Subsoiling as Site Preparation on Ponderosa Pine Plantations of the Yakama Nation Forest

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Abstract

Early logging efforts on the Yakama Nation Indian Reservation in Washington State featured 100 percent piling of logging slash, with minimal concern for soil compaction. Observations of regeneration growth and development indicate that soil compaction may play a role in reducing tree growth on timbered land that was harvested in the era before logging practices were modified to minimize compaction. This article describes a project to document soil compaction on Yakama Nation forest land, compare the operations of two separate machines in subsoiling to break up soil compaction, and examine the growth of seedlings in response to subsoiling.

Introduction

The Yakama Nation Indian Reservation was formally established upon signing of a treaty with the United States Government on June 9, 1855. The Yakama Reservation consists of more than 1.1 million ac (445,155 ha) on the east side of the Cascade Mountains in south-central Washington State and is bounded by the Cascade crest (including Mount Adams) to the west, Ahtanum Creek to the north, and the Yakima River to the east. Over one-half of the reservation is classified as forest, with forest zones ranging from lower to upper timberlines.

The Yakama Nation began commercial timber harvest of its large holdings in the late 1940s. The early timber sales were large expanses concentrated on the drier eastern portion of the Yakama forest, salvaging ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) damaged by bark beetles (Schutter and Charmichael 1993). The extensive nature of the harvesting, combined with low stumpage prices and the Tribe's preference to harvest the forest selectively, resulted in widespread logging impacts on the soil. Handfelled trees were bucked to length, leaving large, unsightly piles of logging slash. The slash was 100 percent machine-piled using bulldozers, and piles were burned in the winter. No records can be found of any timing restrictions regarding slash piling. These practices continued into at least the 1970s.

Over the last 30 years, soil compaction has become recognized as an important issue on forest lands, as numerous studies showed that compacted soils have characteristics unfavorable for plant growth (Cambi et al. 2015). Layers of compacted soil restrict the movement of water, air, and roots, reducing the survival and growth of trees and other plants. Froehlich et al. (1986) found that total growth and the last 5 years of growth in ponderosa pine in south-central Washington on or near compacted skid trails were significantly related to the percent increase in soil bulk density caused by skidding. After that study, completed on the Yakama Reservation in 1983, the Yakama Nation's Forest Management Plan was adjusted to include policies to protect forest soils from heavy-equipment impacts.

Despite these belated preventative measures, soil compaction can persist for decades, depending on a number of factors. Although the soil surface can be de-compacted through natural frost heaving, a compacted layer tends to persist about 30 to 60 cm (1 to 2 ft) deep that the frost cannot reach. Overall, the moderate climate and soil types common to the Pacific Northwest seem to produce very slow rates of recovery from compaction (Adams and Froelich 1981).

Most of the compacting impact on soil usually occurs in the first few machine passes (Han et al. 2006, Wallbrink et al. 2002, Wang, 1997). Williamson and Neilsen (2000) found that, on average, 62 percent of the compaction experienced by the top 10 cm (4 in) of soil occurred after a single machine pass. In the 10-to-20 and 20-to-30 cm layers (4-to-8 in and 8-to-12 in, respectively), compaction increased up to the third pass, when it reached 80 to 95 percent of the final compaction. Therefore, we can logically surmise that the possibility of widespread soil compaction is high in those areas of early harvest on the Yakama forest during which multiple machine passes were common.

The Yakama Nation Tribal Forestry Program has anecdotal evidence of soil compaction having a detrimental effect on its reforestation efforts, especially in the early-harvested drier zone dominated by ponderosa pine. A more recent round of harvesting began in 2005 and focused on regenerating pine stands with extensive Western dwarf mistletoe (*Arceuthobium campylopodum* Engel.) infection. Many of the subsequent reforestation units had seedling survival and growth much less than expected. Planting crews complained that it was extremely hard to dig a planting hole to the appropriate depth in some spots because they hit an impenetrable layer with their shovels. A test project using an excavator revealed sheets of compacted soil several inches below the soil surface which younger tree roots could not penetrate (figure 1). Excavations of seedlings in the area confirmed root issues due to soil compaction (figure 2).

Figure 1. Compacted sheets of soil revealed by excavator work result in difficult growing conditions for planted seedlings. (Photo by Jack Riggin, 2011)

Figure 2. Excavation of a natural seedling shows negative influences on root development due to the compacted soil layer. (Photo by Jack Riggin, 2011)

Conventional agricultural cultivators have difficulty reaching below 30 cm (12 in). Hence, treatment of deep compaction in forest soils requires special equipment called subsoilers, sometimes known as rippers, to fracture them. Subsoiling fractures compacted soil without adversely disturbing plant life, topsoil, and surface residue. Fracturing compacted soil promotes root penetration by reducing soil density, improving moisture infiltration and retention, and increasing air spaces (Kees 2008). Since effectiveness of subsoiling in actually fracturing the compaction layer depends on various factors (soil moisture, structure, texture, type, clay content, etc.), the landowner may need to try different equipment or configurations to find out which is most effective for his or her specific situation.

In 2012, the Tribal Forestry Program received a Conservation Innovation Grant from the USDA Natural Resources Conservation Service (NRCS) to evaluate pine plantation development after subsoiling. Conservation Innovation Grants are used by the NRCS to assess different conservation practices that can, if successful, then justify their inclusion as a sponsored larger conservation practice in their larger programs, such as the Environmental Quality Incentive Program. The grant project goals were to:

- Assess different subsoiling techniques;
- Evaluate the effectiveness of subsoiling in reducing soil compaction;
- Evaluate tree seedling growth response to subsoiling.

Materials and Methods

The project consisted of selecting typical regeneration units, documenting the presence of preexisting soil compaction, implementing compaction-fracturing work (subsoiling), planting with seedlings in a typical manner, and then measuring seedling growth and development as influenced by the subsoiling. Each of these components is described in the following sections.

Forest Regeneration Units

Two units in the White Creek sub-basin were included in this project. The first unit, known as East Hopper's, is located on the east side of Vessey Springs Road, with an elevation of 1,065 m (3,500 ft). The second unit, known as West Hopper's, is located on the south side of the Ixl Crossing Road, with an elevation of about 1,005 m (3,300 ft). Both sites have an average precipitation of 68 cm (27 in), with a fine, sandy loam soil texture. The soils are rated as severe risk for compaction, with a low bearing capacity and poor drainage. The site index (base age 100) is about 30 m (99 ft) for ponderosa pine (USDI 2008).

Evidence exists (old burned logs and snags) that a stand-replacement fire occurred on the units about 100 years ago. The units were logged four times using selective harvesting and/or thinning from 1952 to 1995. In 2010, the areas where both units exist were regenerated due to the presence of dwarf mistletoe in the overstory.

Soil Density Assessment

Soil density was measured using a soil densiometer in the fall of 2012 (figure 3) both before and after the subsoiling work was carried out. Plots in both units revealed a clay layer lying just below the ash-cap layer of surface soil, thus confirming the compacted status of the soil (figure 4).

Figure 3. Soil density was measured on both units using a soil densiometer. (Photo by Jack Riggin, 2017)

Figure 4. A clay layer below the soil surface reveals signs of compaction. (Photo by Jack Riggin, 2017)

Figure 5. This triple-winged shank was used behind a bulldozer for subsoiling treatments on the West Hopper's site. (Photo by Jack Riggin, 2017)

Subsoiling

Subsoiling was carried out on both sites in the fall of 2012. The East Hopper's site was done by dragging a winged shank behind a tractor. The West Hopper's site was done by dragging a triple-winged shank behind a bulldozer (figure 5). The tractor contract was done for $480 per ha ($195 per acre), whereas the inhouse bulldozer work cost an estimated $430 per ha ($174 per acre).

Figure 6. The West Hopper's site 3 years after planting still shows signs of subsoiling work using the bulldozer method. (Photo by Jack Riggin, 2017)

Figure 7. Satellite imagery shows subsoiling work and areas where access was limited due to rocks, debris, or other obstacles. (Google Earth 2017)

The bulldozer was able to cover the ground more extensively than the tractor, and subsoiling work was still evident 3 years after treatment (figure 6). In some areas within the planting units, it was not possible to carry out the subsoiling. Rocky outcrops, areas of many stumps close together, heavy slash areas, and unburned landings were typical problem areas (figure 7). The tractor setup was rather lightweight for the intended job, at times tending to ride up out of the ground. The work shut down a few times due to soggy soils on both units.

Tree Planting

Ponderosa pine seedlings (styro-15) were grown under operational conditions at the Silvaseed Nursery (Roy, WA) during 2012 for planting in both units using local seed. The same seed lot was used in planting units. Seedlings were planted in spring 2013 at about 3.5 by 3.5 m (12 by 12 ft) spacing, or 740 seedlings per ha (300 per acre) (figure 8).

Figure 8. Seedlings were planted on both units after subsoiling. Some were planted directly in the subsoiling slot, as shown in this photo, and others were planted farther from the slot. (Photo by Jack Riggin, 2013)

Monitoring Plots

After planting, monitoring plots (81 m [871 ft²]) were installed on a grid on each planting unit (10 plots on East Hopper's; 11 plots on West Hopper's). Seedlings inside each plot were tallied for initial height and distance from the soil fracture slot. Several plots landed where no subsoiling was done.

Plots were revisited after the end of the first, second, and third growing seasons, during which height and survival were measured on seedlings within each plot.

Results and Discussion

Subsoiling Equipment

The bulldozer was cheaper, covered the ground better, and was easier on the site compared with the tractor. The tractor could only pull one shank through the ground at a time. That shank was in the middle center of the tractor and was light enough that it tended to pop out of the ground when encountering greater resistance. Furthermore, the tractor tires carried the potential of having a negative influence on soil density without being mitigated by additional fracturing behind the wheels.

The bulldozer was heavy enough to drag three shanks at a time, including behind its tracks, and was able to drag continuously below the ground unless it encountered rock. The tracked nature of the bulldozer distributed the weight of the machine over a wide area, reducing negative impacts associated with running heavy equipment over the ground.

Subsoiling Effects on Soil Compaction

Before subsoiling, the West Hopper's unit appeared to have a wider and denser compaction layer than the East Hopper's unit, though both areas showed signs of compaction (figure 9). Soil densiometer plots on both units showed that soil density was reduced in the zones from 7 to 23 cm (3 to 9 in) below the soil surface for both sites (figure 9). The East Hopper's site showed good soil density reduction near the surface, with limited impact after about 23 cm (9 in) (figure 9). This corresponds to the observations that the setup was not heavy enough to remain in the ground sufficiently to accomplish the task. The West Hopper's site, which featured great increases in soil density beginning just 7 cm (3 in) below the surface, showed great reductions in soil density after the subsoiling was completed, with slight declines farther below the surface (figure 9).

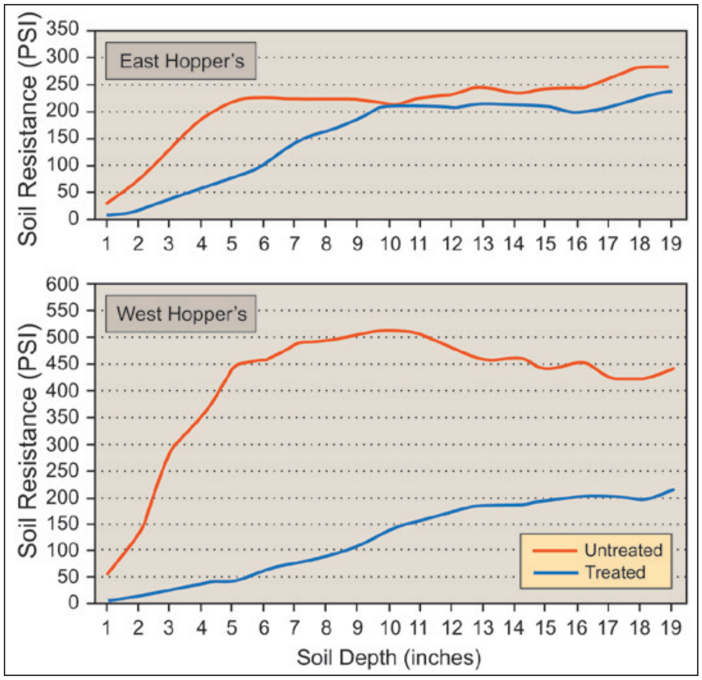

Figure 9. Soil density readings prior to subsoiling shows compaction beginning around 10 cm (4 in) below the surface. After subsoiling, density declined, especially for the West Hopper's site.

Subsoiling Effects on Seedling Growth and Survival

Seedling survival was similar among plots, regardless of distance from the subsoiling slot. The survival results are not unexpected because soil compaction is a long-term impact affecting growth and development and not something that immediately affects a seedling's ability to survive in its first few years.

At the end of the first growing season, no clear patterns in height growth emerged based on distance from the subsoiling (figure 10). It was not unexpected to see no subsoiling effects during the first season because initial root egress is much more directly influenced by available ground moisture in the immediate vicinity of the roots. Planting quality, precipitation patterns, and immediate vegetative competition all affect ground moisture availability to the seedling roots during the first year. After the second and third seasons, however, height growth on both units tended to be greater for trees that were planted closer to the soil fracture slot (figure 10).

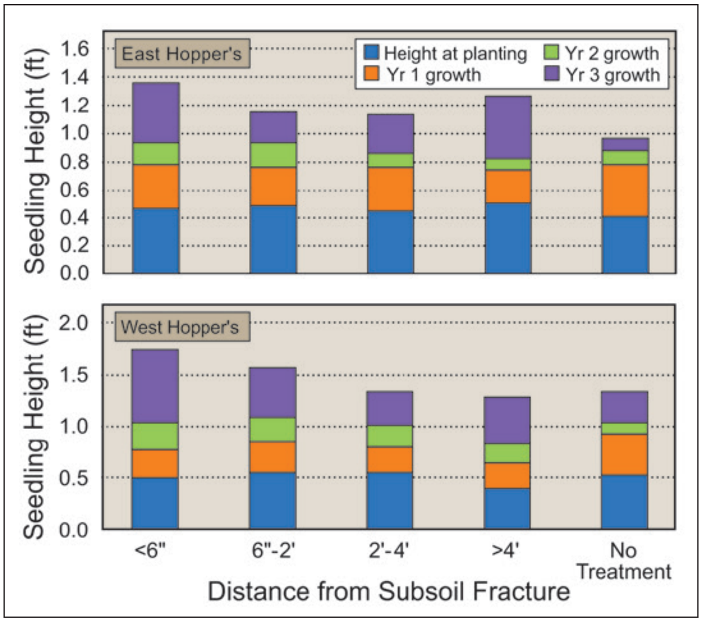

Figure 10. Seedling height growth did not differ greatly during the first year but showed increased growth in years 2 and 3 for seedlings planted closer to subsoiling compared to those that were planted further from the treated areas.

In a similar study, Gwaze et.al. (2006) found that ripping (subsoiling) increased height growth, basal diameter, volume, and crown spread in shortleaf pine (*Pinus echinata* Mill.) in Missouri from the first year. That study found continued increases in most measures through the third year, but revisiting the study after 16 years found slight decreases in diameter and volume compared with the control.

The bulldozer work not only broke up soil compaction below the soil, but also provided the additional benefit of breaking up the grass that had developed into a turf after logging. Grass is a formidable competitor to tree seedlings, especially during the first two seasons after planting. The tractor work, on the other hand, covered less area and was less effective in breaking up grass.

One might conclude that grass control was a more influential factor than subsoiling in improved seedling growth. The data show, however, that growth improved in years 2 and 3, when the impact of the grass control would be diminishing, as grass expands naturally into unoccupied ground. Instead, macro-site characteristics may be improved by subsoiling, something that would logically become more influential as the seedling roots extend further down into the soil profile. Further root egress in years 2 and 3 was perhaps enough to access the fractured layer and the additional volume of moisture and nutrients available there.

Although the current study shows seedling growth trends positively correlated with subsoiling, the literature's perspective on subsoiling is more ambivalent, or worse, when one takes a financial look into the additional preplanting costs that need to be accounted for at harvest time. Blazier and Dunn (2008) compared stock-type (container and bareroot), subsoiling (with or without) and planting densities (746 or 1493 trees per ha) on loblolly pine (*Pinus taeda* L.) in Louisiana. They found the container plus no subsoil plus low density (similar to the standard practice on the Yakama Nation) produced the highest stand volume after 13 years. The container plus subsoil plus low density alternative produced lower heights, tree volumes, and stand volumes. On the other hand, Berry (1986) found subsoiling benefited growth of loblolly and shortleaf pine seedlings in Georgia.

Closer to home, much of the work regarding soil compaction and seedling growth has concentrated on skid trails. In coastal Washington, Miller et al. (1996) found that change in soil bulk density due to logging was not a reliable predictor of growth and yield losses on silt loam soils. Meanwhile, Helms et al. (1986), working in a 16-year-old ponderosa pine plantation in the Sierra Nevada of California, found that tree height in the areas of the highest soil bulk density was 43 percent less at age 1 and 13 percent less at age 15 than those in areas of lowest bulk density. Helms and Hipkin (1986) found that mean tree volume in a landing, a skid trail, and areas adjacent to skid trails showed volume reductions of 69, 55, and 13 percent, respectively, when compared to areas of the same plantation that showed the lowest bulk density.

Peculiarities of the Yakama Situation

The history of timber harvest on the Yakama reservation differs from its neighbors in that multiple entries were made prior to regenerating the stand, including 3 entries prior to the implementation of changes to minimize soil compaction. It is unclear how many acres of compacted soils this early harvesting created. Regardless, an underlying susceptibility to compaction is based on soil properties on the forest. The Yakama forest soils GIS (geographic information system) layer estimates that 34 percent of the Yakama forest's soils are at severe risk to compaction and 35 percent are estimated to be at moderate risk.

Although soil compaction is addressed routinely in the Southeast United States, the economic return of forestry in that region is inherently higher and thus has an easier time supporting the extra cost of subsoiling. The ability to incur the cost of addressing this underlying forest productivity issue is much more questionable for the Yakama forest.

Additional Environmental Benefits to Subsoiling

In addition to the potential for improved seedling growth, subsoiling has other conservation benefits, such as improved runoff absorption and improved stream recharge. Smidt and Kolka (2001) found that subsoiling reduced surface runoff and sediment yield when compared to standard practices for skid trail retirement in Central Kentucky.

Although income from stumpage, raw materials for the Tribal sawmill, and local employment are important to the Yakama people, the protection of natural resource conditions for their use by future generations is also important. Clean water, for both drinking and salmon habitat, is of extreme importance to the Yakama Nation. Anything that can enhance the quantity and quality of water coming off the forest is of great value. As the trustee for the Yakama Nation and the agency in charge of the timber sales program, the Federal Government, via the Bureau of Indian Affairs—Yakama Agency, likewise has a stake in the long-term productivity of the Yakama forest.

Future Needs

Our understanding of the impact of previous timber harvesting on Yakama soils and their productivity is mostly anecdotal. To develop a better understanding of the state of the soil resource, documentation is needed on the extent of actual compaction on the Yakama forest, initially targeting the sites of early timber harvest. We also don’t really understand how variable this compaction is or how severe it is by location. By building that information into a map layer, we could integrate those locations into silvicultural prescriptions for timber sales to trigger compaction amelioration work, such as subsoiling at a practical time (i.e., regeneration) in the life cycle of the affected stands.

More work is needed on the operational aspects of subsoiling at the local level. How can this remediation work be done most efficiently? When is the best time in the stand’s rotation to carry this out? Are there sites that may suffer from this logging-generated soil compaction that are not worth treating?

Given not only the forest health benefits, but also the benefits to the soil/water profile, subsoiling in these situations may be something to consider for a broader conservation portfolio.

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