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Soil Response to Skidder Traffic as Indicated by Soil Stress Residuals

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Abstract

Ground-based timber harvesting systems are common throughout many regions of the United States. Machine movements during harvesting can negatively impact soils leading to increased erosion and soil compaction. This is especially true of skid trails that have been established to facilitate tree removals. Several techniques have the potential to reduce soil compaction including corduroying skid trails with slash or using equipment exerting lower ground pressures. Typical measures of compaction include bulk density and mechanical resistance. Bulk density measurements require destructive sampling and are time consuming while mechanical resistance measurements are highly variable due to soil type, moisture content, and operator consistency. A research project was designed to accomplish two objectives: 1) compare and contrast conventional measures of soil compaction with a newer technique using soil stress residuals, and 2) compare the effects of slash versus bare soil on skid trails trafficked by a rubber-tired grapple skidder and a dozer. The project was conducted within an upland hardwood/pine stand in the Ridge and Valley physiographic region. This paper discusses the results from the new technique using soil stress residuals to account for changes in soil properties. This technique provided results with less intensive setup and analysis than conventional methods.

Keywords. *Forestry, forestry machinery, skidding, soil compaction, rubber-tired machine, tracked vehicles.*

1. Introduction

The forest industry is growing in the Appalachian Mountain region and harvesting is occurring more often and impacting more forest lands. Despite intensive research on many aspects of timber harvesting in the Appalachians, knowledge regarding changes in soil characteristics due to harvest are limited (Wang, et. al, 2007). Ground-based systems are commonly used in this region and the southeastern United States for timber harvesting. These systems rely on equipment to fell, transport, and process timber (Simmons, 1979). Forest machinery is heavy and traffics a portion of mechanically harvested sites. Depending on soil characteristics and site conditions, forest machinery can significantly change soil properties. It is often desirable to characterize the change in soil properties before and after a harvest. After soil series and moisture content are determined, traditional soil properties including bulk density, mechanical resistance, porosity, and saturated hydraulic conductivity can be analyzed (Greacen, et. al, 1980). Bulk density sampling is destructive and requires work in the field and the lab. Mechanical resistance is labor intensive in the field and results are often variable depending on machine operator and location in the soil surface.

To combat the drawbacks of conventional sampling methods, a new method to capture changes in soil properties was tested for application in the field. A non-destructive, simple method for quickly gathering large quantities of high quality data was created by Turner, et. al in 2001 and is referred to as an “AgTech sensor.” The AgTech device and other similar instruments have been used in precisely controlled environments to characterize changes in soil properties, but not in the field. A variation of the AgTech sensor was constructed and used at an active logging site in the Ridge and Valley province of Virginia to compare changes in soil properties. The AgTech sensors were part of a larger project dealing with soil compaction that was carried out and this paper will discuss the results found specifically for the AgTech sensors. The main objectives of the research were: 1) determine if the AgTech sensors could be readily and feasibly deployed in an active logging area, 2) determine if the sensors would yield quality information even though the installation area is not precisely controlled, 3) compare a rubber-tired skidder to a metal-tracked dozer in terms of soil stresses, 4) compare the effectiveness of slash, a BMP cover treatment, to bare forest floor, and 5) compare the changes in soil properties resulting from various numbers of passes of machinery.

2. Methods

2a. Field Site

A harvest was conducted on the Fishburn Forest, Virginia Tech’s research forest, in spring 2015. The study site was located adjacent to a log landing that provided an ideal area for data collection without impacting harvest operations. The site was located on a continuous 7% grade atop a small ridge. The forest was an upland oak system consisting of chestnut, white and scarlet oaks with some white pine interspersed. The forest floor inside the study area was not disturbed during initial project installation. The study site is located on a Berks-Clymer complex where soils are silt loam in texture, moderate to well drained, and shallow in depth containing many coarse fragments. Depth to shale or sandstone bedrock is shallow; 27 – 49 inches (USDA, 1985).

The study site was located next to a ridge road in an area of un-trafficked forest. Trees and brush were cut and removed by hand creating three travel lanes. Equipment was not permitted to enter the study area during preparations to ensure the first two sets of measurements were representative of zero and one machine pass. The site measured 120 ft by 40 ft and consisted of two travel lanes and an adjacent return lane. Each travel lane was divided into six 20 ft long by 20 ft wide segments. The rubber-tired skidder (skid) was assigned to one lane and the tracked skidder (dozer) was assigned to the other. Machinery used the ridge road as a return lane to exit the study area and line up for another pass. Within each travel lane, three segments were assigned to be left bare, and three segments were covered with slash. Slash was considered to be woody debris left on site and was piled to an initial depth of ~ 3 ft. Slash is a commonly used best management practice to reduce soil disturbance. It provides cover and weight distribution aiding in machinery movements (VDOF, 2011). This setup allowed for comparison of machine, cover type, and number of machinery passes on soil quality. Figure 1 shows the site layout with arrows representing travel directions. Each block is 20 ft by 20 ft, and machine type is identified by “Skid” or “Dozer,” numbers represent segments, and cover type is “Bare” or “Slash.”

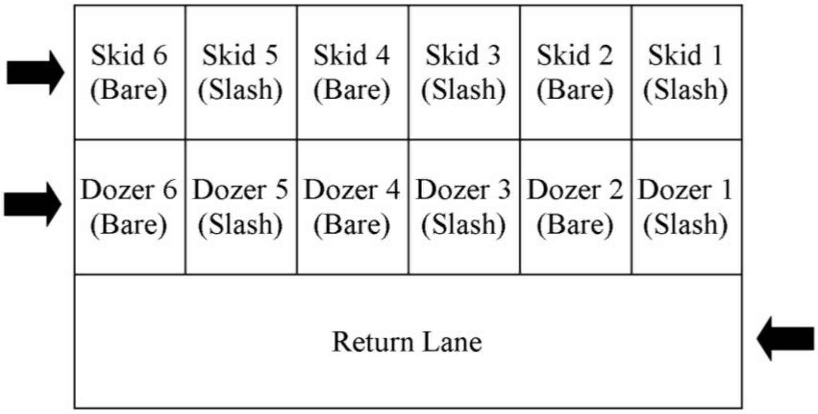

Figure 1. Study site layout; arrows represent travel direction, "Skid" or "Dozer" represent machine type, numbers represent segment, and "Bare" or "Slash" represent cover type.

Data collection was divided into two batches with one batch for the skidder and another for the dozer. An AgTech sensor was deployed in the center of the outer track in each segment of the travel lanes at a depth of 5 in. The AgTech sensor was positioned such that there were no stumps, rocks, or roots present to interfere with measurements. The sensor was also located away from other areas subject to sampling during the experiment. Figure 2 below shows a detail of one of the 20 ft by 20 ft segments.

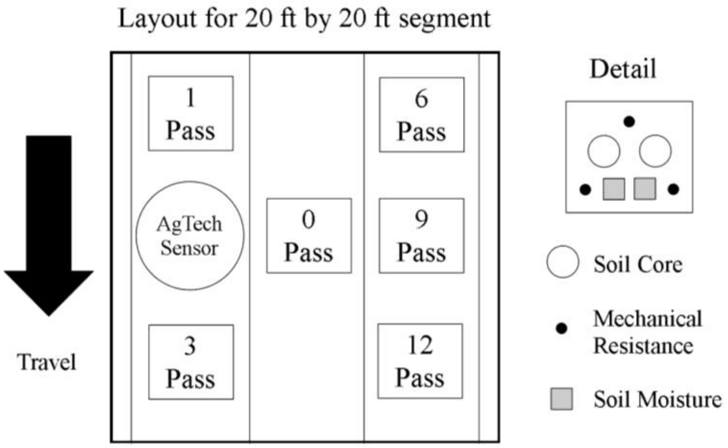

Figure 2. AgTech sensor location in each 20 ft by 20 ft segment relative to other soil samples.

2b. AgTech Sensors

Data collection equipment was constructed using initial designs from (Turner, et. al., 2001) combined with an on-site trial. A 1 in diameter bulb was connected to a standard hydraulic hose using a nipple and clamp. The hydraulic hose was connected to an Omega pressure transducer. The pressure transducer was paired with an Omega data logger and battery to make a self-contained data collection system. The bulb, hose, and open end of the pressure transducer were filled with water and bled until no air was left in the system. The electronic components were housed in small boxes, to protect them from debris and damage, while the hose and bulb were left exposed for installation in the soil profile. A jig and auger were used to drill a hole slightly larger than the bulb into the soil profile to a known depth and location. A piece of small diameter low pressure PVC pipe was cut in half and used to insert the bulb and hydraulic hose into the soil profile. The flanged end was large enough to hold the bulb and the remaining straight section of pipe safely guided the hose into the augured hole. The PVC pipe was removed from the hole leaving only the bulb and hose in the profile.

A pilot project was carried out using six sets of sensors buried at different depths with two lengths of hydraulic hose, 5 and 10 ft. The sensors were subjected to six passes of machinery, and analysis of this initial data led to the choice of a 5 in buried depth paired with a 10 ft hydraulic hose. This combination provided the best results for our specific soils and location. Figure 3 depicts the jig and small diameter auger used to locate the bulb at a known depth and location. Figure 4 shows how the bulb and hydraulic hose were placed into the soil profile.

Figure 3. Auger and jig setup used to install bulb and hose at known depth and location.

Figure 4. Visual of hydraulic hose, bulb, and box used to house electronic components.

2c. Machinery

The skidder is vital to ground-based timber operations and makes the most passes through the harvest area. The skidder is utilized on job sites regardless of the method of felling because it is the machine that transports cut timber from the woods to a landing or collection point (McGonagill, 1978, Simmons, 1979). A small dozer was used to represent a tracked skidder and a grapple skidder was used to represent a rubber-tired skidder. It was impractical to actually pull a complete turn of logs through the course because of disturbing the slash and contaminating the bare treatments. To replicate loaded passes, a weight constructed of metal pipe filled with concrete, was suspended from the dozer's fire plow and the skidder's grapple. The goal was to simulate the butt weight of a turn of logs. The weight was 1412 lb and suspended with 60 lb of chain and binders. It was assumed that the ground supports the majority of the weight of a turn of logs and the machinery only supports a finite amount of each turn.

The dozer was a 1986 John Deere 450E with a fire plow attached to the rear. The dozer was equipped with standard metal tracks. Each track measures 82.2 in long and 18.0 in wide. Both tracks result in a contact area of 2959 in^2. The standard dozer has an operational weight of 15350 lb. These specifications result in a ground pressure of 5.2 psi (John Deere, 1985). For the actual measurements in the study, the fire plow, weight, and bindings were added. The 450E weighed 17500 lb including the fire plow. This combined with the suspended weight resulted in a total weight of 18972 lb and a ground pressure of 6.4 psi. Figure 5 below depicts the bulldozer with attached weight.

The wheeled skidder was a 2014 Caterpillar 525D with dual arch grapple, winch, and front blade. The skidder was equipped with single Firestone Forestry Special size 30.5 L – 32 (20) rubber tires. From published Firestone specifications (Bridgestone Americas Tire Operations LLC, 2015), each of the four tires has a flat plate area of 378 in^2. Total ground contact area supporting the machine is 1512 in^2. From the Carter Caterpillar dealership, the 525D skidder used in the study weighed 45249 lb (Caterpillar, 2014). The addition of the suspended weight brings the total equipment weight to 46721 lb. This results in a ground pressure of 30.9 psi. Figure 6 shows the CAT 525D skidder with the attached weight.

Figure 5. John Deere 450 Dozer.

Figure 6. CAT 525D skidder.

2d. Data Analysis

Following each batch of data collection (12 passes for each machine), text files containing soil stress residual data were downloaded using OM-CP Data Logger Software (Omega Engineering Inc., 2013). Because data loggers were launched prior to beginning the experiment and not stopped immediately following each batch, the start and end times for each set of passes were noted during the field trials. This aided in locating the desired data within each file. The data loggers were setup to collect data every three seconds resulting in high resolution datasets.

The text files were plotted and graphically analyzed with time as the independent variable and bulb response as the dependent variable. The data sets consisted of flat plateaus when there was no traffic and distinct peaks when the machinery passed over the bulb location. The peaks served as clear boundaries between sets of passes. An average value was calculated for each plateau and compared to the initial, zero pass, soil conditions. The difference in magnitude of the plateau values shows how much the soil was deformed. This measurement of soil can be thought of as an elastic band that is being stretched and then loosened. Initially the soil exerts a known pressure on the bulb, the bulb is then run over, a peak, and the soil returns to a new equilibrium. The difference of the new equilibrium from initial shows how much the soil was changed.

JMP statistical software was used to organize and analyze data (SAS Institute Inc., 2012). As this is a preliminary review of the data, mean values of parameters were used. The experiment was designed to allow for separate analysis of each type of machinery for changes in soil stress residuals. Raw values for each set of residuals were compared to the initial conditions yielding the magnitude and direction of change. This method of analysis accounted for initial variation of plots and allowed for meaningful data comparisons due to passes.

3. Results and Discussion

The rubber tired skidder and dozer had an impact on the visual appearance of the soils and cover of the experimental site. The skidder created deep ruts with obvious soil displacement whereas the dozer did not. Slash treatments were compressed and limbs and branches were broken forming a mat. Results are presented separately for the skidder and the dozer because of the major difference in magnitude of weight.

An objective of the study was to determine if cover type on an overland skid trail impacts changes in soil characteristics due to traffic. The average change in soil stress residuals were compared to initial conditions for the entire 12 passes observed. Slash cover had a major effect on the skidder trials. Bare treatments experienced an increase of 468.92 μA while slash treatments only increased by 155.25 μA. Slash cover was three times more effective than bare forest floor at preventing major changes in soil stress. The same results did not apply to the dozer. The slash treatments experienced more change in soil stress than the bare, however the difference is not of a large magnitude. Cover did not have a major effect on changes in soil quality for the dozer. Results are summarized in Table 1.

Table 1. Average results for comparison of cover type by machine for soil stress residuals over the entire 12 passes; reported values are changes from initial conditions.

Machine	Cover	Soil Stress Residual
		μA
Skidder	Bare	468.92
	Slash	155.25
Dozer	Bare	285.80
	Slash	299.97

The effect of the number of machinery passes on soil stress was analyzed for both types of machinery regardless of cover type. For each set of passes for each machine, the average change in soil stress from initial conditions was calculated. The skidder experienced a major change of 298.46 μA after a single pass. There was a steady increase to a stress of 413.85 μA after four passes. For the remainder of the machinery passes, the skidder maintained a consistent value of about 320 μA. The dozer did not experience the same major increase after a single pass. A single pass resulted in an increase of only 91.40 μA. Although each successive pass caused an increase in soil stress, the dozer did not reach the level of stress caused by the skidder's initial pass until between passes four and five. Despite a few fluctuations, the dozer showed a steady increase for all twelve passes with a final soil stress of 484.24 μA. This magnitude of change is higher than that of the skidder after twelve passes. Table 2 contains data related to machinery passes.

Table 2. Results for soil stresses based on machine and number of passes; values reported are changes from initial conditions.

Machine	Passes	Soil Stress Residual
		μA
Skidder	0	0.00
	1	298.46
	2	363.35
	3	377.10
	4	413.85
	5	310.45
	6	295.61
	7	318.44
	8	318.57
	9	354.83
	10	347.57
	11	357.50
	12	301.39
Dozer	0	0.00
	1	91.40
	2	116.84
	3	154.82
	4	269.41
	5	309.11
	6	390.16
	7	381.03
	8	390.61
	9	370.20
	10	405.58
	11	444.09
	12	484.24

Changes in soil stress were compared to cover type and the number of passes for each machine. For the skidder with bare treatment, there was a significant change of 406.56 μA after one pass. Soil stresses continued to increase to 667.75 μA after four passes. Soil stresses did not exhibit a clear pattern after four passes fluctuating at a value around about 490 μA. The magnitude of change associated with the slashed treatments for the skidder was substantially less than that of the bare. After a single pass soil stress residuals were increased by 190.35 μA. Soil stress residuals reached a maximum of 194.27 μA after two passes and fell to 153.54 μA after three passes. Values continued to decrease to 121.06 μA after six passes. For passes six through twelve the skidder with slash treatment steadily increased to about 190 μA. Table 3 below shows the effect of both the number of passes and cover on soil stress residuals for the skidder.

Table 3. Results for soil stress residuals based on machine, number of passes, and cover type; values reported are changes from initial conditions.

Machine	Passes	Cover	Soil Stress Residual
			μA
Skidder	0	Bare	0.00
	1	Bare	406.56
	2	Bare	532.43
	3	Bare	600.67
	4	Bare	667.75
	5	Bare	480.20
	6	Bare	470.16
	7	Bare	485.91
	8	Bare	477.71
	9	Bare	536.28
	10	Bare	497.52
	11	Bare	525.30
	12	Bare	415.49
	0	Slash	0.00
	1	Slash	190.35
	2	Slash	194.27
	3	Slash	153.54
	4	Slash	159.96
	5	Slash	140.70
	6	Slash	121.06
	7	Slash	150.97
	8	Slash	159.42
	9	Slash	173.39
	10	Slash	197.63
	11	Slash	189.71
	12	Slash	187.28
Dozer	0	Bare	0.00
	1	Bare	52.50
	2	Bare	89.16
	3	Bare	132.06
	4	Bare	231.88
	5	Bare	293.10
	6	Bare	370.96
	7	Bare	366.91
	8	Bare	375.70
	9	Bare	378.92
	10	Bare	438.33
	11	Bare	483.35
	12	Bare	502.54
	0	Slash	0.00
	1	Slash	130.29
	2	Slash	144.52
	3	Slash	177.58
	4	Slash	306.94
	5	Slash	325.13
	6	Slash	409.37
	7	Slash	395.14
	8	Slash	405.52
	9	Slash	361.47
	10	Slash	372.84
	11	Slash	404.83
	12	Slash	465.94

The dozer did not show the same trend seen in the skidder data. For bare treatments it took the dozer nine to ten passes to reach the level of disturbance caused by the skidder after a single pass. Soil stress values increased to 52.50 μA after a single pass for the dozer with bare treatments. Stresses continued to increase with each additional pass to a maximum of 502.54 μA after twelve passes. The slash treatments experienced an initially higher impact on soil stresses after a single pass reaching 130.29 μA. Soil stresses steadily increased to a maximum of 409.37 μA after six passes. A decrease was witnessed from passes seven through ten, but the overall trend showed a consistent value of about 390 μA. After twelve passes with slash treatment, the dozer reached a soil stress of 465.94 μA. Table 3 on the previous page shows the soil stress data associated with dozer based on cover type and number of passes.

4. Summary and Conclusions

In all cases, the trafficking associated with overland skidding increased the soil stress residuals. This increase was in the form of μA because of raw data values, but represented a deformation beyond the soil's ability to rebound to initial conditions after trafficking. Soils were changed to a more compacted state after traffic. Some of the results witnessed during the experiment were expected while others were not.

From a visual standpoint, ruts were present following the study for both pieces of machinery. The grapple skidder created deep ruts with obvious soil movement and displacement. The dozer created shallow uniform ruts. Jansson et. al (1998) reported the same types of rutting associated with wheeled versus tracked machinery. Wang et. al (2007) noted that under wet conditions, or in cases where soil moisture is increased, heavy machinery may displace rather than compact soil. This phenomenon was noted by Sheridan (2003) in which traffic increased soil water content leading to soil displacement rather than continued compaction.

When soil stresses were analyzed over the entire twelve passes, interesting and some unexpected relationships between bare and slash cover became apparent. For the skidder, slash was three times more effective than bare treatments at protecting the soil from changes in soil stresses. The same trend did not occur for the dozer. There was not a major difference do to slash cover, but slashed treatments fared worse than bare in terms of increased soil stresses after traffic.

Research is needed to understand the role of slash as a means of soil protection. Slash is an encouraged method for protecting exposed soils from erosion (VDOF, 2011). Although slash provides cover, this study showed that slash does not necessarily alleviate the effects of traffic on the underlying soil profile. Results that showed slash as inadequate for soil protection may be influenced by project design and installation. Wood et. al (2003) found that common failures associated with slashed roads were caused by large diameter slash and slash placement. Large logs can be forced into the soil surface. These results were common after heavy traffic or during turning. Slash roads should be constructed of evenly distributed small diameter material. Eliasson et. al (2007) had similar findings to our experiment. Although slash was expected to reduce rutting and prevent compaction, they found no significant relationship between slash cover and reduced changes in soils. They suspected that excess traffic leads to breakage, thinning, and ultimate failure of slash roads. Wood et. al (2007) found that slash reduced negative changes in the top soil consistent with our findings for the skidder.

Machinery passes were significant in terms of changes in soil quality. The skidder caused substantial change in one pass whereas it took the dozer four to five passes to reach the same disturbance level. This is most likely a result of the difference in machine weight. When cover is analyzed at the same time as passes, the skidder shows major differences. For bare treatments there was an increase to a peak value of disturbance followed by a decline and leveling out. For slashed treatments there was an increase of lesser magnitude to a near constant value. Cover and passes did not influence the impact caused by the dozer. Both treatments saw steady increases with successive passes.

Even though direct comparison cannot be made between machines because of the difference in weight, it was striking that soil stresses could be changed as much by the dozer as the skidder. In fact, regardless of cover type, the dozer had more of an impact than the skidder after twelve passes. Researchers including Sheridan (2003) have found this. They did not find major differences between rubber-tired and tracked vehicles. Despite the major differences in ground pressure, tracked vehicles are subject to higher amounts of vibration. The larger contact area with vibration actually works to tamp the soil or cover leading to changes in soil properties.

The AgTech sensors were successfully implemented in the field and were used to gather meaningful data. The sensors need to be tested in more forest types and under different soil conditions to better understand what soil properties are best represented by the soil stresses. The setup needs to be analyzed to determine if the current bulb, hose, and pressure transducer configuration is the most efficient.

5. References

Bridgestone Americas Tire Operations LLC. (2015). Forestry Special with CRC (WTP). Bridgestone, United States. Available online at: http://commercial.firestone.com/en/agriculture/product/for-spec; accessed July 2015.

Caterpillar. (2014). 525D/535D/545D/555D Wheel Skidders. Caterpillar, United States. Available online at: http://s7d2.scene7.com/is/content/Caterpillar/C10307331; accessed July 2015.

Eliasson, L. and I. Wasterlund. (2007). Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil. *Forestry Ecology and Management*. 252.

Greacen, E. and R. Sands. (1980). Compaction of Forest Soils: A Review. *Australian Journal of Soil Resources*, 18.

Jansson, K. and J. Johansson. (1998). Soil changes after traffic with a tracked and a wheeled forest machine; a case study on a silt loam in Sweden. *Forestry*, 71(1).

John Deere. (1985) 450E Long Track Bulldozer Specifications. John Deere, United States. Available online at: http://murphyused.com/images/specs/99.pdf; accessed July 2015.

McGonagill, Keith L. (1978). *Logging Systems Guide*. Juneau, Alaska: Dept. of Agriculture, Forest Service, Alaska Region.

Omega Engineering Inc. (2013). OM-CP Data Logger Software 4.1.5.1.

SAS Institute Inc. (2012). JMP Pro 10.0.2.

Sheridan, G. 2003. A comparison of rubber-tyred and steel-tracked skidders on soil physical properties. *Australian Journal of Soil Research*, 41.

Simmons, Fred C. (1979). *Handbook for Eastern Timber Harvesting*. Broomall, Pa: U.S. Dept. of Agriculture, Forest Service, Northeastern Area, State & Private Forestry.

Turner, R. and R. Raper. (2001). Soil Stress Residuals as Indicators of Soil Compaction. ASABE Paper No. 01-1063. Sacremento, California: ASAE.

United States Department of Agriculture. Soil Conservation Service, and Virginia Polytechnic Institute and State University. (1985). *Soil Survey of Montgomery County, Virginia*. Washington, D.C.: The Service.

Virginia Department of Forestry. (2011). *Virginia’s Forestry Best Management Practice for Water Quality*. Fifth edition.

Wang, J., C. LeDoux, and P. Edwards. (2007). Changes in Soil Bulk Density Resulting from Construction and Conventional Cable Skidding Using Preplanned Skid Trails. *Northern Journal of Applied Forestry*, 24(1).

Wood, M., A. Moffat, and P. Carling. (2003). Improving the Design of Slash Roads Used to Reduce Soil Disturbance During Mechanised Harvesting of Coniferous Forest Plantation in the UK. *International Journal of Forest Engineering*, 14(1).