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Shepperd, Wayne D. 1993. The Effect of Commercial Harvest Activities on Root Compaction and Suckering of Aspen. Western Journal of Applied Forestry 8 (2): 62-66.

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The Effect of Harvesting Activities on Soil Compaction, Root Damage, and Suckering in Colorado Aspen

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ABSTRACT. Logg*ing activities cause significant compaction on skid trails in commercial aspen harvest areas. Bulk density increases have persisted up to 12 yr following harvest. Compaction of the upper 0.2 m of an undisturbed mineral soil profile increased with each succeeding pass of a tractor where later passes contributed less to the total compaction effect. Compaction effects were similar under wet soil conditions. High organic matter content in the upper mineral soil profile may have decreased the magnitude of compaction effects. Root damage can occur without apparent disruption of the soil profile, especially to fine roots and those in saturated soils. West. J. Appl. For. 8(2):62-66.*

Aspen *(Populus tremuloides)* in the central Rocky Mountains of Colorado and southern Wyoming is routinely regenerated by coppice root sprouting following commercial clearfelling. In most cases, trees are removed using rubber-tired skidders. Schier et al. (1985) reported that concentrated skidding traffic can reduce subsequent suckering of aspen. Aerial and ground observations of aspen clearcuts over the past several years clearly show that some landings and skid trails have not regenerated (Data on file, Rocky Mountain For. and Range Exp. Stn., Ft. Collins, CO).

Root damage undoubtedly occurs in situations where skidding has resulted in deep ruts and major disturbance to the upper soil profile, or at landings where skidder blades are used to clear away logging debris. However, sucker regeneration is absent in some situations where no soil disturbance is apparent. Reduced suckering could be due to direct injury and death of roots, or to soil compaction that indirectly results in root mortality or prevents roots from suckering.

This study tested the hypothesis that soil compaction and associated root damage can be associated with poor suckering on skid trails and landings, even where no visible soil disturbance has occurred. One objective was to determine if differences in soil density and root development actually exist between nonstocked skid trails and regenerated portions of existing aspen harvest areas. Another objective was to identify the amount of vehicle traffic necessary to cause compaction or root injury in undisturbed wet and dry soil.

Methods

Harvest Study

Six aspen harvest units from 1 to 12 yr old were sampled in western Colorado to determine if compaction occurred as a result of commercial harvest and if root biomass was affected by vehicle activity. These areas had been logged by whole-tree skidding with rubber-tired equipment to roadside landings along a network of skid trails. Many of the skid trails were still identifiable as open paths through otherwise dense aspen sucker stands (Figure 1). At each site, a nonstocked skid trail was selected in the interior of a uniformly stocked portion of the cutover area. Although wheel tracks were sometimes present, sections of the skid trail that were rutted, or had been bladed, were not sampled. A series of 10 paired density/moisture determinations were made at 3 m intervals along the skid trail. One determination of each pair was taken within a tracked portion of the skid trail, the other was taken in an adjoining untracked area immediately outside the skid trail.

A CPN Corporation Model MC-3 Portaprobe nuclear density/moisture meter was used to obtain soil moisture and bulk density data. To minimize soil dry bulk density error from surface litter and moisture error from hydrogen-containing compounds, all sample locations were carefully cleared of vegetation and organic matter to a bare mineral soil surface. One-minute gamma penetration and neutron backscatter counts were taken at 0.2 m depth, and converted to density and percent

Figure 1. A nonstocked skid trail passing through a 12-yr-old aspen sucker population. The 3 m root trench is in the foreground. Note the lack of large near-surface aspen roots in this trench.

moisture content by the instrument's software (CPN Corporation 1985).

A 3 m trench was excavated to 0.2 m depth within each transect of density/moisture determinations, using a high-pressure water jet (Figures 1 and 2). The depth and diameter of each root larger than 4 mm intersecting a plane projected down the center line of the trench was recorded. Root density, diameter, and volume were estimated using equations derived by Van Wagner (1968). All aspen suckers within 1 m of each root trench were tallied and extrapolated to a ha basis.

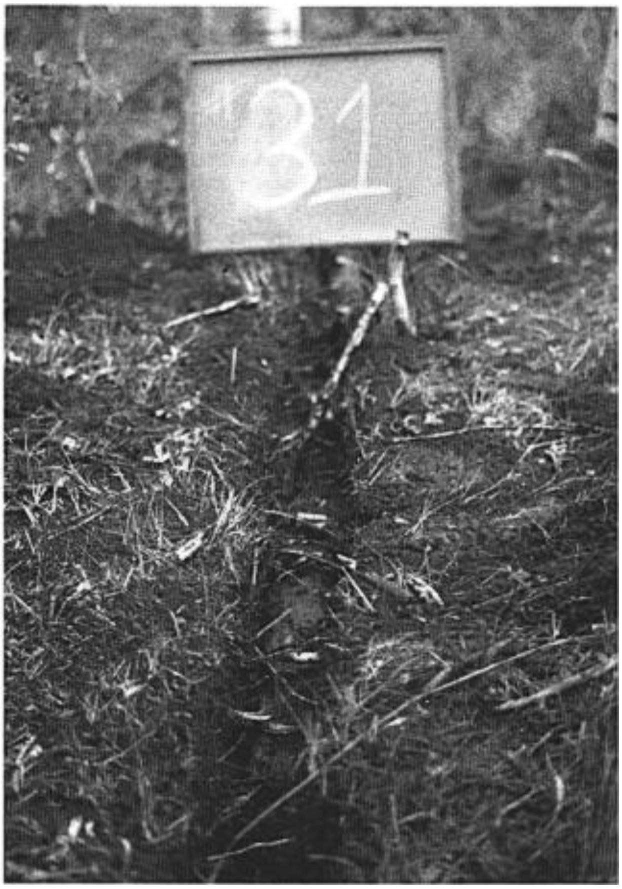

Figure 2. A root trench excavated away from a skid trail. Note the pieces of large, near-surface aspen roots exposed by this trench.

Tractor Study

The effects of equipment traffic on aspen soils and root systems were studied on the Fraser Experimental Forest in central Colorado. A 70-yr-old aspen clone located on a deep, mollic, Cryoboroll soil was used. This site is located at 2740 m elevation on a 1–5% easterly sloping broad alluvial fan.

Corridors 5 m wide were cleared through a uniformly stocked portion of the clone. Trees were felled by chainsaw, bucked, and removed from the site by hand. Care was taken to minimize walking in the cleared corridor and to avoid repeatedly stepping in the same area when it was necessary to enter the corridor. Soil pits were dug and moisture and bulk densities sampled at random points along the corridors to verify uniform pretreatment conditions.

A tractor with 0.43 m × 0.76 m rear tires, similar to those of a skidder, was weighted with 4500 kg on the rear axle then driven repeatedly over the same wheel tracks in the corridors for 1,2,4,8,16, and 32 passes. Each tractor tire exerted a static pressure of roughly 37,500 kg/m^2 on the soil surface, compared to 4,500 kg/m^2 for an 80 kg person with a 0.018 m^2 footprint. Two complete replications of the treatments were applied. Treatments within each replication were accomplished within a 2-hr period to ensure uniform soil moisture conditions.

Soil moisture and bulk density determinations were taken immediately following treatment using 1-min nuclear density/moisture meter counts with the density probe set at 0.2 m depth. Four paired determinations were made within the corridor cleared for each treatment. In each case a sample taken in the tractor wheel tracks was paired with one from an adjoining untracked position less than a meter away. The treatment effect was the difference in dry bulk density between each pair of treated and untreated samples.

The effects of wet soils on compaction and root damage were assessed by sprinkle-irrigating additional sections of the corridors at a rate of 29 liters/m^2 (29 mm precipitation equivalent) prior to treatment. Wet soil effects were intended to be tested at 4- and 32-pass treatment levels; however, the latter treatment was truncated at 24 passes to avoid miring the tractor.

Root collections were also made at each sample cluster. A 0.4 m wide, 0.2 m deep, and 0.5 m long excavation was made in a wheel track. Each aspen root found in the excavation was carefully removed, washed, and examined for breakage, abrasions, or other injury.

Results

Harvest Study

Logging impacted soil density, root survival, and the number of aspen suckers in skid trails compared to other areas in the aspen clearcuts. Dry soil density under skid trails averaged nearly 30% more than that of untracked areas. Skid trails contained less than a third of the roots found in untracked areas, with similar differences in root volume. Consequently, about ten times as many aspen suckers were found in untracked areas compared to skid trails (Table 1).

Table 1. Mean values and standard errors of data obtained in skid trails versus adjoining untracked areas of six aspen clearcuts in western Colorado. T-tests of sample differences (unequal variance) were significant for all variables ($P = 0.05$).

	Skid trails	Untracked
Soil Dry Density (kg/l)	1.37 (±0.028)	1.08 (±0.017)
Root density (no./3m × 0.2m trench face)	7.64 (±1.950)	25.36 (±2.743)
Root volume (m^3/ha)	6.04 (±2.046)	24.09 (±5.238)
Suckers (no./ha)	4,922 (±2,538)	47,819 (±9,185)

Dry soil densities of skid trails differed among the six clearcuts, but compaction did not appear to diminish with the time that had elapsed since harvest (Figure 3). Variation among the clearcuts was probably due to differences in soil type, equipment, and logging techniques used, and conditions at the time of harvest.

Too much time had elapsed to attempt any evaluation of root damage in the clearcuts, or whether the scarcity of roots in the skid trails was due to compaction or injury. However, it seems reasonable to assume the differences in root biomass and aspen sucker stocking were a result of harvest activities and not preharvest stand conditions.

Tractor Study

Dry densities of untreated aspen soils in the two replications ranged from 0.79 to 1.27 kg/l with mean of 1.098 kg/l and standard error of 0.014 kg/l. Soil moisture content at the time of treatment averaged 31.6% with a standard error of 1.19%. Average dry density after treatment ranged from 1.136 kg/l (a 2.5% increase) after a single pass of the tractor to 1.30 kg/l (a 18.4% increase) following 16 or 32 passes. Average change in soil dry density increased with each higher tractor-pass treatment (Figure 4) from 2–16 tractor passes, but did not increase further with the 32-pass treatment.

The observed change in density was quite variable in all treatments (Figure 4). Part of this was due to variation in hydrogen atom concentration measured by neutron backscatter counts in adjoining treated and untreated sample pairs. This effect may have been due to differences in soil moisture content, or different amounts of hydrogen containing organic compounds (roots, duff, charcoal etc.) in the soil profiles of the adjoining sample plots. In either case, the percentage difference in hydrogen atom concentration between treated and untreated sample pairs (*HDIFF*) was inversely related to the difference in dry density observed between the samples (*DRYDIFF*). This effect accounted for about 40% of the overall variation in density:

$$DRYDIFF = 0.1438 - 0.0131425*HDIFF$$

($r^2 = 0.39, P < 0.00001$)

Analysis of changes in soil dry density from the paired measurements using *HDIFF* as a covariate indicated a highly significant increase in density was produced by 32 passes of the tractor. Average soil density had increased by nearly 25% at this treatment level. Polynomial contrasts indicated a strong relationship between compaction and each increasing level of treatment.

Regression analysis was used to quantify these effects. First, the linear relationship between *HDIFF* and *DRYDIFF* was used to calculate an adjusted change in dry density for each of the 48 paired samples. A nonlinear power function model was fit to the resulting curvilinear pattern of the adjusted data yielding a prediction of change in adjusted density given number of tractor passes.

This model was still inadequate because it did not account for possible interactive effects between HDIFF and the number of tractor passes. To remedy this, parameters from both models were algebraically combined and refit to estimate *DRYDIFF* given *HDIFF* and the number of tractor passes (*PASSES*):

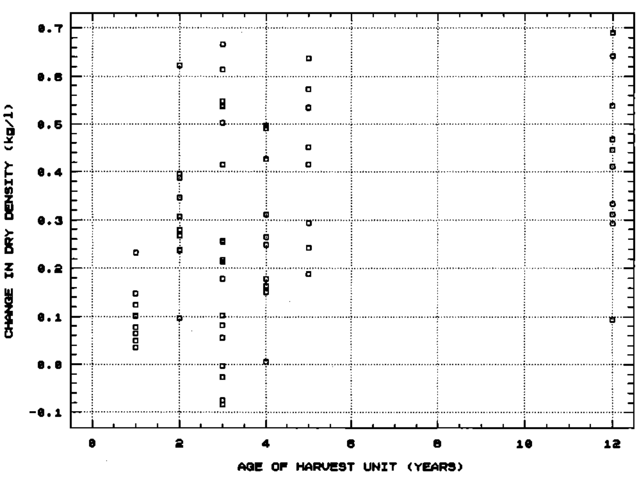

Figure 3. Observed density increases in the skid trails of aspen harvest units plotted against the number of years since logging.

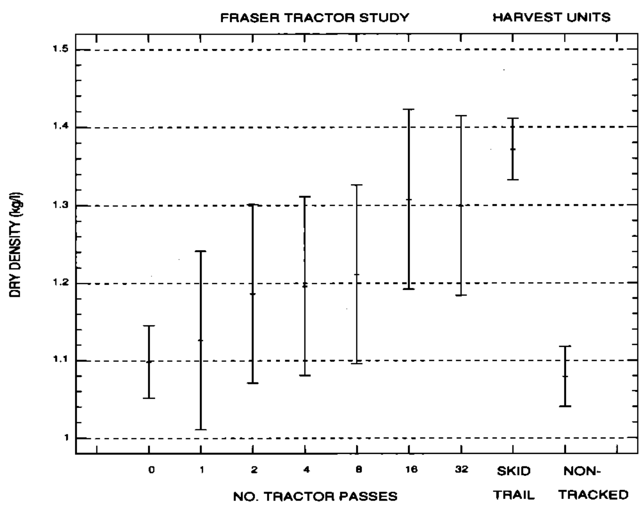

Figure 4. Average soil dry bulk density (with 95% confidence intervals) of control and six tractor pass treatment levels in the Fraser study plotted with similar data obtained from skid trails and nontracked areas in existing aspen clearcuts. Densities of the untreated control in the tractor study were similar to those observed in untracked portions of the clearcuts. Although the tractor was not loaded with logs, maximum densities in the tractor treatments were similar to those observed in skid trails.

$$DRYDIFF = (PASSES^{0.0472834}) - (0.013889*HDIFF) - 0.9421$$

(Est. $r^2 = 0.65$, $SE = \pm 0.073$ kg/l)

This model accounts for differences in hydrogen atom concentration of the soil under paired plots and provides a more accurate estimate of expected average treatment effect (Figure 5).

The irrigation treatments did not significantly affect the increase in dry density that resulted from the tractor treatment. Average dry density increased 0.16 kg/l in the irrigated 4-pass treatment and 0.10 kg/l in the nonirrigated 4-pass treatment. Dry density increases in the irrigated 24-pass treatment averaged 0 26 kg/l and those in the 32-pass nonirrigated treatment averaged 0.24 kg/l.

Effect of Compaction Upon the Aspen Root System

Only occasional damage was observed to aspen roots in the upper soil profile, after 1–8 tractor passes. The dense mat of vegetation, forest floor debris, and the intertwining roots of understory plants seemed to cushion and protect aspen roots from damage. However, at the 16- and 32-pass treatment levels, 26 and 48% of the root samples were damaged, respectively.

The most common type of damage (57% of all damaged roots) was the stripping of small diameter (< 2 mm) roots from larger lateral roots as the tractor repeatedly passed over the root mat at the higher treatment levels. Other classes of damage included broken roots (22%), skinned roots (17%), and cracked roots (4%).

Root damage was more extensive in the irrigated treatments. Although these soils did not compact to any greater extent than the nonirrigated soils, they were very plastic. Some roots in the 4-pass treatment were broken or skinned as the root mat was pressed into the underlying soil. Few intact roots remained at all in the 24-pass treatment because the tractor completely penetrated the upper 0.2 m of the soil profile.

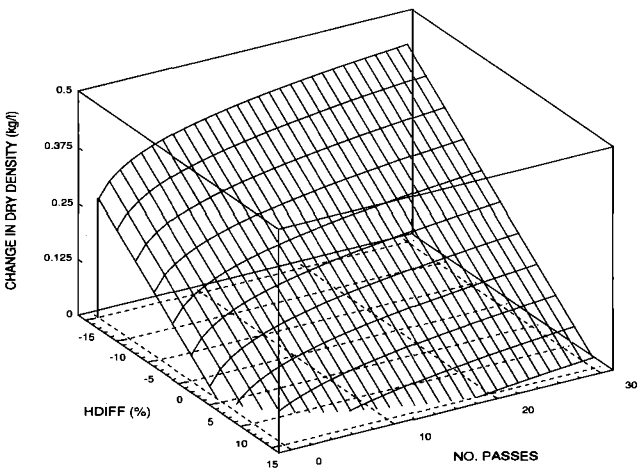

Figure 5. The response surface of expected increase in soil dry density given the variation in atomic hydrogen concentration between adjoining paired treated and untreated samples and the number of tractor passes applied. Ninety-five percent confidence intervals for the model lie within ± 0.02-0.07 kg/l of the plotted response surface. Variation in soil moisture and organic matter content represented by the atomic hydrogen concentration strongly influences the compaction caused by a given number of tractor passes.

Discussion

Although the design and objectives of these two studies were quite different, the results are consistent. Average dry soil densities in the untracked portions of the commercially clearfelled harvest units were not significantly different than those observed in the untreated measurements in the Fraser Tractor Study (Figure 4). Although skidders may have made more than 32 passes over the trails and were loaded with logs, skid trail densities in the clearcuts were not significantly greater than those observed after 32 tractor passes. Many skidders also weigh more than the tractor used in the this study, especially with a full turn of logs suspended behind them.

Root damage observed in the excavations at Fraser and the decreased numbers and volumes of roots under skid trails in the harvest units both indicate that damage to lateral aspen roots can occur without apparent disruption of the upper soil profile. Fine roots and those occurring in wet soils appear most susceptible to vehicle damage. Loss of these fine roots would undoubtedly decrease water absorption capability and further stress root systems disrupted by timber harvest. The consequences of compaction-related damage to the lateral roots of aspen is evidenced by the large differences in sucker stocking between skid trails and untracked portions of the harvested areas. Skid trails not only thwart aspen regeneration from existing roots, but apparently act as a barrier to a future phalanx-like (Lovett Doust 1981) spread of the clonal root system.

The response model in Figure 5 illustrates the dramatic effect that hydrogen ion concentration in the soil can have on the potential compaction caused by logging equipment. The differences in hydrogen concentrations measured by the nuclear gauge in this study may be due to differences in either the amount of water or organic matter in the soil profile. Unfortunately, soil samples were not assayed to determine organic matter variability throughout the study site, because this effect was not anticipated in the study design.

However, it is likely that both soil moisture and organic matter could vary from place to place in an undisturbed forest soil containing tree roots, charcoal, decaying wood, etc. Their presence would locally affect soil porosity, bulk density, and water holding capacity by displacing volume otherwise occupied by minerals. A reduction in organic matter would reduce the hydrogen concentration and increase the bulk density of the soil and explain the inverse relationship between hydrogen concentration and density.

In effect, this relationship supports the reasoning that the amount of organic matter in the soil profile can have a pronounced effect on the soil compaction caused by a vehicle passing over the forest floor. The response surface shown in Figure 5 has utility in any situation where a paired plot approach is used to evaluate the compaction of undisturbed forest soils and, with calibration, might be used to predict the consequences of planned management activities.

The results of these two studies are also consistent with research done elsewhere. Vora (1988) reported bulk density differences of 0.11–0.35 kg/l between skid trails and off-trail locations. Helms and Hipkin (1986) found a 30% increase in soil bulk density in skid trails.

The lack of observable recovery from compaction within the 12-yr age range of the clearcuts studied here is also not surprising. Compaction effects have been reported to persist for as long as 25 yr in Idaho (Froehlich et. al 1985) and 40 yr in California (Vora 1988).

The nonlinear increase in density following repeated tractor passes is similar to that observed by Froehlich et al. (1980) in California. Using a nuclear density instrument, they studied compaction effects from repeated round trips of loaded skidders that returned empty. Several of their findings were similar to the results of the Fraser study. About 60% of the increase in bulk density occurred during the first six round trips. Increases in bulk density below 0.3 m were negligible, and there was no relationship between soil moisture content and compaction.

The concern for the effect of compaction on aspen root condition and subsequent sucker survival is also valid in the management of other species. The upper 0.2 m of the soil profile is the initial rooting zone of both natural and planted conifer seedlings. Increases in density within this zone affect air permeability, soil porosity, and hydraulic conductivity (Froehlich et. al 1980). The stresses imposed by these factors affect root penetration, respiration, and water relations and can result in reduced seedling growth on compacted areas (Helms and Hipkin 1986). Where partial cutting is used to harvest a stand in two or more entries, physical injury to existing roots would subject surviving trees to even more stress. Reduced growth in residual trees following logging has also been attributed to compaction and soil displacement (Clayton et al. 1987).

These potentially long-term impacts of skidding activities in aspen harvest areas necessitate careful consideration of how and when these areas should be harvested. Significant compaction can occur regardless of soil moisture conditions, and can result from a relatively few tractor passes. Soil moisture content can greatly affect the amount of physical damage to lateral aspen roots from a passing tractor.

The easiest way to minimize compaction and root damage under precipitation regimes in the southern Rockies would be to consider fall and winter harvesting when soils are dry, frozen, or covered with snow. Areas harvested under these conditions exhibit very good stocking with little evidence of skid trails in the regenerated sucker stands. Otherwise, use of skidding equipment should be restricted to skid trails and halted when soils are wet to minimize the impacted acreage and avoid unnecessary damage to lateral root systems.

Successful long-term management of the extensive aspen resource in the central Rocky Mountains will require implementation of these and other measures. Until then, concern about the effects of soil compaction in commercially harvested aspen stands is warranted.

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