SOC Sequestration Rates for Age Chronosequence of Reclaimed Soils

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ABSTRACT

Surface mining operations severely deplete soil organic carbon (SOC). The reclaimed soils are large sinks for SOC because of their unfilled protective capacity. This preliminary study was undertaken in south eastern Ohio with the objective of assessing the soil physical properties and SOC concentrations in reclaimed minesoils (RMS). The experimental sites were reclaimed with and without topsoil application and were characterized by distinct age chronosequences of RMS. Three core and three bulk soil samples were collected from each of the experimental site and one unmined site (UMS) for 0-15 cm and 15-30 cm depths, and soil bulk density (ρ_b), texture, saturated hydraulic conductivity (Ks), volumes of transport (VTP) and storage (VSP) pores, available water capacity (AWC; θ at 30 kPa – θ at 1500 kPa), pH, electrical conductivity (EC), SOC and total nitrogen (TN) concentrations and stocks, and nonhydrolizable carbon concentrations were determined. The preliminary results from sites reclaimed with topsoil indicated that the sand content was highest (24%) and clay content was lowest (17%) for site reclaimed in 2003 (R03) for 0-15 cm depth. The ρ_b was higher for R03 (1.24 Mg m^{-3}) than sites reclaimed in 1987 (R87; 1.02 Mg m^{-3}), 1978 (R78; 0.98 Mg m^{-3}) and UMS (0.96 Mg m^{-3}) for 0-15 cm depth. No significant differences were observed in Ks, VTP, VSP, AWC among these sites ($P<0.05$). For 15-30 cm depth ρ_b varied in the order R03 (1.61 Mg m^{-3})> R87 (1.42 Mg m^{-3}) = R78 (1.40 Mg m^{-3}) = UMS (1.34 Mg m^{-3}). Soil pH was > 5.5 and EC < 4 dS m^{-1} for all sites and depths and was favorable for vegetation growth. The SOC and TN stocks were lower in R03 (3.5 Mg ha^{-1} and 0.6 Mg ha^{-1}; respectively) than R78 (30.1 Mg ha^{-1} and 1.6 Mg ha^{-1}) and UMS (18.7 Mg ha^{-1} and 1.8 Mg ha^{-1}) for 0-15 cm depth. The SOC and TN stocks were also lower in R03 (2.9 Mg $ha^{-1}$and 0.8 Mg ha^{-1}; respectively) than R87 (22.5 Mg ha^{-1} and 1.1 Mg ha^{-1}) and R78 (22.2 Mg ha^{-1} and 1.1 Mg ha^{-1}) for 15-30 cm depth. The SOC stocks in soils reclaimed with topsoil application and under grass increased from a base line value of 1.85 Mg ha^{-1} at a rate of 0.69 Mg ha^{-1} y^{-1} topsoil in 0-15 cm depth. For 15-30 cm depth, the SOC stocks increased from a baseline value of 1.07 Mg ha^{-1} at a rate of 0.73 Mg ha^{-1} y^{-1}. For sites reclaimed without topsoil application, ρ_b was higher for site reclaimed in 1957 under grass (R57; 1.6 Mg m^{-3}) than under forest (R57-F; 1.2 Mg m^{-3}) for 15-30 cm depth only. No significant differences were observed in clay content, Ks, VTP, VSP, AWC, SOC and TN stocks among sites reclaimed without topsoil application ($P<0.05$). Ignoring stochastic effects of topsoil application, the SOC increased at a rate of 0.89 Mg ha^{-1} yr^{-1} and 0.56 Mg ha^{-1} yr^{-1}. The SOC stocks in reclaimed sites show a high rate of increase. The nonhydrolizable carbon concentration was also in general high in all sites and was particularly high in R69 (31.2 g kg^{-1}) and R57-F (26.4 g kg^{-1}), which further suggested that SOC rates were influenced by coal carbon. Therefore, these preliminary results will be validated when detailed soil sampling is carried out during year 2004.

INTRODUCTION

Surface mining causes drastic disturbances to soil profile and alters soil physical and structural properties (Shukla et al., 2004a; b). Constructed or reclaimed minesoils may exhibit physical conditions drastically altered by anthropogenic perturbations rather than natural soil forming processes (McSweeney and Jansen, 1984). Restoration of disturbed minesoil can improve soil quality, biomass productivity, SOC concentration, and C sequestration (Lal et al., 1998; Shukla et al., 2004b). Few studies have been undertaken on the potential of reclaimed minesoils for SOC sequestration by comparing them with the undisturbed soil. Akala and Lal (2001), and Shukla et al. (2004b) reported a two-fold increase in SOC pools 20 years after topsoil application in some reclaimed minesoils in Ohio. In order to find out the sustainability of a system, it is important to study the SOC sequestration potential of reclaimed minesoils under different land use and management systems. Therefore, the objectives of this preliminary study were to evaluate: (1) soil physical quality of reclaimed minesoils under an age chrocosequence of reclaimed minesoils, and (2) assess the SOC sequestration rates and potentials of reclaimed minesoils.

Material and Methods

Three sites were reclaimed prior to the 1972 without topsoil application (prior to Ohio mineland reclamation act or the 1977 surface mining reclamation and control act, SMRCA), and other three were reclaimed after the 1972 with topsoil application. These sites are owned by the

American Electric Power (AEP) Co., and are located along the borders of Guernsey, Morgan, Noble, and Muskingum Counties of Ohio.

Soil Sampling

Three core samples were collected using 6 cm long and 6 cm diameter stainless steel cores from each of the experimental sites site reclaimed in 1978 (R78), 1987 (R87) and 2003 (R03) with topsoil application and under continuous grass cover from 0-15 and 15-30 cm depths. Three bulk soil samples were also collected from each of the site for both depths using a push probe. Similarly, three soil samples were collected from each of the sites reclaimed in 1957 (R57), 1969 (R69) both under continuous grass cover and 1957 (forest) (R57-F) without topsoil application. Soil samples were also collected from one control unmined soil (UMS) under grass-forest cover (Table 1).

Soil Bulk Density

All soil cores collected in the field were brought to the lab and trimmed at both ends and bulk density (ρ_b) was obtained according to the method described by Blake and Hartge (1986).

Particle Size Distribution

All soil samples from both depths were air-dried and clods were broken using rolling wooden pins and passed through 2-mm sieve. About 50 g of soil was used for the determination of particle size distribution by the hydrometer method (Gee and Bauder, 1986).

Soil Moisture Characteristic Curve

The soil moisture characteristic curves were determined on intact soil cores for 1 kPa, and 6 kPa suctions using the tension table (Leamer and Shaw, 1941), and for 30 kPa, 300 kPa and 1500 kPa suctions using the pressure plate apparatus (Klute, 1986). In terms of their functions in relation to plant growth, pores of equivalent cylindrical diameter (e.c.d.) > 50 µm are described as transmission pore (TrP). Since we did not measure moisture content corresponding to 0.5-µm e.c.d., we assumed that all pores between 0.2 and 50 µm diameter are storage pore (StP), (Greenland, 1977).

Soil Organic Carbon

About 1 g of the soil (< 0.250 μm) was used for the determination of total carbon (TC) and total nitrogen (TN) concentrations by the dry combustion method (Elementar, GmbH, Hanau, Germany). About 2 g of soil was mixed with 5 ml of 1N HCL solution and allowed to rest for two hours. This paste was dried for 24 hours at 50^{o}C and organic carbon (SOC) and nitrogen (TN) concentrations were determined again by the dry combustion method. The SOC and TN stocks were calculated as the product of SOC or TN concentration, ρ_b and the specific depth of soil layer. The carbonate content of the soil was calculated as the difference between TC and SOC. About 2 g of soil sample (< 0.250 μm) was mixed with 6N HCL and allowed to rest for 2 hours. Subsequently, sample was heated at 105^{o}C for 3 hours and then washed thrice and centrifuged to remove HCl (Paul et al., 2001). The residue was dried and the resident or nonhydrolizable C concentration was obtained by the dry combustion method.

Soil pH and Electrical Conductivity

The electrical conductivity (EC) and pH were measured on soil pastes (1:1 in soil:water suspension) using a hand held conductivity meter and pH electrode (Mclean, 1982; Rhoades, 1982).

Statistical Analysis

The analysis of variance (ANOVA) was computed for treatment x replicate interactions using Statistical Analysis System (SAS Institute, 1989) separately for soils reclaimed with topsoil application and without it for each depth. Significant mean interactions and the least significant differences (LSD) for mean separation were calculated for chronosequence within: (i) topsoil, and (ii) no topsoil, separately for each depth for $P \leq 0.05$.

Results and Discussion

Sites Reclaimed with Topsoil Application

There were some small variations in sand, silt and clay contents of the soil in sites reclaimed with topsoil application (Table 1).

Table 1. Particle size distribution in soils reclaimed with topsoil application for 0-15 cm depth

Properties	R78	R87	R03	BMC (0.5)
Sand (%)	25.19a	12.61b	23.95a	9.36
Silt (%)	53.67c	64.67ab	59.33bc	8.02
Clay (%)	21.15a	22.72a	16.72b	2.73

The ρ_b was higher for R03 than other sites reclaimed with topsoil application and UMS for both depths. The high ρ_b for R03 was in agreement to soil compaction associated with the reclamation procedure. Soil pH for all sites and depths was > 5.5 and EC < 4 dS m^{-1} and was favorable for vegetation growth. Low EC further improved soil structure, increased water infiltration rate, enhanced water retention and availability to plants, and increased root development and grass growth.

Table 2. Bulk density, pH and electrical conductivity of soils

Properties	Control	R78	R87	R03	BMC (0.5)
			0-15 cm		
ρ_b (Mg/m^3)	0.96b	0.98b	1.02b	1.24a	0.16
			15-30 cm		
ρ_b (Mg/m^3)	1.34b	1.40b	1.42b	1.61a	0.14
			0-15 cm		
pH	7.1b	8.3a	8.2a	6.3c	0.7
EC (dS/m)	0.11c	0.22b	0.58a	0.06c	0.10
			15-30 cm		
pH	5.8b	8.3a	8.3a	6.3c	1.1
EC (dS/m)	0.07b	0.63a	0.63a	0.04b	0.26

Water transmission properties such as Ks, VTP, VSP, AWC were similar among R03, R87, and R78 for 0-15 cm depth ($P<0.05$). All sites were under continuous uniform and dense grass cover and water transport seemed mainly influenced by root density.

The TN and SOC stocks in sites reclaimed with topsoil application and grass cover were lower in R03 than R78 and R87 for both depths (Fig. 1).

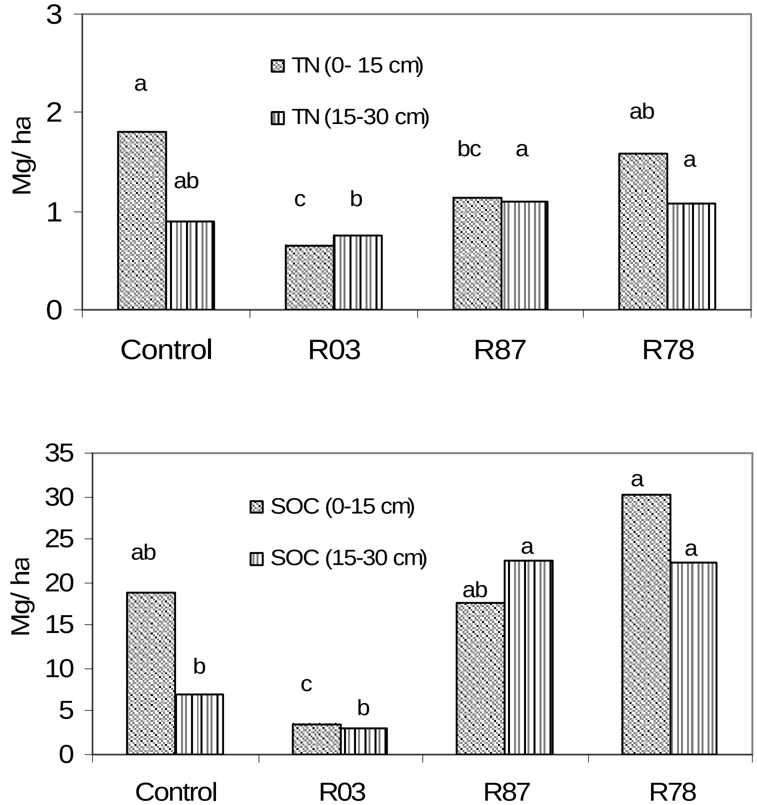

Fig. 1. Total nitrogen (TN) and soil organic carnon (SOC) stocks in sites reclaimed with topsoil

Overall SOC stocks increased at the rate of 0.69 Mg ha^{-1} y^{-1} from a base line value of 1.85 Mg ha^{-1} in 0-15 cm depth and 0.73 Mg ha^{-1} y^{-1} from a baseline value of 1.07 Mg ha^{-1} in 15-30 cm depth. Very low SOC stock for R03 was expected as a strip mined soil is drastically disturbed with severe loss in structure and SOC stocks. The low SOC stock of R03 also indicated that the reclamation was done with sufficient care so as not to contaminate the soil with coal. The grass roots were shallow in R03 thus SOC stocks were not contaminated by root SOC (C content ~ 20-

21 %). The same may not be true for the SOC stock in other reclaimed sites, where coal contamination (carbon content ~ 40%) cannot be totally ruled out.

Sites Reclaimed Without Topsoil

Sites R56, R69 and R56-F are probably one of the oldest sites reclaimed 9 to 22 years prior to 1977 SMRCA Federal Law in Ohio. There were some small variations in sand, silt and clay contents of the soil in sites reclaimed with topsoil application (Table 3).

Table 3. Particle size distribution in soils reclaimed without topsoil application for 0-15 cm depth

Properties	R57	R69	R57-F	BMC (0.5)
Sand (%)	15.28b	35.95a	17.95b	5.13
Silt (%)	61.67a	44.33b	59.67a	4.60
Clay (%)	23.05	19.72	22.39	NS

The ρ_b remained similar for 0-15 cm depth but varied in the order R57 > R57-F for 15-30 cm depth. A comparison of soil pH and EC showed no significant differences among R57, R69 and R57-F. No significant differences were observed in Ks, VTP, VSP, AWC among these sites for 0-15 cm depth ($P<0.05$) The SOC and TN stocks were also similar among sites and depths indicating that the SOC stocks are close to their saturation potential.

Ignoring the stochastic effects of topsoil application, the SOC stocks increased from a base value of 1.59 Mg/ha at the rate of 0.89 Mg/ha/yr for 0-15 cm depth (Fig. 2). SOC stocks increased from a base value of 2.42 Mg/ha at the rate of 0.56 Mg/ha/yr for 15-30 cm depth (Fig. 3).

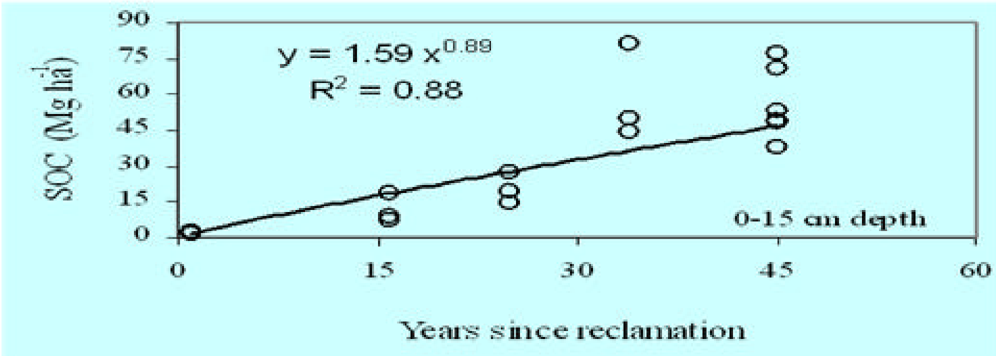

Fig. 2. SOC stocks from all reclaimed sites for 0-15 cm depth

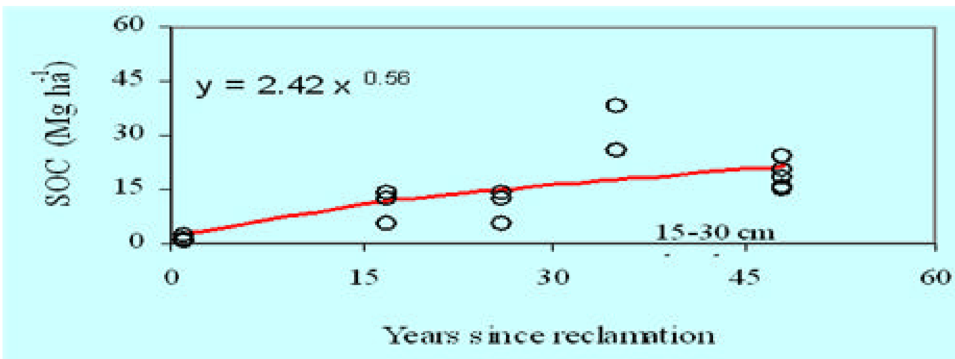

Fig. 3. SOC stocks from all reclaimed sites for 15-30 cm depth

The sites reclaimed without topsoil seems to have reached the equilibrium, however, the sites reclaimed with topsoil still have unfilled C-sink capacity, an indication of further SOC sequestration overtime. The nonhydrolizable SOC was also from all reclaimed sites (Fig. 4). Therefore, SOC values of whole soil were influenced by coal carbon.

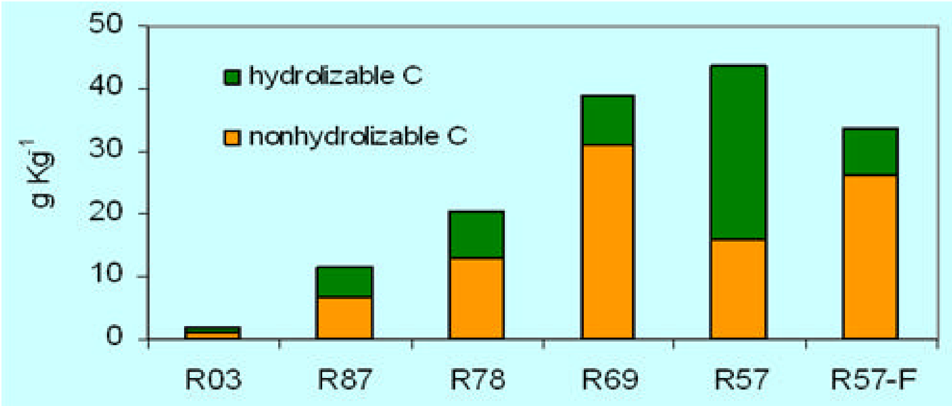

Fig 4. Nonhydrolizable carbon concentration in all sites for 0-15 cm depth

Conclusion

The soil physical quality has improved upon reclamation and soil bulk density is low and pH is high. The soil disturbance due to the mining operation severely decreased SOC as is evidenced by the low SOC (3.5 Mg ha^{-1} for 0-15 cm depth and 2.9 Mg ha^{-1} for 15-30 cm depth) for site reclaimed in 2003. Reclamation with topsoil increased the SOC at the rate of 0.69 Mg ha^{-1} yr^{-1} in 0 to 15 cm depth and 0.73 Mg ha^{-1} yr^{-1} in 15-30 cm depth. The nonhydrolizable C concentration was high in most reclaimed sites and contamination due to coal C can not be ruled out. These values are high still they show the unfilled C-sink capacity of reclaimed sites. However, these results are preliminary estimates and need to be verified by a detailed soil sampling.

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