these soils once the soils' structure has been changed: Froehlich et al (1985) found that even after 20 –35 years these soils were still severely compacted.

Understanding of how these soils are affected by compaction is limited because there have been only two studies of soil compaction in this region (Page-Dumroese 1993; Page-Dumroese et al. 1998) although such several studies have been done in central Idaho (Froehlich et al. 1986, Lenhard 1978). Soil compaction has been of great concern for forest managers in relation to sustainable forest management of forest resources since soil compaction can cause degradation of site productivity and increased surface runoff. Operational studies are necessary to expand our knowledge on spatial distribution of skid trails along with number of machine passes, planning and layout of skid trails, and harvesting system design. This information will greatly support the idea of minimizing soil impacts from thinning operations while reducing wildfire risks in the interior of northwest.

Two faculty members at the University of Idaho (UI) are teamed with a soil scientist from the USDA Forest Service to broaden our knowledge on characteristics of soil compaction from thinning operations and the effect of soil compaction on surface runoff and nutrient availability. The field work of this study will take place within the Experimental Forest near Potlatch, Idaho, in collaboration with the office of the Experimental Forest, University of Idaho. One PhD student at UI and one field technician from the Forest Service will be conducting field data collection and analysis under supervision of three principal investigators.

Previous Work

Soil compaction has been defined as "a process of densification in which porosity and permeability are reduced, strength" (Soane and Ouwerkerk 1994). Greacen and Sands (1980) define it as "an increase in soil strength while total porosity is reduced at the expense of large voids". Soil compaction results in an increase in bulk density (Dickerson 1976), decrease in infiltration capacity (Johnson and Beschta 1980), decrease in gaseous exchange (Steinbrenner 1959) and an increase in resistance to penetration (Forristall and Gessel 1955).

Adams and Froehlich (1984) listed a number of factors that affect the amount of soil compaction: amount and type of pressure, vibration applied, depth and nature of surface litter, soil texture and structure and moisture content. Compaction normally occurs in the first 10 passes of a harvesting machine (Gent et al. 1984) with the most compaction occurring in first few passes (Froehlich 1978). On volcanic soils, Lenhard (1986) reported that soil density reached a maximum after only four trips with an unloaded skidder.

One of the approaches to soil protection is the use of a designated skid trail system to limit the area of compacted soils since first few machine trips cause detrimental trips. A wide spacing of skid trails is often planned for the use of designated skid trails. This approach can restrict compacted areas to 10% or less of the harvest area, compared to 20% to 35% trail area with random skid trails (Froehlich et al. 1981; Adams and Froehlich 1984; Bettinger et al. 1994). More than 40% of a total harvesting unit was covered by old and new skid trails in a partial cutting unit in western Oregon (Wert and Thomas 1981).

The amount of water in the soil is directly correlated to its potential for compaction (Moehring and Rawls 1970; Alexander and Poff 1985). As a soil reaches its field capacity the soil particles begin to lose their structural cohesion resulting in a non-cohesive soil. For example, in wet conditions one pass of a machine is equal to four passes in dry conditions (Steinbrenner 1955). Soil compaction can increase surface runoff because of reduced infiltration rates. Increased run-off occurs on logged sites, but most of this is due to the removal of vegetation (Dickerson 1976).

Nutrient changes related to harvest activities have been shown to occur because the surface organic matter layer is removed (i.e. Miller and Brewer 1984; Jurgensen et al. 1997). Often the combination of mechanical compression of the soil and loss of nutrients results in decreased site productivity. Newer logging methods may not be as detrimental since often logging slash is left on the site and forest floor material is not disturbed. Soil compaction reduces the macropores in the soil, affecting the growth rate of plants by inhibiting root growth, reducing soil drainage, and slowing the exchange of nutrients and gases. Ponderosa pine on compacted skid trails had reduced total height, diameter and volume of 4.8, 7.7 and 20.4%, respectively (Froehlich et al. 1986).

Objectives

The overall objective of this study is to characterize soil compaction from fire hazard reduction and ecosystem restoration treatments and to assess its impacts on productivity loss and surface runoff in a watershed scale.

1) To quantify the areas of skid trails categorized by the number of machine passes,
2) To measure the level of soil compaction and disturbance, Han
3) To estimate an economic impact ($/acre) of productivity loss in relation to the extent of soil disturbance
4) To estimate soil nutrient changes and availability Debbie
5) Tim… the effect of soil compaction on surface runoff. Tim

Method:

Object 1. to quantify the areas of skid trails categorized by the number of machine passes.

The study site will be selected within the UI Experimental Forest and maintained to monitor the effect of soil compaction on tree growth for a long term. Two ground-based systems thinning high density stands will be examined. The skid trail map will be surveyed and developed before harvesting occurs. This can be done with any mapping software such as Arcview. This map will be used in the field to record the actual extent of machine movement over all trails. The study area will not be so large (less than 20 acres) so that three field researchers can have a 100% observation of the logging operations. The researchers will follow the machines and detail the number of machine passes on each skid trails along skidding distance information on the map. Machine passes will be categorized along with its percentage.

Object 2. to measure the level of soil compaction after logging operations are completed

Soil bulk densities will be measured at random spots after skid trail map has been developed but before operation begins. Following operations bulk densities will again be randomly measured with care taken to ensure sampling areas with varying number of machine passes. Bulk density sampling will be done using the core sampling method with samples being taken at 10 cm, 20 cm, and 30 cm underground. Soil bulk density (Mg/m^3) is measured by taking a soil core (100 ml), weighing it and then oven drying the sample for 24 hours at 105^oc before reweighing it.

The penetrometer equipped with a GPS unit has recently purchased in the Forest Products Department and will be used to measure the resistance (kPa) or soil strength of the soil to penetration. The GPS unit allows for a researcher to skid trail information while collecting soil strength data, and the information will be used to validate the skid trail surveyed.

Object 3. to estimate an economic impacts ($/acre) of productivity loss in relation to the extent of soil disturbance.

We will be using the relationship between growth reduction (%) and soil compaction (%) summarized in the previous studies (Froehlich 1979; Stewart et al. 1988; Wert and Thomas. 1981). A tree growth model will be used to estimate the future volume over a different time period. Sensitivity analysis on productivity loss will be done in relation to the extent of soil disturbance.

Object 4. to estimate soil nutrient changes and availability

Samples collected to measure soil compaction-*see objective 2* (bulk density cores) will be used to estimate changes in total carbon and nitrogen (High temperature induction furnace, LECO Corp, St. Joseph, MI), organic matter (loss-on-ignition; Ball 1964), soil acidity on a 2:1 water/soil paste, calcium and magnesium by atomic absorption spectroscopy, and potassium by flame emission. Samples will be composited by disturbance level – undisturbed by logging equipment, skid trail track, center of skid trail, and uncut forest.

Sample depths will be 0-10 cm, 10-20 cm, and 20-30 cm. Soil will be sieved to pass a 2-mm sieve, rocks and roots weighed. Nutrient changes will be expressed on a Mg ha^{-1} fine-fraction soil basis (Page-Dumroese et al. 1999).

Object 5.

Outputs: Expected research outcomes

Recent disastrous wildfires and unhealthy dense stands in the Inland-Northwest region require harvesting operation to reduce fuels and improve stand conditions by removing trees in partial. Much of interest has given to financial feasibility of fire hazard reduction and ecosystem restoration treatments because the operations deal with low-value, small-diameter trees. Multiple negative impacts on soils and residual trees are also to be clearly understood since those treatments are expected to increase. This study will explain both environmental and financial picture of those impacts, along with harvesting production rates and cost information of harvesting small-diameter trees.

In respond to increasing interests of using Cut-To-Length (CTL) system to harvest small-diameter trees, we will be expanding our knowledge on environmental impacts and economic analysis associated with CTL harvesting in this study. Some guidelines to minimize environmental impacts and to maximize logging efficiency will be developed as well. The follow-up study will be developed to test the effectiveness of those guidelines and their effects on harvesting productivity. This will include both CTL and conventional harvesting (hand felling – line skidder) systems.

Collaboration

Timeline

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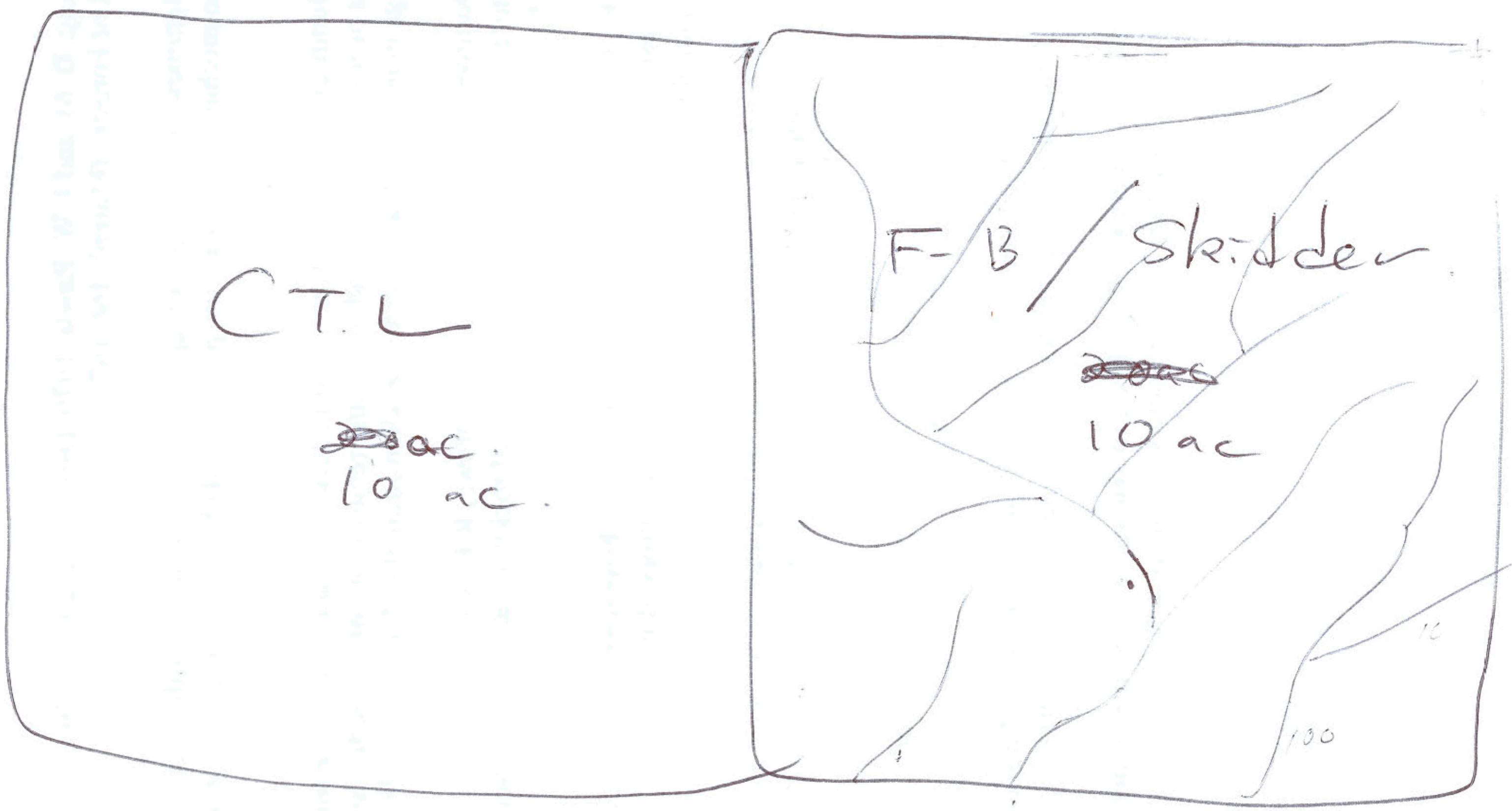
slope: less than 20%.



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