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Effects of logging activities on selected soil physical and hydraulic properties for a claypan landscape

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A B S T R A C T

Previous studies have shown that once compacted, forest soils often recover slowly over many decades to pre-disturbed levels for soil properties such as bulk density or penetrometer resistance. This study was conducted to evaluate the effects of selected harvesting techniques on soil physical and hydraulic properties. The effects of logging roads, log landing areas, and logged areas on soil properties of water retention, saturated hydraulic conductivity (K_{Sat}), pore-size distributions, and bulk density were investigated on harvested sites within the Mark Twain National Forest in Callaway County, Missouri, USA on claypan landscape with a moderately well-drained Keswick soil (fine, smectitic, mesic Aquertic Chromic Hapludalfs). Soil cores (7.6 cm by 7.6 cm) were removed in four 10-cm depth increments. Bulk density was significantly greater ($P < 0.01$), and K_{Sat} was significantly lower ($P < 0.01$) under the logging road and log landing areas as compared to the logged area treatment. No statistical differences in bulk density and K_{Sat} values occurred among treatments at the deepest sampling depth (30 to 40 cm). For the 0 and −0.4 kPa soil water pressures, water retention was 14% greater and 9% greater for the logged areas versus the logging road and log landing areas averaged across all soil depths, respectively. For the macropores (>1000 μm diameter) and coarse mesopores (60 to 1000 μm diameter) combined, values were 131% greater for the logged area compared to logging road and log landing areas within the 0 to 10 cm depth. From this study, the methods used in the logged area appear to have caused small changes to soil physical and hydraulic properties; however, significant changes to these properties occurred for logging road and the log landing areas.

1. Introduction

Various studies have shown that once compacted by harvest activities, forest soils often recover slowly to pre-disturbed levels of bulk density (Sands et al., 1979; Froehlich et al., 1985; Tiarks and Haywood, 1996). Recovery rates are dependent on many factors, but chief among them are the number of repeated harvest cycles, soil moisture conditions during harvest, soil texture, and rock-fragment content (Miller et al., 1996; Williamson and Neilsen, 2000; Liechty et al., 2002). The extent of compaction, initial bulk density, depth of impact, and subsequent soil recovery are all factors that determine the consequences of timber harvesting or site preparation on productivity (Page-Dumroese et al., 2006). In addition, duration and variability of compaction can be significant from site to site or at different depths in the soil profile (Beckett and Webster, 1971; Blyth and MacLeod, 1978; Courtin et al., 1983). For instance, variability within soil textural groups, forest stands, or along skid trails can be as great as or even greater than the variability between them (Courtin et al., 1983).

Compaction is caused by traffic when soils have insufficient strength to support the load (Siegel-Issem et al., 2005). When soils fail, defined an increase in density due to the excess load, the bulk density of the soil increases, thus giving the soil enough strength to support the load (Hillel, 1998). Ultimately, the degree of compaction caused by harvesting or site preparation is affected by soil properties (e.g., texture, organic matter, and water content) at the time of disturbance (Block et al., 2002). Soil water content is one of the most important factors influencing the compactibility of soils (Soane, 1990). Higher soil water content reduces the soil strength, allowing greater increases in density during wet conditions (Jansson and Johansson, 1998). Wet conditions cause the soil to exhibit less strength.

Soil hydraulic properties are very sensitive to compaction (Blanco-Canqui et al., 2004). Jansson and Johansson (1998) found that saturated hydraulic conductivity decreased at the 10 cm depth by two orders of magnitude due to wheel traffic. In forested settings, compaction not only decreases production but increases runoff and erosion and negatively affects water quality (Powers et al., 1990). Thus, management is critical for maintaining good hydraulic properties to minimize runoff and erosion, and improve water quality (Mudgal et al., 2012; Senaviratne et al., 2013).

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The mass of the equipment used during harvest activities plays a significant role in determining the depth to which soil physical parameters are altered. The depth to which compaction occurs is also dependent upon the soil water content (Braunack and Williams, 1993; Jansson and Johansson, 1998). A practical recommendation is to minimize traffic in order to affect the soil as little as possible (Jansson and Johansson, 1998).

Maintaining optimal soil hydraulic properties in managed forest sites is critical for environmental conservation. Although the effects of timber harvest on bulk density have been studied considerably, not many studies have been conducted to determine harvest activity effects on soil physical and hydraulic properties. The purpose of this study was to assess the effects of different levels of timber harvesting traffic (four years after harvest) for a claypan landscape on soil bulk density, saturated hydraulic conductivity, water retention, and pore size distributions.

2. Materials and methods

2.1. Experimental site history

The area selected for this study was located on the Cedar Creek unit of the Mark Twain National Forest near Fulton, Missouri. The site was initially managed under private ownership until the 1940s. European settlers in the 1800s through the early 1900s used the land for timber harvesting. After clearing, these lands were subsequently used as grazing land for cattle and other livestock.

The forests originally consisted of an oak-hickory mix including some other less dominant species. Recent surveys indicate the land contains about 45% oak-hickory, 12% cedar and other hardwoods, 6% bottomland hardwoods, and 1% locusts (Kingsley and Law, 1991). The oaks include white oak (*Quercus alba*), red oak group (pin oak (*Quercus palustris*), northern red oak (*Quercus rubra*), and black oak (*Quercus velutina*)). The other 36% of the land is open (usually pasture with fescue (*Festuca arundinacea*) and some warm season grasses) and brush.

Most of the land of the Cedar Creek unit was acquired by the U.S. federal government during the 1940's which undertook a restoration program to improve the land. Most of the land was degraded due to overgrazing, cropping on unsuitable soils, and clearing of timber (USDA Forest Service, 2004). Conservation management included fencing of water resources and pastures to control grazing; pastures were also managed with rotational grazing (USDA Forest Service, 2004).

2.2. Experimental site information

For the experimental site, the average temperature in winter is −0.4 °C, and the average daily minimum temperature is −5.5 °C (30-year average). In summer, the average temperature is 23.7 °C, and the average daily maximum temperature is 29.6 °C. The total annual precipitation is 114.4 cm. The average seasonal snowfall is about 49.8 cm (USDA, 1992; Guinan, 2013). The soils in the harvested areas were mapped as Keswick loam (fine, smectitic, mesic Aquertic Chromic Hapludalfs). These soils are formed in a thin layer of pedisediments with an underlying weathered glacial till typical of claypan landscapes.

Soil profiles were studied from samples taken from a representative location within one of the Logged Area treatments. Analyses were conducted for the soil horizons, and data on soil physical and chemical properties for the site are shown in Table 1. Clay content, silt content, CEC, organic matter, and water pH (pH_w) are shown for the upper soil horizons in the table. In this study area, the claypan occurred at about the 18 cm depth on the average.

The study was conducted in portions of four harvested areas that were delineated by vegetative type into timber stands within the Cedar Creek unit. The three treatments for this experimental study were defined as follows: logged area (Logged Area), logging road (Logging Road), and log landing area (Log Landing). In addition, an historical logged area (Logged Area-H) was selected for comparison purposes only. Oak and hickory were the dominant species in these stands. The oak and hickory were harvested in October and November of 2007. Size of trees selected for harvest were 30 cm DBH (diameter at breast height) or larger.

Four replicate harvested areas were selected and used to investigate the effects of logging management on soil physical properties. The Logged Area treatment was harvested in October and November 2007 using uneven-aged harvest methods. Within the Logged Area treatment, the harvesting equipment used to retrieve the logs from the logged area through the logging road to the log landing was a rubber-tired skidder. Static axle loads of the skidder were 6.8 g Mg with 71 cm wide tires (about 170 kPa interface pressure). Soil water content conditions were relatively moist (slightly below field capacity) during harvest activities. The logs at the landing were stacked approximately 2.0 m high or about six logs deep; total mass was approximately 14.5 Mg and the storage time was about one month. For comparison purposes, an additional nearby area was investigated; this area was historically logged (harvested 70 years before present with clear cutting).

2.3. Sampling procedures

Undisturbed soil cores, 7.6 cm in diameter and 7.6 cm in length, were taken to determine soil water retention, porosity, saturated conductivity (K_{Sat}), and bulk density. Two sample cores were taken from each depth, treatment and replicate during June 9–14, 2011 (96 core samples). Sample cores were taken in the center areas of the Log Landing and Logging Road treatments. Cores were taken in proximity of a harvested tree in the Logged Area treatment. Additionally, two sample cores were taken at each depth in four random locations in the Logged Area-H treatment (32 core samples). The core samples from the Logged Area-H were for comparison purposes only. Samples were taken from four depths: 0 to 10 cm, 10 to 20 cm, 20 to 30 cm, and 30 to 40 cm. These depths corresponded in part to soil horizons: the first two depths were in the A or AE horizon and the third and fourth depths were in the BE or 2Bt horizon. The samples were then secured in plastic bags, transported to the laboratory, and stored in cold rooms at 4.0 °C until laboratory measurements were conducted.

2.4. Laboratory analysis

For the saturated hydraulic conductivity measurement, the samples were removed from the cold room, and the plastic bags were removed

Table 1
Soil physical and chemical properties for the study location (Keswick silt loam, 5 to 9% slope) presented by profile horizon with standard deviations indicated in parentheses.

Soil horizon	Soil depth	Sand	Silt	Clay	Organic matter	pH_w
	cm	$g\ kg^{-1}$	$g\ kg^{-1}$	$g\ kg^{-1}$	$g\ kg^{-1}$	
A	0–10	19.6 (3.32)	808.7 (2.9)	171.8 (0.5)	28.8 (5.0)	5.21 (0.26)
AE	10–18	18.1 (0.67)	833.2 (27.0)	148.6 (26.4)	9.55 (0.42)	4.83 (0.10)
BE_1	18–28	15.4 (0.72)	760.4 (28.0)	224.1 (27.3)	12.83 (3.99)	4.71 (0.05)
BE_2	28–40	13.0 (0.01)	708.3 (0.19)	278.7 (0.18)	3.08 (4.33)	4.58 (0.04)
2Bt	40–60	14.2 (1.70)	542.8 (28.0)	443.0 (26.4)	2.90 (2.50)	4.60 (0.05)

Number in parenthesis is the standard deviation of the mean of 2 observations.