Principles and Processes of Subsoiling in Forest Ecosystems

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Forest ecosystems east of the cascades in Oregon and Washington almost always function under less than optimum conditions. One or more stress factors may adversely affect physical, chemical, and biological processes. These processes in turn affect growth, determine biological presence, absence, and thrift. Some stress factors may be management related and thus may be minimized by careful planning of management activities and by post-harvesting rehabilitation treatments. This paper will focus on soil impacts which add to the stress experienced by both seedlings and residual trees.

Soil Compaction

An increase in soil density is achieved by a combination of pressure and vibration applied to the soil surface. Undisturbed forest soils normally have very low densities in the surface layers of soil. Geist and Strickler (1978) report that ash soils were found to have a mean bulk density of about 0.66 gcm^{-3} over the first 30 inches of soil. Basalt soils had a mean bulk density of 0.89 for the 0-15 inch layer and 0.94 gcm^{-3} for the 15 to 30-inch layer. These low densities are associated with high porosity and low soil strength. Allbrook (1986) reports that on a basalt soil on the Ochoco National Forest, the undisturbed soils had a bulk density ranging from 0.82 gcm^{-3} at a depth of two inches to 0.93 gcm^{-3} at a depth of 12 inches. Shear strength as measured by a shear-vane instrument ranged from 27 kPa at two inches depth to 33 kPa at 12 inches. Allbrook (1986) also reported that in a skid trail adjacent to the undisturbed site, "compaction resulted in increases in bulk density of up to 25%, in shear vane strength up to 157%, and in cone index up to 220% along with a decrease in pore space >10 nm of 69%. Bulk density, vane shear and penetrometer measurements were found to be highly correlated."

Froehlich, et al. (1980) have shown that crawler tractors, rubber-tired skidders, and torsion suspension machines used in logging all can compact soil over a wide range of soil moisture. The number of trips over the same trail is the major variable in estimating the increase in soil density. The increase in density is greatest near the surface and declines with depth. Most compaction is limited to the surface 18-inches of soil, and the first several trips cause the greatest increase in density per trip. It is estimated that the first five trips with a skidding machine may increase the soil density by about 70 percent of the density produced by 30 trips with the same machine.

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It is common to identify or rate logging equipment by the static of the machine on a smooth, level surface. However, the actual forces applied while a machine is in motion and loaded with a turn of logs may be two to three times greater than the static load (Lysne and Burditt, 1983).

Proportion of Area Compacted

Skid trails and landings commonly cover from 20 to 40 percent of a harvested area. Davis (1992) found that 66% of an ash soil site in eastern Oregon had a density of 20% or greater than the site in an undisturbed condition. The average density of the disturbed soil was 35% higher than the undisturbed average (0.73 gcm^{-3}). On an adjacent site the average density was 23% higher than undisturbed cobbly loamy soil (0.92 gcm^{-3}) without an ash cap. These two sites had been harvested by rubber-tired skidders followed by slash piling with crawler tractors. The results of Davis' work are higher than usual for a first-entry harvest, but not uncommon for multiple-entries of a harvest unit.

Howes, et al. (1983) have developed and tested a method for assessing physical conditions of soils after timber harvesting. One of the efforts to apply this method was completed by Sullivan. His examination of 24 harvest units in Eastern Oregon showed that 15 of the 24 units monitored had more than 20 percent of the area detrimentally impacted. Five additional units were found to have between 15 to 20 percent detrimentally impacted.

Effect of Seedling and Tree Growth

Research results from numerous studies around the world have reported a negative effect of soil compaction on seedlings and young tree growth. Reviews by Greacen and Sands (1980), Froehlich and McNabb (1984), and Ruark, et al. (1982) are examples of wide spread interest in the effect of soil compaction on the growth of many tree species.

The results of the numerous studies varies considerably, but virtually all show a decrease in some growth variable such as leader growth, total height, stem diameter, root extension, root mass, and others. Fewer studies have included larger trees, but of those reported, the effects on growth have been measurable. On a stand basis, the volume reductions range from 5% to 15%. Stem volume growth appears to be affected to a greater extent than tree height growth. Froehlich and Robbins (1983) found that a 26% increase in bulk density was associated with a 13% reduction in height growth and a 33 percent reduction in stem volume of 17-year-old stands of P. ponderosa in south central Washington. Similarly, Helms (1986) found that a 24% increase in bulk density of skid trails produced a 17% reduction in height growth and a 31% decrease in stem volume of 16-year-old P. ponderosa.

The persistence of the compacted condition as reported by these studies clearly indicates that this is a long-lasting problem. Skid trails formed during tractor logging 30 to 40 years ago are still evident today. Froehlich, et al. (1983) examined numerous skid trails in central Idaho and report that except for the surface few inches of some granitic soils, there is still not complete recovery 25 years after tractor logging.

Amelioration of Compacted Condition

We have searched the literature from United States and other nations to find the results of efforts to improve the soils where it was assumed that soil density was a limiting condition. The results are highly variable, but then the conditions being treated and the techniques used to ameliorate the compacted condition were also highly variable (Andrus, 1982). Of 12 treatments reported, they all showed some improvement in growth. Increases in height growth ranged from 8 to 73 percent. Clearly, some mechanical method to consistently ameliorate the compacted condition is desirable and apparently feasible.

After carefully observing the results of numerous efforts to loosen compacted skid trails, Andrus (1982) concluded that rock-rippers of several designs and various types of disks were not capable of adequately loosening the soil. The characteristics of adequate tillage that was desired included 1) the ability to fracture the full depth of the compacted layer, 2) an ability to fracture soil without plowing or turning over the soil layers, 3) the capability of tilling the full width of typical skid trails in a single pass, and 4) be able to accomplish good tillage at an acceptable cost. It was found that a prototype of a towed winged subsoiler came closest to meeting these goals.

Subsoiling Guidelines

The key to subsoiling is the fracturing of the compacted layer of soil by drawing a set of wings through the soil just below the compacted layer. As the wings slice through the soil, the compacted layer is lifted slightly and fractures as it flows over the back edge of the wings. The wings are mounted at the base of the curved, sharpened shank. Ideally, the wings should be adjustable to meet the wide variety of soil conditions encountered. The wings are up to 20-inches wide and mounted on the moveable shanks.

To be effective when tilling among stump, boulders, etc., the shanks need to be equipped with a tripping mechanism which automatically releases each shank individually when it encounters an obstacle. Areas with excessive slash, especially large debris, are difficult to subsoil, but the long shanks (- 3 ft.) and wide spacing (up to 4 feet) make it possible to subsoil most skid trails without slash piling. When the subsoiler is drawn by a crawler tractor equipped with a brush rake, occasional large debris accumulation can be piled during the tillage operation.

In summary, the goals of the original subsoiling tool is now achievable. Even severely compacted landings can be loosened to restore a large proportion of its growth potential if sufficient soil remains.

Operating Limits of Subsoiling

While subsoiling has proven to be effective in restoring a high level of tilth to compacted soils, there are conditions where tillage may not be appropriate. Subsoiling is not usually effective in controlling surface vegetation. Masses of bound soil tend to be torn into large chunks.

Shallow soils above a stony layer and sites with numerous large boulders have been tilled but the end product has not always been acceptable. Subsoiling should probably be limited to slopes under 40%. However, when tilling with a subsoiler on steep skid trails, the tractor may turn off of the skid trail at intervals to create effective water diversions. After creating a water diversion or water bar, the equipment is positioned several feet down the skid trail from the water bar and begins tilling again. This "discontinuous tillage" helps to assure that water cannot be routed down a steep section of skid trail to create an erosion problem. It is especially important to subsoil completely through the compacted layers to allow water to infiltrate into the slope rather than be concentrated on an impermeable compacted layer.

The soil and slope characteristics of eastern Oregon and Washington are highly variable. Good judgement is required by the subsoiling operator to avoid creating undesirable results such as deep furrows, up-turned boulders or operating in unexpected wet swales. Well written contracts and adequate training are a necessity for guiding both the equipment operator and the contract administrator.

Subsoiling Near Residual Trees

The research and field application of subsoiling has concentrated on reducing the compacted soil condition on skid trails and landings in clear-cut harvest units. Very little is known about the effect of subsoiling among residual trees. Of course, tilling within the root zone will cut the roots that are now in the compacted skid trail. If the compaction is severe, the existing roots will likely die or have reduced ability to function. If the trail is subsoiled, new roots will have to recolonize the site to replace the severed roots. The question then becomes, "will the new root growth made possible by the subsoiling allow greater tree growth than when the tree has a portion of its root system in compacted soil?" Some random digging in compacted skid trails several years after the trails were made showed that few live roots are present in the compacted layer. A co-operative research project has been developed between the Bureau of Land Management, Eugene District and Oregon State University, FE Department. This project will measure the effect of subsoiling adjacent to skid trails in a commercial thinning of young *Pseudotsuga menziesii* in western Oregon. Additional research is needed in P. ponderosa region.

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