*Research article*

# Logging Effects on Soil Organic Carbon and Hydraulic Property in North Appalachian Region of Ohio USA

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**Abstract** Forest soils play an important role in the global carbon cycle. Thus, documenting changes in carbon stocks and hydraulic property by logging are essential to sustainable management. However, information on logging in relation to soil organic carbon (SOC) stock is scarce and it can be site specific. Thus, the effects of logging on the SOC stock and hydraulic property were analyzed after logging at a site in the North Appalachian Experimental Watershed (NAEW) near Coshocton, Ohio, USA. The objectives of the study were to quantify the impacts of logging on SOC stock and hydraulic property. Results show that for the 0-30 cm soil depth, SOC stock after logging (61.5 Mg $ha^{-1}$) was 54.5% lower than that before logging (135.3 Mg $ha^{-1}$). Further, soil water retention at different potential was consistently higher before logging than that after logging. A plot of the hydraulic capacity vs. suction under natural forest differed significantly than that after logging at 0-10 cm soil depth. Thus, logging reduced SOC stock, and degraded hydraulic property of the surface layer.

**Keywords** forest logging, soil organic carbon, soil water retention

## INTRODUCTION

Soils in forest ecosystems are a major sink of global carbon, in part due to the large area involved at a global scale. World soils contain an estimated 1550 Pg of carbon to 1 m depth, an amount that is nearly twice that contained in the atmosphere (Lal, 2004). Within the forest biomes, forest soils constitute 31% of the total carbon stock (Kimble, 2003). Thus, forest soils play an important role in the global carbon cycle. However, land use change causes disturbance of the forest ecosystem and can influence the soil organic carbon (SOC) stock and soil hydraulic property (Lal, 2005). There have been numerous studies on forest resources and their management (Lorenz and Lal, 2010). However, field studies on forest management practices in relation to soil is scarce (Kimble, 2003). In addition, the effect of SOC stock and hydraulic property can be soil and site specific. Therefore, there is a need for significant advances in measurement of SOC stock and hydraulic property in the forest ecosystem. In the United States, the Renewable Resources Planning Act Assessment Report showed that in 2003, about 33% of the total land area was under forest compared with 46% in 1630. About 120 Mha of forestlands have been logged for the forest resources and converted to other uses (e.g., agriculture). Logging creates soil disturbance and compaction by machinery such as bulldozers, tractors etc. During logging, the use of heavy machinery is common in the United States and many parts of the world, which alters soil hydraulic and mechanical properties and adversely affect plant growth (Soane, 1990). Disturbed and compacted soil is highly prone to accelerated erosion and increased surface runoff (Sidle and Drlica, 1981). Displacement of surface soil can also occur during the logging operations. A soil under undisturbed native forest has a high macro porosity and low bulk density, and it is prone to compaction by heavy machinery (Huang et al., 1996, Lacey and Ryan, 2000). These factors adversely affect plant growth due to restricted root growth, and reduced air and water availability.

## OBJECTIVE

The goal of this study was to assess differences in SOC stock and hydraulic properties for before and after logging sites in the surface layer. The hypothesis tested in this study was that logging reduces the SOC stocks, degrades hydraulic properties.

## METHODOLOGY

### Study Site and Soil Sampling

The experimental site was located at the North Appalachian Experimental Watershed (NAEW) near Coshocton, Ohio, USA (40°22’N, 81°48’W). The NAEW was established in the late 1930s to study the effect of soils, land management, geology and climate on water flow characteristics from agricultural and forest lands (Kelley et al., 1975). The NAEW is located within the mixed oak region of the unglaciated Allegheny portion of the Appalachian Plateau in east central Ohio (Kelley et al., 1975). The mean annual precipitation at this watershed is 950 mm and the mean annual temperature is 10.3 °C (Lorenz and Lal, 2010). Soils at NAEW are classified as Berks silt loam (loamy-skeletal, mixed, active, mesic, Typic Dystrudepts) (Dick et al., 1998; Kelley et al., 1975). The wooded areas were logged in July 2012. Soil sampling was carried out during September 2012 at after logging at shoulder position with triplicate, and before logging with triplicate.

### Soil Organic Carbon and Total Nitrogen

SOC and total nitrogen (TN) concentrations were determined by the dry combustion method (960 ˚C) using a Vario TOC analyzer (Elementar Inc., Hanau, Germany). The SOC stocks were calculated based on an equivalent soil mass (ESM) basis to correct for differences in compaction among the sites (Lee et al., 2009; Ellert and Bettany, 1995). The SOC stock (Mg ha$^{-1}$) was computed by multiplying the SOC concentration by the bulk density and the equivalent soil depth using following Eq. 1:

$$SOC_{ESM\ stock} = \rho_b \times d \times SOC_{con} \times 10^4 (m^2\ ha^{-1}) \tag{1}$$

where, $SOC_{ESM}$ *stock* is the SOC stock associated with ESM (Mg ha$^{-1}$), $\rho_b$ is the soil bulk density (BD) (Mg m$^{-3}$), $d$ is the equivalent thickness of soil depth (m), and $SOC_{con}$ is the SOC concentration (g kg$^{-1}$).

### Soil Water Retention Curve

Soil water retention curve (SWRC) was assessed by using a combination of tension table and pressure plate extractors (Dane and Hopmans, 2002). The SWRC was determined at 0, –0.4, –1, –2.5, and –5 kPa with tension table and at –10, –20, –30, and –1500 kPa with pressure plate methods. All available soil hydraulic models, the van Genuchten-Mualem model is the most widely used in simulation of SWRC (van Genuchten et al., 1991). The function in Eq. 2 describes the SWRC:

$$\theta = \theta_r - \frac{\theta_s - \theta_r}{[1 + (\alpha|\psi_m|)^n]^{1-1/n}} \tag{2}$$

where, $\theta$ is the volumetric water content (m$^3$ m$^{-3}$), $\theta_r$ is the residual volumetric water content (m$^3$ m$^{-3}$), $\theta_s$ is the saturated volumetric water content (m$^3$ m$^{-3}$), and $\psi_m$ is the matric potential (kPa). Parameters $\alpha$ (cm$^{-1}$) and $n$ are the empirical fitting parameters characterizing the shape of the retention curve by using Eq. 2. Change in soil structure, land use, or plotting the differential SWRC indicates soil management practices. A plot of the slope of SWRC $d\theta/d\psi_m$ vs. $\psi_m$ can be used as an indicator of the change in soil structure and hydraulic properties, due to changes in land use (Radcliffe and Šimůnek, 2010; Lal and Shukla, 2004).

$$C_\theta = |d\theta/d\psi_m| \tag{3}$$

where, $C_\theta$ is hydraulic capacity (kPa$^{-1}$)

### Statistical Analysis

Statistical analysis was carried out for each soil depth separately, with different management before and after logging sites. The data were statistically analyzed using SAS code PROC UNIVARIATE GLMM (Generalized Linear Mixed Model) procedure(SAS 2007). Statistical significance was computed at $p \leq 0.05$, unless otherwise stated.

## RESULTS AND DISCUSSION

### Soil Bulk Density, Texture, pH and EC

Results for soil BD, texture, pH, and electrical conductivity (EC) at 0-10, 10-20, and 20-30 cm soil depths at before and after logging sites are shown in Table 1. For before logging, soil BD increased with increase in depth. However after logging, soil BD slightly decreased from 1.64 to 1.43 Mg m$^{-3}$ going from 0-10 and 10-20 cm depths then increased to 1.56 Mg m$^{-3}$ at 20-30 cm. For the 0-10 cm soil depth, soil BD under after logging (1.64 Mg m$^{-3}$) was 49.0% higher than that before logging (1.10 Mg m$^{-3}$). For the 10-20 cm soil depth, soil BD under after logging was slightly higher than that before logging, but not statistically different at $P \leq 0.05$. Before logging soil had 36.3 and 8.2% clay content at 0-10 and 10-20 cm soil depth, respectively, but not statistically different those after logging soil. The pH and EC did not differ among before and after logging at any soil depths.

**Table 1 Effects of logging on soil texture, pH, electrical conductivity (EC), and bulk density (N=6 for each depth)**

| Site | Depth (cm) | Sand % | Silt % | Clay % | Texture Class | pH - | EC µS cm$^{-1}$ | Bulk Density Mg m$^{-3}$ |
|---|---|---|---|---|---|---|---|---|
| After Logging | 0-10 | 28.5a* | 55.0a | 16.5a | Silt Loam | 4.99a | 243a | 1.64a |
| | 10-20 | 27.5a | 54.3a | 18.2a | Silt Loam | 5.05a | 152a | 1.43b |
| | 20-30 | 28.7a | 52.7a | 18.6a | Silt Loam | 5.23a | 114a | 1.56b |
| Before Logging | 0-10 | 30.0a | 47.5a | 22.5a | Loam | 5.34a | 244a | 1.10c |
| | 10-20 | 27.6a | 52.7a | 19.7a | Silt Loam | 5.50a | 155a | 1.32b |
| | 20-30 | 28.3a | 55.5a | 16.2a | Silt Loam | 5.47a | 129a | 1.60a |

**Means with different letters (a, b, and c) among before vs. after logging soil for each depth are not significantly different at $p \leq 0.05$.*

### Soil Organic Carbon and Total Nitrogen

Results for SOC and TN stock associated with ESM (Mg ha$^{-1}$) for 0-10, 10-20, 20-30, and 0-30 cm soil depths for before and after logging are shown in Fig. 1. The logging event significantly influenced the

SOC stock in 0-10, 10-20, and 20-30 cm soil depths ($P$<0.01, $P$<0.01, and $P$<0.01, respectively). For 0-30 cm depth, SOC stock after logging soil (61.5 Mg $ha^{-1}$) was 54.5% lower than that before logging soil (135.3 Mg $ha^{-1}$). For 0-10, 10-20, and 20-30 cm soil depths, SOC stock was 58.3, 48.5, and 53.8 %, respectively, higher before logging soil (62.8, 37.7, and 34.7 Mg $ha^{-1}$, respectively) than after logging soil (26.2, 19.4, and 16.0 Mg $ha^{-1}$, respectively). For both before and after logging soils, SOC stocks decreased with increase in depth. Logging effects were more predominant in the surface layer. The TN stocks were significantly affected by logging at 0-10 and 10-20 cm soil depths ($P$<0.01, and $P$<0.01). Lower TN stocks were observed after logging soil (2.39, 1.85, and 1.62 g $kg^{-1}$, at 0-10, 10-20, 20-30 soil depths, respectively) than before logging soil (4.19, 2.69, and 2.67 g $kg^{-1}$, at 0-10, 10-20, 20-30 cm soil depths, respectively). For 0-30 cm soil profile, TN stocks after logging soil (5.87 Mg $ha^{-1}$) were 38.5 % lower than those before logging soil (9.55 Mg $ha^{-1}$).

**Soil Water Retention Curve**

The data in Fig. 2 (top) show the SWRC for 0-10, 10-20, and 20-30 cm soil depths for before and after logging, and fitted SWRC by van Genuchten-Mualem model using RETC code (van Genuchten et al. 1991). The hydraulic capacity vs. soil moisture potential are shown in Fig. 2 (bottom).

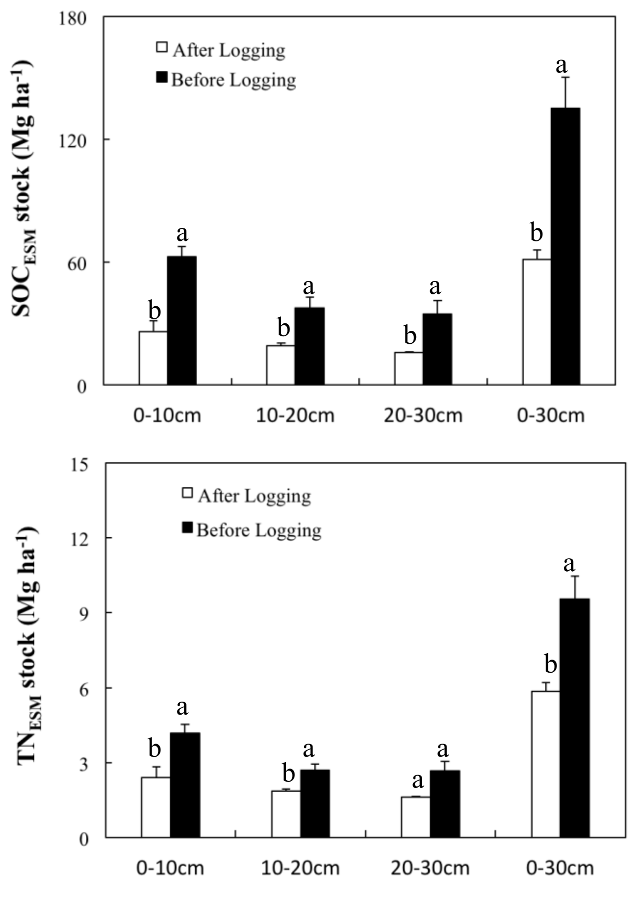


**Fig. 1 Effects of logging on soil organic carbon (SOC) and total nitrogen (TN) stocks associated with equivalent soil mass (EMS) at the 0-10, 10-20, 20-30, and 0-30 cm soil depths. Means with different letters among after vs. before logging for each depth are not significantly different at $p \leq 0.05$. Error bars indicate standard error (N=3)**

The SWRC were well described by the van Genuchten relationship ($R^2$ > 0.94). Overall the SWRC before logging soils were consistently higher than those after logging soils at all depths. Between saturation and approximately 10 kPa, hydraulic capacity before logging soil was consistently higher than that after logging soil at 0-10 cm soil depth. For 10-20 and 20-30 cm soil depths, the hydraulic capacity across the suction did not differ among before and after logging soils.

## Discussion

Logging significantly affected SOC stocks at all depths (Fig. 1). For the 0-30 cm soil depth, SOC stocks after logging soils were 54.5% lower than those before logging soils. Decline in SOC stocks two months after logging may be due to logging practices such as harvesting, which involve heavy machinery for cutting and transporting of trees, causing severe soil compaction, drastic soil disturbance and a mixing of the forest floor into the mineral soils (Kimble, 2003). Furthermore, logging can cause altered soil water content and temperature regimes, which can accelerate decomposition and decrease net primary production (NPP) (Lal, 2005). The exposure of the soil also exacerbates losses due to soil erosion and leaching of dissolved organic carbon (Kimble, 2003). Further, SOC sequestration could be also decreased due to the reduction of biotic activities and decrease in soil moisture content (Lal, 2005). Effects of logging on the reduction of SOC stocks were more predominant in surface soil layer, due to the smaller inputs of fresh litter, decrease in decomposition with increase in depth. The SWRC is an important indicator of soil structure, and relative distribution of micro and macro pores (Nakajima and Lal, 2014). The SWRC at each potential was consistently higher before logging soil than that after logging soil (Fig. 2 top), primarily due to having greater hydraulic capacity between matric potential 0 to 10 kPa at the 0-10 cm soil depth (Fig. 2 bottom). At 0 kPa matric potential, (or saturation point), before logging soils had greater water holding capacity than after logging soils, indicating greater occurrence of macro pores. This trend persisted to 10 kPa, also an indication of greater occurrence of intermediate and micro sized pores and clay content. A lower hydraulic capacity over time or change in management practice indicates progressive declines in soil structure and degradation of soil physical properties (Lal and Shukla, 2004).

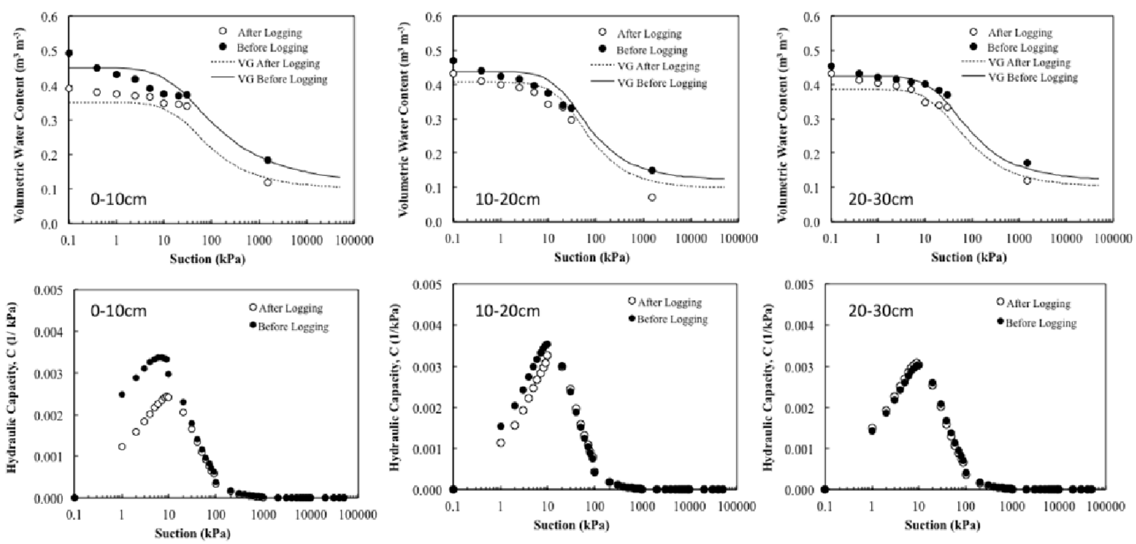


**Fig. 2 Effects of logging on soil water retention curve (SWRC) (top) and hydraulic capacity vs. suction (bottom) for the 0-10, 10-20, and 20-30 cm soil depths. Lines (top) show the fit of van Genuchten equation (VG) SWRC using RECT code**

## CONCLUSION

The hypotheses that logging in this study decrease SOC stocks and degrade soil hydraulic property were supported by the results. Results also supported the following conclusions (1) the SOC stocks after logging soil were 54.5% lower than those before logging soil for the 0-30 cm soil depth. The SOC stocks declined sharply by logging within 2-month period (2) logging adversely affected SWRC, especially in the 0-10 cm soil depth, probably due to decrease in macro pores and meso pores.

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