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ABSTRACT

This research project is aimed at assessing the soil organic carbon (SOC) sequestration potential of reclaimed minesoils (RMS). The experimental sites were characterized by distinct age chronosequences of reclaimed minesoil and were located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio. These sites are owned and maintained by Americal Electrical Power. These sites were reclaimed (1) with topsoil application, and (2) without topsoil application, and were under continuous grass or forest cover. 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), pH and electrical conductivity (EC), SOC, total nitrogen (TN) concentrations and stocks were determined. The preliminary results from sites reclaimed with topsoil and grass indicate that 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 highest 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 grass 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 significantly different between sites reclaimed in 1957 (R57; 1.6 Mg m^{-3}) under grass and 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 these sites ($P<0.05$). Taking SOC stocks of R03 as baseline, the SOC stocks for sites reclaimed without topsoil increased from 13 to 19 times in R57 and R57-F in 0-15 cm soil depth and 14 to 20 times in 15-30 cm depth. These results are preliminary and will be validated further when detailed soil sampling is carried out during April-Sept. 2004.

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1.0 **Executive Summary**

This research project is aimed at assessing the soil organic carbon (SOC) sequestration potential of reclaimed minesoils (RMS) and is supported by US Department of Energy- National Energy Technology Laboratory. The proposed research focuses on: (1) assessing the sink capacity of RMS to sequester SOC in selective age chronosequences, (2) determining the rate of SOC sequestration, and it's spatial (vertical as well as horizontal) and temporal variation, (3) developing and validating models for SOC sequestration rate, (4) identifying the mechanisms of SOC sequestration in RMS, (5) assessing the potential of different methods of soil reclamation on SOC sequestration rate, soil development, and changes in soil mechanical and water transmission properties, and (6) determining the relation between SOC sequestration rate, and soil quality in relation to soil structure and hydrological properties.

Before 1972, surface mining operations were performed by removing the soil and underlying strata and piling them on a side. After mining operations were complete, due to the nonexistence of any specific reclamation guidelines, the excavated area was planted to trees or grass without grading or reclamation. After 1972, Ohio Mineland Reclamation Act (also 1977 SMRCA) made it mandatory to grade the area back to it's original topography and reclaim it with topsoil application. In this project, several experimental sites were identified, which were reclaimed both prior to SMRCA regulation (without topsoil under grass or forest) and after (with topsoil under grass or fores). All these sites are characterized by distinct age chronosequences of reclaimed minesoil, and sites are located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio, and are maintained and owned by American Electrical Power.

A total of six sites were identified for the preliminary investigation that were reclaimed with topsoil application, out of which three are under forest and three under continuous grass cover. Three sites were identified in reclaimed soil without topsoil application, out of which one was under forest and two under grass cover. In addition, two unmined sites, one each under forest and grass cover, are also identified. The unmined sites and those reclaimed after 1972 with topsoil application have gentle or regular slope gradients and are easily accessible. The sites reclaimed before 1972 without topsoil application under forest have steep and abrupt slope and are not easily accessible.

Soil samples were collected in December 2003 and again in March 2004 from 0-15 cm and 15-30 cm depths. Three core and three bulk soil samples were collected from each of the experimental site and one unmined site (UMS) for both depths and soil bulk density (ρ_b), texture, saturated hydraulic conductivity (Ks), volumes of transport (VTP) and storage (VSP) pores, available water capacity (AWC) were determined on soil cores. The pH and electrical conductivity (EC), and SOC, total nitrogen (TN) concentrations and stocks were determined on air dried bulk soil samples <2mm and <0.5 mm, respectively. The preliminary results of the study from sites reclaimed with topsoil and grass indicate that 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 highest for R03 (1.24 Mg m^{-3}) than sites reclaimed in 1987 (R87; 1.02 Mg m^{-3}), 78 (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 topsoil depths and was adequate for grass 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 significantly different between sites reclaimed in 1957 (R57; 1.6 Mg m^{-3}) under grass and 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 these sites ($P<0.05$). Taking SOC stocks of R03 as baseline, the SOC stocks for sites reclaimed without topsoil increased from 13 to 19 times in R57 and R57-F in 0-15 cm soil depth and 14 to 20 times in 15-30 cm depth. However, these results are preliminary and will be validated further when detailed soil sampling are carried out during April-September 2004. The high SOC stock for 0-15 cm layer for site reclaimed in 1978 showed the high sequestration potential upon reclamation and establishment of the grass cover. The increase in SOC stock is important for improving the soil and environment quality and soil productivity. The overall results of this study will be used to: (i) assess the degree to which soil carbon sequestration in RMS can offset fossil fuel emissions from the power plant in the vicinity, (ii) provide guidelines to land managers for trading carbon credits, and (ii) strengthen the terrestrial carbon sequestration data base to assist policy makers on land use changes for sustainable management of natural resources.

2.0 Experimental

2.1 Experimental Sites:

The experimental sites identified were: (1) reclaimed prior to the 1972 Ohio Mineland Reclamation Act or the 1977 surface mining reclamation and control act (SMRCA), under continuous grass and forest and without topsoil application, and (2) reclaimed after the 1972 Ohio Mineland Reclamation act, which made application of topsoil mandatory for reclamation, under continuous grass and forest. These sites are maintained by the American Electric Power (AEP) Co., and are located along the borders of Guernsey, Morgan, Noble, and Muskingum Counties of Ohio (Fig. 1).

This report includes the analysis of soil data from: (i) three sites reclaimed without topsoil application, one of them under continuous forest and two under continuous grass cover, and (ii) three sites reclaimed with topsoil application, and under continuous grass cover, and (iii) one unmined control site (UMS) under continuous forest and grass cover.

2.2 Collection of Soil Sample

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 UMS under grass-forest cover.

2.3 **Analysis of Soil Samples**

2.3.1 **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).

2.3.2 **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).

2.3.3. **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), those between 0.5 and 50 µm as storage pore (StP), and those < 0.5 µm as residual pore (Greenland, 1977). 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 pores.

2.3.4**. Soil Organic Carbon Concentration and Stocks**

The air-dried soil was ground to pass through 0.25 mm sieve. About 1 g of the soil 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 2N H_2SO_4 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 carbonate content of the soil was calculated as the difference between total carbon and organic carbon concentrations. The SOC and TN stocks were calculated as the product of SOC or TN concentration, ρ_b and the specific depth of soil layer.

2.3.5 **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).

2.4. **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 $P \leq 0.05$.

3.0 **Results and Discussion**

3.1 **Sites Reclaimed with Topsoil Application and Under Grass**

A comparison between sites reclaimed with topsoil application and under continous grass showed that sand content varied in the order R78 = R03 > R87; silt content R87 > R78, and clay content R78 = R87 > R03 ($P < 0.05$; Table 1). The ρ_b was highest for R03 (1.24 Mg m^{-3}) than sites reclaimed in 87 (R87; 1.02 Mg m^{-3}), 78 (R78; 0.98 Mg m^{-3}) for 0-15 cm depth. 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}). This was in accord with the soil compaction associated with the reclamation procedure leading to high ρ_b immediately after reclamation. Soil pH was higher for R78 (8.3) and R87 (8.2) than R03 (6.3) but EC varied in the order R87 (0.58 dS/m) > R78 (0.22 dS/m) > R03 (0.06 dS/m) for 0-15 cm depth. Similar variations in soil pH and EC were observed in 15-30 cm depth (Table 1). Soil pH for all sites and depths was > 5.5 and EC < 4 dS m^{-1} and was favorable for vegetation growth. No significant differences were observed in Ks, VTP, VSP, AWC among these sites for 0-15 cm depth ($P<0.05$). All sites were under continuous uniform and dense grass cover. Thus, water transport characteristics, which were mainly influenced by root density, were similar among sites. Low EC further improved soil structure, increased water infiltration rate, enhanced water retention and availability to plants, and increased root development and grass 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}) 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. 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, aggregation 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. Although the site had a good grass cover, the roots were shallow thus SOC stock of R03 was not influenced by root SOC. The same may not be true for the SOC stock in other reclaimed sites, where coal contamination cannot be totally ruled out.

3.2 **Unmined Control vs. Sites Reclaimed with Topsoil Application**

The ρ_b for UMS was 0.96 Mg m^{-3} for 0-15 cm depth and 1.34 Mg m^{-3} for 15-30 cm depth, which was statistically similar to R78 and R87 sites. The pH and EC of UMS were lower than R78 and R87 sites for both depth but were favorable for vegetation growth. No significant differences were observed in Ks, VTP, VSP, AWC among UMS and RMS for 0-15 cm depth ($P<0.05$). The SOC and TN stocks in UMS (18.7 Mg ha^{-1} and 1.8 Mg ha^{-1}) were similar to those in R78 and R87 for both depths. This clearly demonstrates the soil quality improvement in R87 and R78.

3.3 **Sites Reclaimed Without Topsoil Application**

Sites R56, R69 and R56-F are probably one of the oldest sites reclaimed 9 to 22 years prior to 1977 SMRCA Federal Law. The sand content varied in the order R59 (36%) > R57-F (18%) = R57 (15%), silt content R57 (62%) = R57-F (60%) > R69 (44%), but clay content was similar among all three sites ($P< 0.05$; Table 2) for 0-15 cm depth. The ρ_b remained similar for 0-15 cm depth but varied in the order R57 (1.62 Mg m^{-3}) > R57-F (1.17 Mg m^{-3}) for 15-30 cm depth. A comparison of soil pH and EC showed no significant differences among R57, R69 and R57-F. Soil pH was about 8.2 and EC < 0.6 dS m^{-1} for all sites and depths, and was favorable for plant growth. 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

A comparison between soils reclaimed without and with topsoil application showed that the average SOC stocks for the former were higher than the later. A comparison between R78 and R57 showed 1.5- folds increase in SOC stock from 30.1 Mg ha^{-1} for 1978 to 44.8 Mg ha^{-1} for 1957 reclaimed site for 0-15 cm depth and > 2 fold increase from 22.2 Mg ha^{-1} for 1978 to 50.9 Mg ha^{-1} for 1957 reclaimed site for 15-30 cm depth. A 10- fold increase in SOC stock from 3.5 Mg ha^{-1} to 44.8 Mg ha^{-1} was observed in the site reclaimed in 1957 compared with that in 2003 for 0-15 cm depth, and a 16-fold increase from 2.9 Mg ha^{-1} to 50.9 Mg ha^{-1} 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.

4.0 **Conclusion**

The soil disturbance due to the mining operation severely decreased the SOC stock as is evidenced by the low SOC stock (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 stock 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, and showed the unfilled C-sink capacity of reclaimed sites. The increases in SOC are important for improving soil and environment quality, and soil productivity.

5.0 **Tasks to be performed in the next Quarter (April- June 2004**

1. Collection of soil samples from remaining sites under similar age chronosequence under forest cover and determination of SOC and soil nitrogen concentrations, pH and electrical conductivity, and other soil physical properties,
2. Collection of core samples for determining soil bulk density and SOC stocks from each experimental field on a grid and at various landscape positions,
3. Identification and geo referencing of sampling points in each experimental field,
4. Performing statistical analysis for data on soil physical and chemical properties.

6.0 **References**

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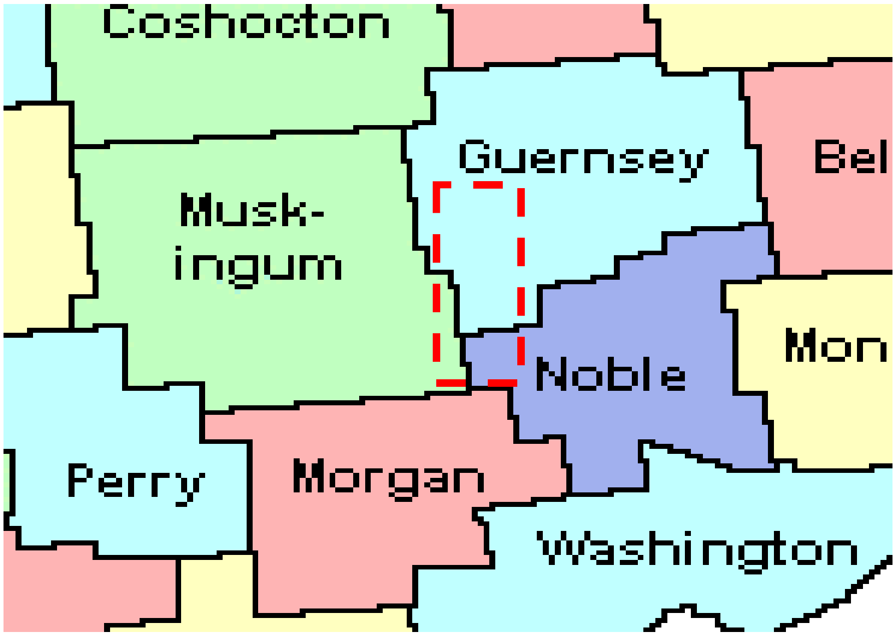

Fig. 1. The location map of experimental sites

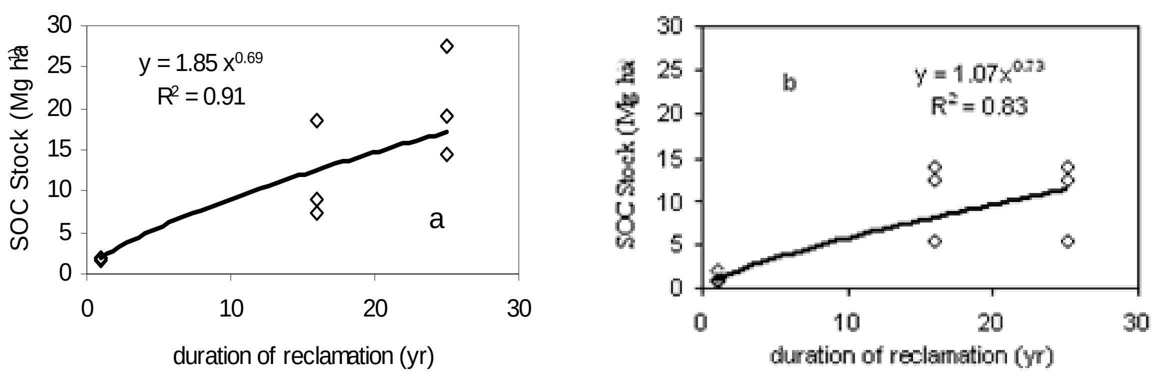

Fig. 2. Increase in SOC concentration with increasing age chronosequence of reclaimed soil with topsoil application under continuous grass cover: (a) for 0 to 15 cm depth, and (b) for 15-30 cm depth

Table 1. Soil physical and chemical properties in an age chronosequence of reclaimed minesoils with topsoil application and unmined control under continuous grass cover

Treatment	Control	R78	R87	R03	LSD (0.5)
			0-15 cm		
Sand (%)	9.28b	25.19a	12.61b	23.95a	9.36
Silt (%)	70.33a	53.67c	64.67ab	59.33bc	8.02
Clay (%)	20.39a	21.15a	22.72a	16.72b	2.73
ρ_b (Mg m^{-3})	0.96b	0.98b	1.02b	1.24a	0.16
pH	7.1b	8.3a	8.2a	6.3c	0.7
EC (dS m^{-1})	0.11c	0.22b	0.58a	0.06c	0.10
TN (g kg^{-1})	1.25a	1.07a	0.74b	0.34c	0.29
SOC (g kg^{-1})	12.94a	20.41a	11.64ab	1.90b	9.97
TN (Mg ha^{-1})	1.81a	1.58ab	1.14bc	0.64c	0.58
SOC (Mg ha^{-1})	18.7ab	30.1a	17.7ab	3.5c	14.7
VTP (cm^{-3} cm^{-3})	0.10	0.10	0.09	0.08	NS
VSP (cm^{-3} cm^{-3})	0.21	0.24	0.23	0.19	NS
AWC (cm^{-3} cm^{-3})	0.19	0.23	0.21	0.17	NS
Ks (cm min^{-1})	1.84	1.68	2.54	0.86	NS
			15-30 cm		
ρ_b (Mg m^{-3})	1.34b	1.40b	1.42b	1.61a	0.14
pH	5.8b	8.3a	8.3a	6.3c	1.1
EC (dS m^{-1})	0.07b	0.63a	0.63a	0.04b	0.26
TN (g kg^{-1})	0.45a	0.51a	0.51a	0.31b	0.08
SOC (g kg^{-1})	8.4a	10.6a	10.6a	1.2b	5.2
TN (Mg ha^{-1})	0.90ab	1.08a	1.10a	0.75b	0.25
SOC (Mg ha^{-1})	6.9b	22.2a	22.5a	2.9b	10.8

where ρ_b is soil bulk density, EC- electrical conductivity, TN is soil nitrogen concentration or stock, SOC is soil organic carbon concentration or stock, VTP and VSP are volumes of transport and storage pores, AWC is available water capacity, and Ks is saturated hydraulic conductivity

Table 2. Soil physical and chemical properties in an age chronosequence of reclaimed minesoils with without topsoil application under continuous grass (R56, and R69) and forest (R56-F)

Treatment	R57	R69	R57-F	LSD (0.5)
		0-15 cm		
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
ρ_b (Mg m^{-3})	0.88	0.98	1.02	NS
pH	8.3	8.2	8.1	NS
EC (dS m^{-1})	0.6	0.35	0.09	NS
TN (g kg^{-1})	1.50	1.93	1.83	NS
SOC (g kg^{-1})	43.6	39.01	33.78	NS
TN (Mg ha^{-1})	2.42	2.90	2.32	NS
SOC (Mg ha^{-1})	44.8	58.5	66.9	NS
VTP (cm^{-3} cm^{-3})	0.10ab	0.11a	0.09b	0.02
VSP (cm^{-3} cm^{-3})	0.16	0.21	0.17	NS
AWC (cm^{-3} cm^{-3})	0.15	0.19	0.15	NS
Ks (cm min^{-1})	2.20	2.12	1.95	NS
		15-30 cm		
ρ_b (Mg m^{-3})	1.62a	1.54ab	1.17b	0.42
pH	8.3	8.2	8.1	NS
EC (dS m^{-1})	0.6	0.35	0.09	NS
TN (g kg^{-1})	1.50	1.93	1.83	NS
SOC (g kg^{-1})	43.6	39.01	33.78	NS
TN (Mg ha^{-1})	1.57	1.07	2.14	NS
SOC (Mg ha^{-1})	50.9	71.8	50.5	NS