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Rates of Soil Compaction and Compaction Recovery in Areas of Logging Disturbance

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ABSTRACT

Soil compaction is one form of disturbance caused by large machinery operating on a landscape, especially in the forestry industry. This research aimed to discover how different levels of activity affected soil compaction and how compacted soils change over a three year period. Three sites were chosen to test rates of soil compaction; bare soil, grass field, and hardwood forest, with five treatments per site (0 passes, 1 pass, 2 passes, 3 passes, and 4 passes). Three sites were chosen to test rates of soil compaction recovery; a site logged one year ago, one logged two years ago, and one logged three years ago, with two treatments (off-trail and on-trail). Hypothesis 1 is that the difference in bulk density between 0 passes and 1 pass would be greater than the difference between 3 passes and 4 passes. Hypothesis 2 is that difference in bulk density between on-trail and off-trail would be greater on the site logged one year ago compared to the site logged three years ago. The results were mixed. There was statistically significant support for hypothesis 1 in the bare soil site, observed support in the forest site, and inconclusive results in the grass field site. Hypothesis 2 was not supported; the data showed higher differences between on-trail and off-trail in year 3, and the lowest differences in year 1.

INTRODUCTION

Modern forestry activities cause significant amounts of disturbance. With the use of large machinery like processors, skidders, and forwarders, a large area within a forest will have some form of disturbance when it is logged. The research conducted focuses on the Forwarder (pictured in *Figure 1*). This is a machine that transports wood from where it was cut down to a decking site, where the wood will be hauled away by truck. Trails are created throughout the forest by these machines to transport the cut timber. Observation of many logging operations has shown that some trails are still visible for years to come. Being a forwarder operator, the author has wondered how operators could reduce impact. Do they travel a few trails many times, in hopes to reduce the disturbed area? Or, do they travel many trails only a few times, in hopes that lower intensity disturbance across a larger area is better? To begin to answer these questions, research has been conducted on the rates of soil compaction by forestry equipment, as well as research on how trails with high intensity travel, change over the years, in regards to soil compaction.

LITERATURE REVIEW

Disturbance from forestry activity largely affects soil compaction, porosity, water content, and gas content. It also affects organic material content and understory plant life. In reviewing current literature, common themes arise in how these areas are affected.

When a skidder or forwarder passes over the land, there is an increase in soil bulk density (Makineci et al 2007) and an overall reduction in porosity (Najafi et al 2009). There is, however, an increase in microporosity (Alakukku 1996). With changes in porosity, there are changes in gas composition. Oxygen levels decrease in a non-significant manor and carbon dioxide content increases in a significant manor (Conlin and van den Driessche 2000). Available nitrogen levels are negatively affected by compaction in the short term (Tan et al 2005). Greatest compaction occurs on haul roads, less occurs on skid trails, while no compaction occurs in undisturbed areas (Buckley et al 2003). Soil compaction can persist over time, even after years of tillage and freeze/thaw cycles (Alakukku 1996).

Disturbance caused by forestry equipment is similar to larger disturbances, like fire, in that it allows different species to colonize in these conditions. Species richness on old skid roads and old haul roads can be higher than in areas of no disturbance. Skid roads can open up areas for invasive species (Zenner and Berger 2008). A higher occurrence of wetland species are found on skid trails and haul roads (Alakukku 1996). Soil compaction has mixed results on biomass production. Some soils showed an increase in production, some soils showed a decrease. Compaction reduced total stand biomass of Aspen trees, but had no effect on other species (Ponder et al 2012). There is a critical point of compaction for each type of soil where plant growth is inhibited (Ponder and Tadros 2012). Amounts of organic matter in the soil are usually reduced (Makineci et al 2007) and leaf litter is reduced as well (Najafi et al 2009).

HYPOTHESIS

1. (Mean of Treatment 1 – Mean of Treatment 0) > (Mean of Treatment 4 – Mean of Treatment 3) across sites *BS, GF,* and *F. (in words: more compaction is done on the first run)*
2. (Mean of Year 1 On-trail – Mean of Year 1 Off-trail) > (Mean of Year 3 On-trail – Mean of Year 3 Off-trail). *(in words: soils become less compact over time)*

METHODS

Equipment and Terminology

In this research, the machine being used is a 1968 Massey Ferguson Iron Mule Forwarder (Figure 1). Its total mass is approximately 6,000kg (Machine mass plus 1.5 cords of Red Oak). This exact machine will be used in all immediate compaction testing. It was also used at all of the sites being tested for compaction recovery. In this context, a *pass* is when the Forwarder drives forward over a given area once, travelling at 1.38 km/h. Pressure on the ground exerted by the machine ranges from 60 to 165 Kpa. The high end measurement is when only tread area is in contact with the ground, the low end is calculated for tread and non-tread area being in contact with the ground (tread seen in Figure 1). Mass distribution between the front axle and rear axle is unknown; Kpa values assume equal distribution across all 4 tires. Soil samples are collected with a device constructed from galvanized steel pipe, self-named the "soil sampler" (Figure 2). The detachable sampling portion of the unit is *5.08cm* in diameter, *13.97cm* in height, with a volume of *283 cubic centimeters.*

Figure 1 Massey Ferguson Forwarder

Figure 2 Soil Sampling Tool

Site Descriptions

There are six sites in this research. Three for testing rates of immediate compaction *(BS, GF, and F)* and three for testing rates of compaction recovery *(Year 1, Year 2, and Year 3).*

Bare Soil (BS)*:* Located on personal private property (Yellow box in Figure 6), this site has seen regular agricultural activity for the past 25 years. The site was disked one week prior to sample collection with a tractor and disk that penetrates approximately 20 cm (Figure 3).

Grass Field (GF)*:* Located on personal private property, this site saw agricultural activity in the early 1900's, and then again for one year approximately 25 years ago. No large machine activity has taken place since. Tall grasses and wildflowers make up the plant life (Figure 4).

Forest (F)*:* Located on the private property of *land-owner C,* 2 miles west of Sagola, Michigan. This site was select cut in the winter of 2014, when the ground was frozen. No other large machine activity has occurred in the past 50 years. Forest composed of Northern Hardwoods (*Figure 5*).

Year 1*:* Located on the private property of *land-owner A*, ½ mile north of Sagola, Michigan (Orange box in *Figure 6*). This site was select cut by Dbl. D Logging in the fall of 2015/winter 2016. No other large machine activity has taken place off of established roads for at least 40 years. Forest composed of Northern Hardwoods with understory of Balsam fir.

Year 2*:* Located on the private property of *land-owner B*, 2 miles west of Sagola, Michigan (Blue box in *Figure 6*). This site was select cut by Dbl. D Logging in the fall of 2014. No other large machine activity has occurred in the past 50 years. Forest composed of Northern Hardwoods.

Year 3*:* Located on the private property of *land-owner C*, 2 miles west of Sagola, Michigan (Red box in *Figure 6*). This site was select cut by Dbl. D Logging in the fall of 2013/winter 2014. No other large machine activity has taken place off of established roads in the past 50 years. Forest composed of Northern Hardwoods.

Figure 3 Bare soil site

Figure 4 Grass field site

Figure 5 Forest site

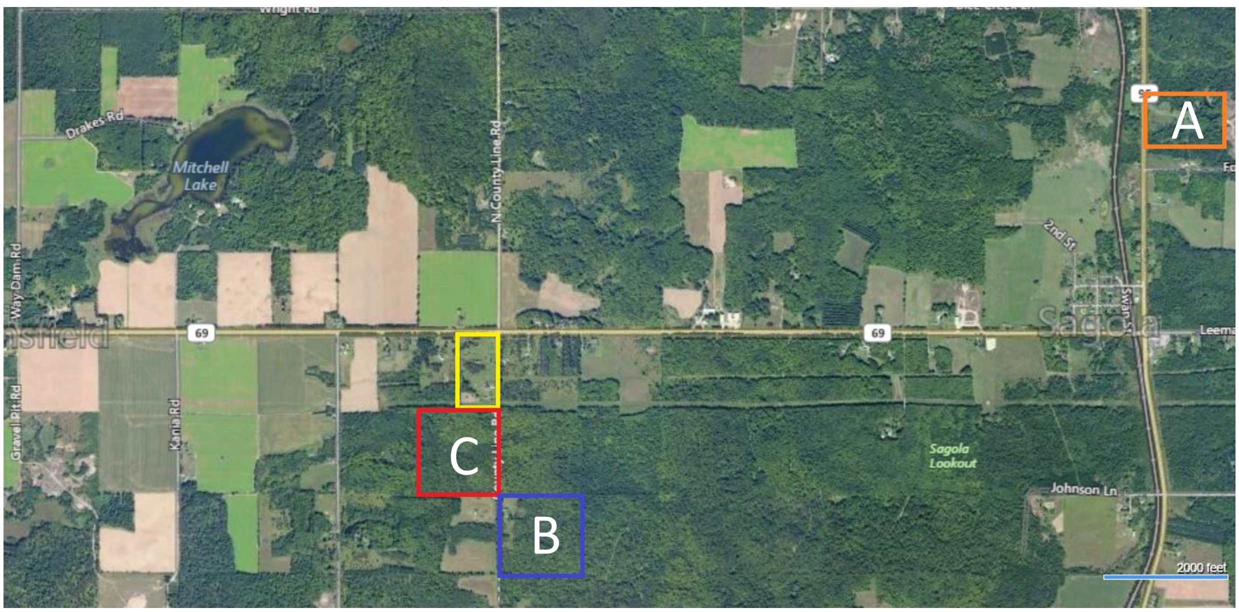

Figure 6 Local Map of involved land

Immediate compaction

Testing of immediate compaction took place on three sites: *Bare Soil, Grass Field, and Forest*. Four treatment zones were marked on each site. Each zone measured 3 meters wide and 30 meters long. Each zone received a treatment of either 1, 2, 3, or 4 passes. The control of zero passes was collected from six randomly located spots spanning across the four established zones (taken before forwarder activity began). Six soil samples were collected from each zone, 3 in the left tire track and 3 in the right tire track. Each sample was spaced approximately 5 meters apart, running the length of each zone. Deeper depressions caused by the tire tread were visible, so samples were taken randomly, some falling inside the depressions, some in-between the depressions. This factor is not recorded in the data, for I am looking at the effect of the whole tire profile.

Site preparation

Site ***BS*** was disked to a depth of 20cm and hand-raked level one week before data collection began. Each treatment zone was marked, with no other activity inside the zones other than forwarder travel and soil collection. Site ***GF*** was left as is. Grass was removed from the location of each soil sample taken. In site ***F***, large branches and other debris were removed for safety and ease of sample collecting. No undergrowth was removed.

Compaction recovery

Testing of compaction recovery took place at three sites, (*Year 1*, *Year 2*, *Year 3*) which were all logged by the same company, using the same equipment,h at the same time of year (fall), in each respective year. Verbal permission to conduct data collection was granted by all private landowners involved. On each site, a network of trails were established by the Forwarder to extract cut timber from cutting location to a decking location. A 20-meter section of trail was chosen at each site using the following criteria:

- Had at least 3 loaded *passes* on it, along with multiple empty *passes*.
- Must NOT have been a previously established road or trail; meaning the trail was created by our forestry activity, used only for such at that time, and not used since.
- The trail is fairly straight and on somewhat level ground.

Five soil samples will be taken from off the trail (within 5 meters of trail). Five samples will be taken from on the trail, spaced approximately 4 meters apart.

Soil Description

All test sites, excluding the site *year 1*, are classified as *H24B Emmet fine sandy loam, moraines, 1-6% slopes.* *Year 1* site is classified as *13D fine sandy loam, 6-18% slopes* (Soil Survey Staff).

Density Collection

To measure soil compaction, the bulk density is determined. Each individual sample was placed in its own sealed, quart sized freezer bag immediately after extraction. Each bag was labeled with site ID, treatment, and sample number *(Bare soil, 1 Pass, sample 3).* When all samples were collected, moisture was removed from each sample by heating them in a Humboldt brand soil oven, at 105 degrees Celsius for 24 hours. Once moisture was removed, the mass of each sample was determined. Knowing the volume and the mass of each sample, a bulk density measurement (g/cm^3) was determined for each sample. Samples containing large rocks were not recorded in the data.

DATA ANALYSIS

Data was analyzed using IBM's SPSS statistical software. The mean for each treatment has been determined. The difference of means in treatment zones (0 and 1) and (3 and 4) within sites *BS*, *GF*, and *F*, are compared using a Paired-Samples Test at a 90% confidence interval. In the data, negative values for "mean" in the Paired-Samples Test, represents zone 1 and 4 being greater than zone 0 and 3, respectively. The difference in means of o*ff-trail* and *on-trail* will be run through the same test. Negative values for "mean" represent *on-trail* being greater than *off-trail* Graphic representations of each site were also created to show trends in the collected data.

RESULTS

Bare Soil

Table 1.1 Means of treatment zones at site **BS**

	BS0	BS1	BS2	BS3	BS4
Mean	1.1283	1.3180	1.4650	1.5083	1.5167
N	6	5	6	6	6
Std. Deviation	.04875	.07530	.05010	.04070	.08165

Table 2.1 Paired-Samples test at site **BS**

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
BS0 - BS1	-.19800	.07120	.03184	-.26589	-.13011	-6.218	4	.003
BS3 - BS4	-.00833	.07083	.02892	-.06660	.04993	-.288	5	.785

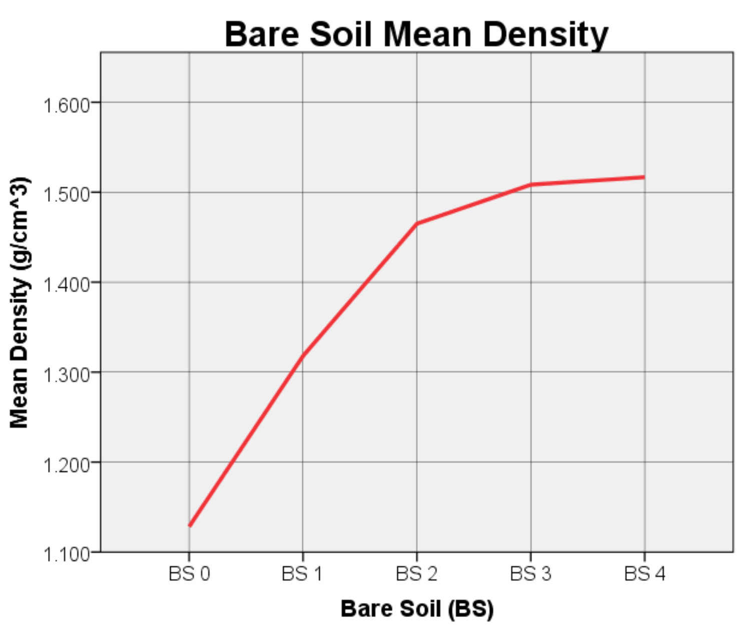

Figure 7.1 Graph of means at site **BS**

Grass Field

Table 1.2 Means of treatment zones at site **GF**

	GF0	GF1	GF2	GF3	GF4
Mean	1.1800	1.2367	1.2483	1.2767	1.3200
N	6	6	6	6	6
Std. Deviation	.05967	.05428	.06178	.03445	.04099

Table 2.2 Paired-Samples test at site **GF**

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
GF0 – GF1	-.05667	.09852	.04022	-.13772	.02438	-1.409	5	.218
GF3 – GF4	-.04333	.04844	.01978	-.08318	-.00348	-2.191	5	.080

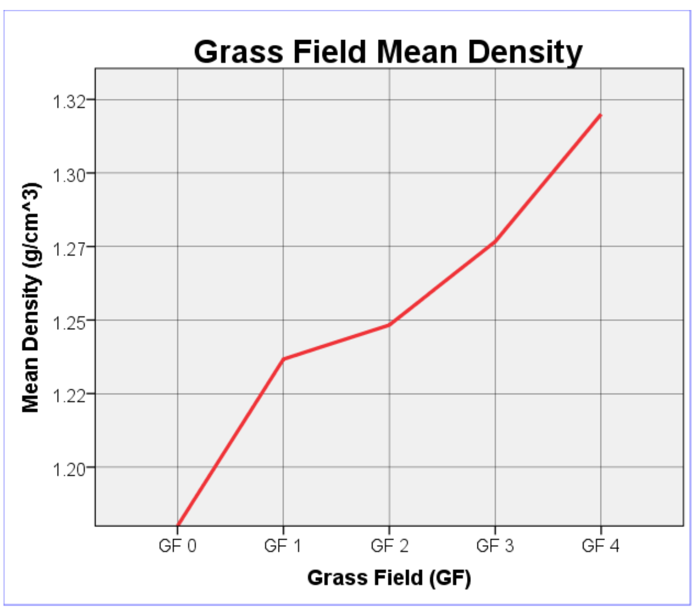

Figure 7.2 Graph of means at site **GF**

Forest

Table 1.3 Means of treatment zones in site **F**

	F0	F1	F2	F3	F4
Mean	.9533	1.1483	1.0917	1.1020	1.1650
N	6	6	6	5	6
Std. Deviation	.11201	.12671	.11923	.13122	.13081

Table 2.3 Paired-Samples test in site **F**

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
F0 – F1	-.19500	.11929	.04870	-.29313	-.09687	-4.004	5	.010
F3 – F4	-.08600	.05367	.02400	-.13716	-.03484	-3.583	4	.023

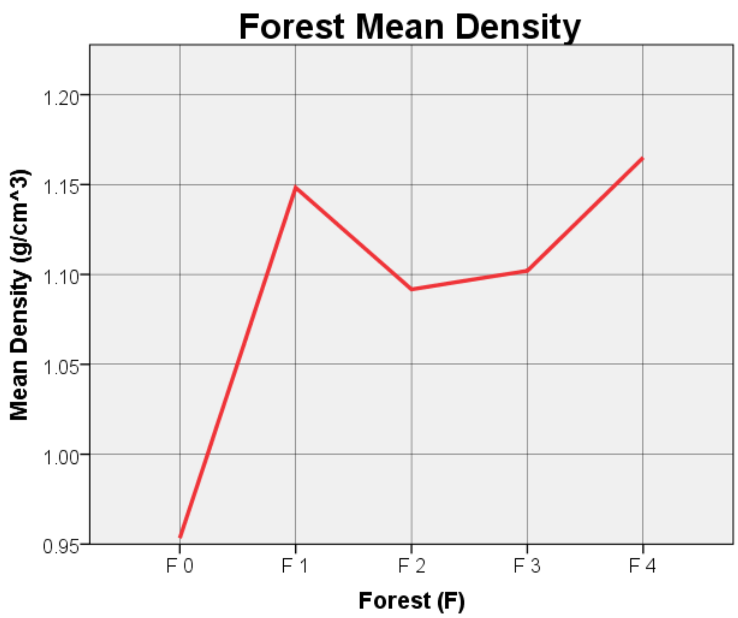

Figure 7.3 Graph of means in site **F**

Year 1

Table 3.1 Paired-Samples test at site *Year 1*

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
Y1_Off – Y1_On	.00800	.08871	.03967	-.07658	.09258	.202	4	.850

Year 2

Table 3.2 Paired-Samples test at site *Year 2*

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
Y2_Off – Y2_On	-.15250	.09979	.04990	-.26992	-.03508	-3.056	3	.055

Year 3

Table 3.3 Paired-Samples test at site *Year 3*

	Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
				Lower	Upper			
Y3_Off – Y3_On	-.34200	.16574	.07412	-.50002	-.18398	-4.614	4	.010

Figure 8 Difference in means across all years

ANALYSIS

Hypothesis 1, (Mean of Treatment 1 – Mean of Treatment 0) > (Mean of Treatment 4 – Mean of Treatment 3) across sites BS, GF, and F, was somewhat supported. In site BS, it was found that the difference of 0 and 1 was significantly more than the difference between 3 and 4, testing at a 90% confidence interval. In site F, a greater difference was observed between 0 and 1, but testing at a 90% confidence interval did not provide statistical significance to this observation. In site GF, a slightly greater difference was observed, but the difference was very small and was not statistically significant.

Hypothesis 2, (Mean of Year 1 On-trail – Mean of Year 1 Off-trail) > (Mean of Year 3 On-trail – Mean of Year 3 Off-trail) was found to be inconclusive in this data. It was observed that Year 3 had the largest difference, and year 1 had no observed, or statistical difference.

DISCUSSION

Site *BS* was designed to be a control in testing immediate compaction rates. The purpose of disking the soil was to treat the area in a way that created a consistent soil structure across the entire site. It largely removed the influence that above earth plant structure, as well as root structure, has on how soils are compacted. The other two sites, GF and F, were chosen to bring variety in root structures. The grass field has a thick structure of roots in the shallow soil, where the forest has more of its root structure in the large trees, which occur deeper, with less non-woody plant structure in the shallow soil. Seeing the trends in *Figures 7.1, 7.2,* and *7.3* , it is entirely possible that soils with different root structures react differently to operation of large machinery. Further research on sites like site *F* and site *GF* will be necessary; It was inconclusive if the majority of soil compaction occurred over the course of four passes, unlike the results on the site BS. Since the intention of this research was to discover the rates of compaction over varying levels of disturbance, the author did not explore if the observed bulk densities could have ecological effects.

Results from exploring past sites of compaction seemed to contradict Hypothesis 2. The data is valid from site-to-site, but it would be unwise to conclude that an area most recently compacted will always have lower bulk densities than an area less recently compacted. This portion of the research was latitudinal, in that I researched at three different sites, representing three years in time, at the same time. This was done because of time restraints. Performing a test like this brings in more uncontrollable variables. It is important to note that observed off-trail bulk density was highest on site *Year 1*, and lowest on site *Year 3*. Local variations in the soil could have been a factor. Ideally I would monitor sites like this over several years.

CONCLUSION

After analyzing the results and applying them to the initial questions raised in the introduction, the following conclusions can be made: When operating machinery in areas similar to site BS, reducing impact area is most important. This would mean establishing the least amount of trail possible, and using it as many times as necessary. In a forest setting, the results from this research point in the same direction, but more research is necessary to draw definitive conclusions. Lastly, it can be concluded that many factors influence how individual sites react to this form of disturbance. This research has answered questions, left questions unanswered, and created new ones. Future research is necessary and will be conducted.

APPENDIX

The full listing of collected data can be made available upon request by emailing (dudishaw@nmu.edu)

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