Assessing Soil Compaction Following a Winter Harvest of Northern Hardwoods

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Abstract.—Harvesting during winter is encouraged as a best management practice to protect soils during logging operations. We assessed the effects of machine traffic and slash volume on soil bulk density following a winter harvest of a northern hardwood forest on unfrozen cobbly silt loam soils. Soil samples were extracted from areas representing four levels of machine traffic (i.e., high, medium, low, and none) and two levels of overstory treatment (i.e., clearcut and partial cut). Results indicate that even low levels of traffic increased bulk density at the 0–5 cm depth. However, at the 5–10 cm depth, increases in bulk density were detected only in high traffic areas (i.e., >7 passes). No significant effects of slash volume on bulk density were detected. The mitigating effects of snow depth require further research.

INTRODUCTION

Mechanized harvest systems provide increased productivity and safety relative to manual harvesting (Cambi et al. 2015) and are widely used in the Lake States region (Gc et al. 2020). However, high ground pressures exerted by modern logging machines can impact soils (McDonald et al. 1995, McNabb et al. 2001) by altering soil structure and decreasing porosity, resulting in reduced saturated hydraulic conductivity (Jansson and Johansson 1998, McFero Grace et al. 2006), and possibly restricted root growth (Kozlowski 1999, Meyer et al. 2014).

Winter harvesting is generally encouraged to protect sensitive soils (Smith and Wass 1976, Krag et al. 1986). Ideally, winter harvests would occur over frozen ground to take advantage of the increased shear strength. However, in regions that experience early and persistent snowfall, soils remain unfrozen due to the insulating effects of the snowpack. Such is the case in Michigan's Upper Peninsula, where harvesting of northern hardwoods stands during winter is common.

The aim of this study is to assess the impacts of a mechanized winter harvest of northern hardwoods on soil bulk density in the Western Upper Peninsula. The harvest was part of the Northern Hardwood Silvicultural Experiment to Enhance Diversity (NH-SEED), and featured multiple overstory treatments, including clearcut, shelterwood, and single-tree selection (Hupperts et al. 2020).

METHODS

Harvesting occurred during February and March of 2017 within the NH-SEED study area, located at Michigan Tech University's Ford Research Forest in Baraga County, MI. The site consisted mainly of the Champion soil series, which are characterized by cobbly silt loam soils. The harvest area was dominated by sugar maple (*Acer saccharum* Marsh) and featured mild to moderate

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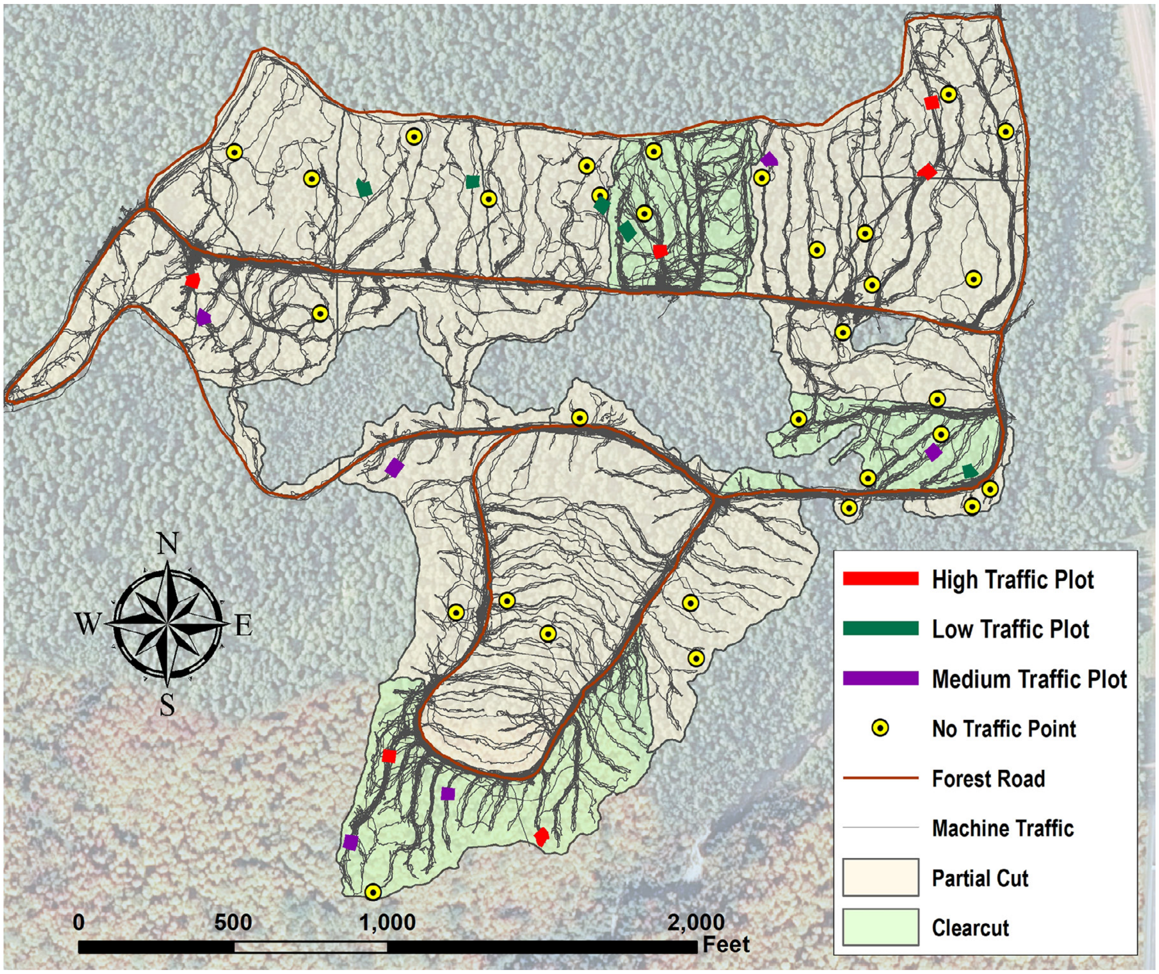

Figure 1.—Showing all skid trails and the different levels of machine traffic, where low represents 1–3 machine passes, medium represents 4–7 machine passes, and high represents areas that experienced 8 or more machine passes. Each level of machine traffic was sampled across six plots, while 31 random samples were collected in no-traffic areas.

slopes. The harvest was cut by two cut-to-length systems (i.e., harvester and processor; see Rahman 2019 for equipment information).

Each machine was affixed with a Garmin Alpha 100 or T15 receiver. Global positioning system (GPS) waypoints were collected every 3 seconds throughout the harvest. These data were analyzed in ArcMap (Esri, Redlands, CA) to identify skid trails of varying traffic intensities according to number of machine passes. Skid trails were divided into 12-meter segments (i.e., plots), and classified as low traffic (i.e., 1–3 passes), medium traffic (i.e., 4–7 passes), and high traffic (i.e., >7 passes).

Three replicated plots were randomly selected for each unique combination of traffic intensity (i.e., 3 levels) and overstory treatment (i.e., two levels), resulting in a total of 18 plots (Fig. 1). Stratifying by overstory treatment—clearcut and partial cut—was done to account for differences in slash volumes placed on the skid trail by harvester operators to protect soils. Within each plot, 12 sample points were located 2 meters apart along each side of the skid trail within the tire tracks. An additional 31 random "no-traffic" sample points were identified in ArcMap.

Soil samples were extracted using an AMS (Art's Manufacturing and Supply, American Falls, ID) soil core sampler (aka slide hammer) and a 20 cm × 5 cm cylinder. Each sample was divided into three depths (i.e., 0–5 cm, 5–10 cm, 10–20 cm), and then dried and weighed to determine bulk density. Rock fragments greater than 2 mm were separated and weighed to determine percent rock content.

Snow depth within plots could not be measured during the harvest because plots were identified post-harvest using GPS data. Thus, the effect of snow depth was not included in this analysis. However, for context, the average daily snow depth in the general area during the harvest operation was approximately 11 inches, with a maximum of 19 inches, according to data acquired from a weather monitoring station located 1 mile from the harvest site and at similar elevation.

Slash volume (m^3/m^2) was estimated at each sample point by estimating the packing ratio of woody debris within a square meter quadrat. A field guide containing examples of known packing ratios was developed in advance to assist. The field guide included packing ratios for a range of representative sample points along with photos. The packing ratios in the field guide were determined by extracting and weighing slash from within a quadrat using hand saws and a luggage scale, and then converting weight to volume using a conversion factor of 706.5 kg/m^3, which represents the wood density of sugar maple at 23 percent moisture content (Simpson and TenWolde 1999). The height of each field guide plot was measured from the ground to the top of the highest piece of debris in the plot to determine a three-dimensional space above the point. Thus, the packing ratio represents the percent volume of wood relative to the volume of the three-dimensional space.

SAS version 9.4 (Cary, NC) was used to analyze the data. A mixed-effects model was used within a complete random design with subsampling, with machine traffic included as a fixed-effect variable, slash volume as a random-effect variable, and bulk density as the dependent variable. The unit of analysis was the plot, which included six replications for each level of machine traffic and 31 independent samples from no-traffic areas.

RESULTS AND DISCUSSION

Traffic level was a significant factor affecting soil bulk density within the 0–5 cm layer (F-value = 5.06, P-value < 0.021), 5–10 cm layer (F-value = 2.43, P-value = 0.0659). Significant differences in bulk density were detected between no-traffic areas and all other traffic levels for the 0–5 cm depth (Fig 2). However, in the 5–10 cm layer, only high levels of traffic areas (i.e., >7 passes) had significantly higher bulk density than no-traffic areas.

These results are like previous studies that report effects of machine traffic on increased soil compaction. Jourgholami et al. (2014) observed some changes in bulk density and total porosity after fewer than 5 passes, but significant increases in penetration resistance occurred after 10 passes. Jansson and Johansson (1998) found that bulk density increased with increasing traffic (i.e., 4–8 passes) for wheeled machines and a tracked machine.

The amount of slash placed on skid trails in clearcut treatments was greater than in partial cut treatments. However, this difference was not statistically significant. Also, according to the mixed-effects model, slash volume had no significant effect on bulk density. This result may be a residue of the large number of sample points with no slash, resulting in a zero-inflated probability distribution. Further analysis may be needed to address the effects of slash.

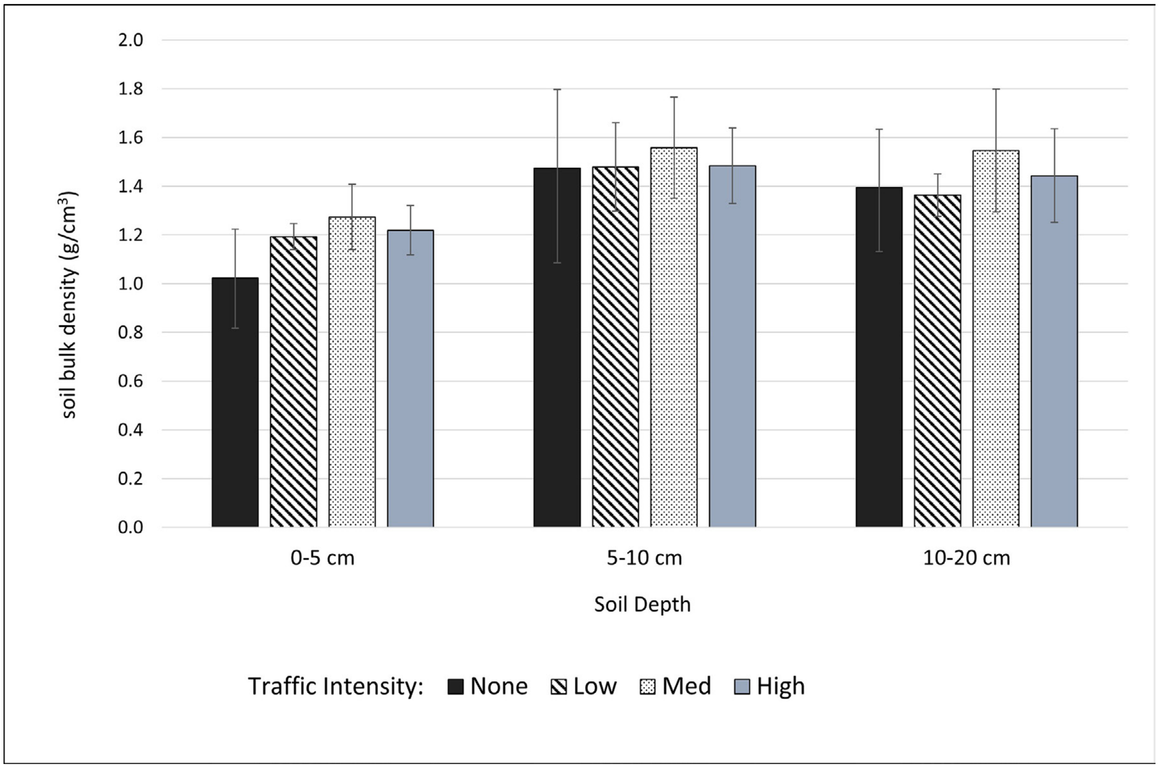

Figure 2.—Mean soil bulk density for four levels of machine traffic at three soil depths, where low represents 1–3 machine passes, medium represents 4–7 machine passes, and high represents areas that experienced 8 or more machine passes. Differing letters indicate significant difference in mean bulk density between traffic levels at α = 0.05 level.

Previous research on the mitigating effects of slash on soil compaction are somewhat mixed. McDonald and Seixas (1997) found that slash provided some protection against compaction from a forwarder after two or more passes on loamy sand soils. In contrast, Han et al. (2006) reported no significant effects of slash when operating a cut-to-length system on fine loamy soils, though the authors noted that slash placed over skid trails can help reduce rutting.

CONCLUSION

Winter harvesting over unfrozen soils under snowpack can result in increased soil bulk density with increasing machine traffic. Thus, loggers and foresters must be attentive to soil conditions and potential impacts, even during winter harvests when soils are not frozen. While placement of logging slash on skid trails did not have a significant mitigating effect in this study, this practice is nevertheless recommended given past findings that placing slash on skid trails can effectively protect soils from rutting and compaction. A more controlled approach to studying the effects of snow depth during harvest operations would improve future research. Overall, the highest mean bulk densities reported here are just approaching levels that could restrict plant growth for silt loam soils (Daddow and Warrington 1983). Thus, the impacts of this winter harvest on future plant and tree growth might be minimal. Future research is needed to measure tree growth across plots to determine if areas with greater soil in soil bulk densities due to increased machine traffic have lasting effects on tree growth.

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