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Report Title: Carbon Sequestration in Reclaimed Mined Soils of Ohio

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ABSTRACT

This research project is aimed at assessing the soil organic carbon (SOC) sequestration potential of reclaimed minesoils (RMS). Experimental sites characterized by distinct age chronosequences of reclaimed minesoil were identified. These sites are owned by Americal Electrical Power and are located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio. The sites chosen were: (i) reclaimed without topsoil application (three under forest and three under continuous grass cover), (ii) reclaimed with topsoil application (three under forest and three under continuous grass cover) and (iii) unmined sites (one under forest and another grass cover). Soil samples were collected from 0 to 15 cm and 15 to 30 cm depths from each of the experimental site under continuous grass and SOC and, total nitrogen (TN) concentration, pH and electrical conductivity (EC) were determined. The results of the study for the quarter (30 September to 31 December, 2003) showed that soil pH was > 5.5 and EC < 4 dS m^{-1} for all sites and depths and therefore favorable for grass growth. Among the three reclamation treatments, SOC concentration increased from 1.9 g kg^{-1} for site reclaimed in 2003 (newly reclaimed and at baseline) to 11.64 g kg^{-1} for site reclaimed in 1987 (a 5-fold increase) to 20.41 g kg^{-1} for sites reclaimed in 1978 (a 10- fold increase). However, for sites reclaimed without topsoil application, soil pH, EC, SOC and TN concentrations were similar for both depths. The SOC concentrations in reclaimed sites with topsoil application in 0 to 15 cm depth increased from a base value of 0.7 g kg^{-1} at the rate of 0.76 g kg^{-1} yr^{-1}. The high SOC concentration for 0-15 cm layer for site reclaimed in 1978 showed the high carbon sequestration potential upon reclamation and establishment of the grass cover on minesoils.

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1.0 **Executive Summary**

This research project is aimed at assessing the soil organic carbon (SOC) sequestration potential of reclaimed mine soils (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.

In this project, several experimental sites were identified, which are characterized by distinct age chronosequences of reclaimed minesoil. These sites are located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio, and are owned by American Electrical Power. The sites selected were those: (i) reclaimed before 1972, and (ii) after 1972. 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.

The experimental sites identified for collecting soil samples were reclaimed with and without topsoil application and are under continuous grass and forest cover. A total of six sites were identified that were reclaimed with topsoil application, out of which three are under forest and three under continuous grass cover. Similarly, six sites were identified in reclaimed soil without topsoil application, out of which three are under forest and three 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 a gentle or a regular slope gradients and are easily accessible. The sites reclaimed before 1972 without topsoil application have steep and abrupt slope and are not easily accessible.

Soil samples were collected in December 2003 from 0 to 15 cm and 15 to 30 cm depths from each of the experimental site under continuous grass. A push probe sampler capable of collecting samples up to a depth of 30 cm was used. Three samples were collected from each experimental site. The samples were brought to the lab and were air-dried and SOC and total nitrogen (TN) concentrations, pH and electrical conductivity (EC) were determined. The results of the study showed that soil pH was > 5.5 and EC was < 4 dS m^{-1} for all the sites and depths and therefore favorable for grass growth. A comparison among the three reclaimed sites with topsoil application showed that SOC concentration increased from 1.9 g kg^{-1} for site reclaimed in 2003 to 11.64 g kg^{-1} for site reclaimed in 1987 (a 5-fold increase) to 20.41 g kg^{-1} for sites reclaimed in 1978 (a 10- fold increase). However, for sites reclaimed without topsoil application soil pH, EC, SOC and TN concentrations were similar for both depths. A

comparison between all the reclaimed sites under grass cover showed that older sites reclaimed without topsoil had higher SOC concentrations that younger sites reclaimed with topsoil application. The SOC concentrations for 0 to 15 cm depth in reclaimed sites with topsoil application increased from a base value of 0.7 g kg^{-1} at the rate of 0.76 g kg^{-1} yr^{-1}. The high SOC concentration 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 concentration is important for improving the soil and environment quality and soil productivity. The results of this study will be used to: (i) assess the degree to which soil carbon sequestration in RMS can offset fossil fuel emissions, (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 modifications to mitigate climate change due to greenhouse gas buildup in the atmosphere.

2.0 Experimental

2.1 Identification of Experimental Sites:

The objective was to identify experimental sites in Ohio characterized by distinct age chronosequences of reclaimed minesoil. Some important selection criteria were:

(i) 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

(ii) reclaimed after the 1972 Ohio Mineland Reclamation Act which made application of topsoil mandatory for reclamation, under continuous grass and forest and with topsoil application.

For making valid comparisons among soil properties, all the experimental sites must be located in the same eco-region. Several experimental sites have been identified with the support and cooperation of the American Electric Power (AEP). These experimental sites are located in and around the city of Cumberland, Guernsey County and also in Morgan, Noble, and Muskingum Counties of Ohio (Fig. 1). All experimental sites are owned by AEP.

2.2 **Identification of Age Chronosequences**:

The objective was to identify distinct age chronosequences comprising:

(iii) six sites reclaimed without topsoil application, three under continuous forest and three under continuous grass cover, and

(iv) six sites reclaimed with topsoil application (e.g., reclaimed after 1972), three under continuous forest and three under continuous grass cover.

Characteristics of selected age chronosequences are outlined in Tables 1 to 4. In addition, two unmined control sites were also identified, one each under continuous forest and grass cover.

2.3 **Approval for Access**:

The AEP has provided the approval for accessing the experimental sites. In this regard a memorandum of understanding was signed between the Ohio State University (Mr. William Shkurti) and AEP (Mr. T. Archer).

2.4 Collection of Soil Sample

Soil samples using a push probe were collected from 0 to 15 cm and 15 to 30 cm depths from each of the experimental site. Three soil samples were collected from each of the site reclaimed in 1978, 1987 and 2003 with topsoil application and under continuous grass cover. Similarly, three soil samples were collected from each of the sites reclaimed in 1956, 1969 (both under continuous grass cover) and 1956 (forest) without topsoil application. Soil samples were also collected from two unmined controls under: (i) grass, and (ii) grass-forest cover.

2.5 **Analysis of Soil Samples**

2.5.1 **Soil Organic Carbon Concentration**

All soil samples from both depths were air-dried, ground and passed through 0.5 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 (TC) 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.

2.5.2 **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).

2.5.3 **Statistical Analysis**

The analysis of variance (ANOVA) was computed using the randomized block design of the Statistical Analysis System (SAS Institute, 1989). Significant interactions ($P \leq 0.05$) and the least significant differences (LSD) for mean separation were calculated for chronosequence within: (i) topsoiled grass, and (ii) no topsoil, separately for each depth.

3.0 **Results and Discussion**

3.1 **Sites Reclaimed with Topsoil Application**

Data in Tables 5 and 6 show a comparison between chemical properties of soil under grass cover for age chronosequence of sites reclaimed with topsoil application and undisturbed soil for 0 to 15 cm and 15 to 30 cm depths. Soil pH varied in the order site reclaimed in 1978 = reclaimed in 1987 > unmined control > site reclaimed in 2003. Soil pH for 0 to 15 cm depth was the lowest for the youngest site reclaimed in 2003 (pH = 6.3), neutral (7.1) for unmined control and > 8.1 for sites reclaimed in 1978 and 1987. Soil pH was > 5.5 for all the sites and depths and was generally favorable for growth of grass.

Electrical conductivity of soil (EC) varied in the order site reclaimed in 1987 > control = site reclaimed in 2003 for both depths. The EC was lower for the site reclaimed in 1978 than reclaimed in 1978. The highest recorded EC of 0.63 dS m^{-1} among all sites and depths was much lower than the 4 dS m^{-1} limit and therefore was favorable for grass growth (Tables 5, 6). The low EC improved soil structure, increased water availability to plants, and enhanced root development and grass growth.

The total soil nitrogen concentration (TN) for 0 to 15 cm depth varied in the order unmined control = site reclaimed in 1978 > reclaimed in 1987 > reclaimed in 2003. For 15 to 30 cm depth, no significant differences were observed among control and sites reclaimed in 1978 and 1987 ($P<0.05$).

The soil organic carbon concentration for both depths was higher for control and for site reclaimed in 1978 than newly reclaimed site in 2003. Among the three reclamation treatments, the SOC concentration increased from 1.9 g kg^{-1} for site reclaimed in 2003 (newly reclaimed and at baseline) to 11.64 g kg^{-1} for site reclaimed in 1987 (a 5-fold increase) to 20.41 g kg^{-1} for sites reclaimed in 1978 (a 10- fold increase). The average C:N ratios ranged from 5.6 for site reclaimed in 2003 to 21.0 for site reclaimed in 1978. Since C:N ratio is < 30, N availability to plants is not limited and no fertilizer or manure application is necessary to facilitate the decomposition of residues and maintaining an upward trend for C sequestration in the soil.

3.2 **Sites Reclaimed Without Topsoil Application**

Data in Tables 7 and 8 present a comparison between soil chemical properties of two sites reclaimed in 1956 and 1969 and under grass cover, and one reclaimed in 1956 but under forest cover. These sites are probably one of the oldest sites reclaimed 9 to 22 years prior to 1977 SMRCA federal law. A comparison of soil pH and EC showed no significant differences among sites reclaimed in 1956, 1969 and 1956-F (forest). The pH was about 8.2 and EC < 0.6 dS m^{-1} for all sites and depths, and was favorable for plant growth. Soil nitrogen and SOC concentrations were also similar for both depths for sites reclaimed without topsoil application.

A comparison between soils reclaimed without topsoil and with topsoil application showed that the average SOC concentration for the former was higher than the later an indication of a high SOC sequestration potential. A comparison between sites reclaimed in 1978 with topsoil application and those reclaimed in 1956 without topsoil application under grass cover showed 3- folds increase in SOC concentration from 10.6 g kg^{-1} in 1978 to 39.0 g kg^{-1} in 1969. Among sites reclaimed in 2003 and 1956, 40- fold increase in SOC concentration from 1.2 g kg^{-1} to 39.0 g kg^{-1}, respectively, was observed.

3.3 **Soil Organic Carbon Concentration in Age Chronosequence**

Soil organic carbon concentrations for 0-15 cm depth increased with increase in age since reclamation and a linear relationship explained 76 % of variability in SOC concentrations with respect to age ($P<0.05$; Fig. 2). The SOC concentrations increased in 0 to 15 cm depth from a base value (or intercept) of 0.7 g kg^{-1} at the rate of 0.76 g kg^{-1} yr^{-1}. The high SOC concentration for 0-15 cm layer for site reclaimed in 1978 showed the high sequestration potential upon reclamation and establishment of the grass cover.

4.0 **Conclusion**

The soil disturbance due to the mining operation severely decreased the SOC concentrations as evidenced by the low concentration (1.9 g kg^{-1}) for site reclaimed in 2003 compared with 12.9 g kg^{-1} in the adjacent unmined control. Reclamation of mined soils increased the SOC concentration at the rate of 0.76 g kg^{-1} yr^{-1} in 0 to 15 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**

1. Collection of soil samples from remaining sites, which are under similar age chronosequence but planted or under forest cover for the determination of SOC concentration, soil nitrogen concentration, pH and electrical conductivity.
2. Collection of core samples for determining the bulk density and SOC stocks from each experimental field.
3. Identification and geo referencing of sampling points in each experimental field.

4. Identification of a missing site reclaimed in 1964 without topsoil application and under continuous grass cover.
5. Analysis of means for data on bulk density, SOC and soil nitrogen concentration and stocks, and pH and electrical conductivity.
6. Preparation of a report on "soil organic carbon sequestration rates for age chronosequence of reclaimed soils with and without topsoil application under pasture and grass cover".

6.0 **References**

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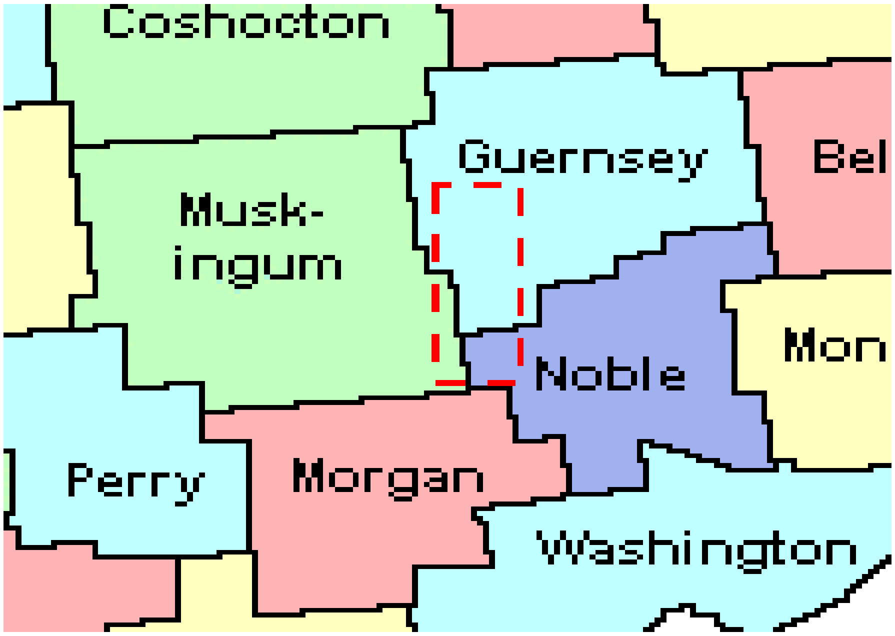

Fig. 1. The location map of experimental sites

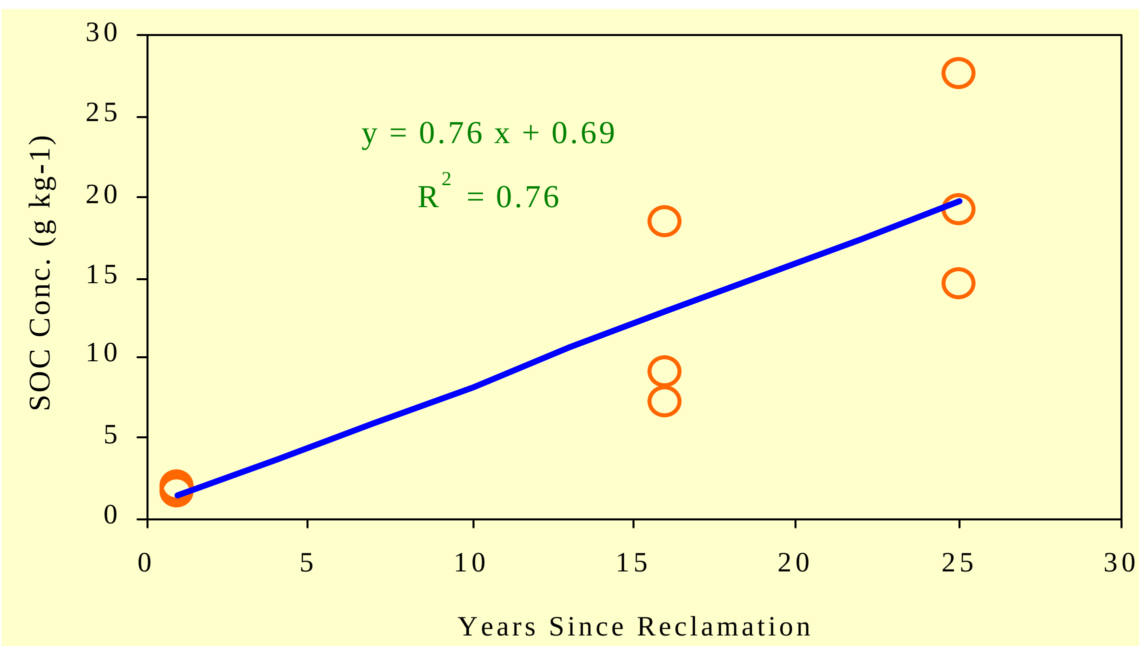

Fig. 2. Increase in SOC concentration with increasing age chronosequence of reclaimed soil with topsoil application under continuous grass cover for 0 to 15 cm depth

Table 1. Age chronosequence under continuous grass and with topsoil application

Site	Year Mined	Year Reclaimed	Age	Location ID	Longitude	Latitude
1	1976-77	1978	25	Wilds	81^{o}41.56’	39^{o}40.46’
2	1986-87	1987	16	Switch Grass Project	81^{o} 37.53’	39^{o} 47.50’
3	2002-03	2003	0	Active site	81^{o} 41.44	39^{o} 44.35’

Table 2. Age chronosequence under continuous grass and without topsoil application

Site	Year Mined	Year Reclaimed	Age	Location ID	Longitude	Latitude
1	1954-55	1956	25	Dyes fork	81^{o}41.56’	39^{o}40.46’
2	1963-64	1964	?	-		
3	1969	1969	0	Spencer Project	81^{o} 40.01	39^{o} 51.54’

Table 3. Age chronosequence under forest and with topsoil application

Site	Year Mined	Year Reclaimed	Year Planted	Age	Location ID	Longitude	Latitude
1	1972-73	1973	1977-78	25	Dyes fork	81^{o}41.56’	39^{o}40.46’
2	1982-83	1983	1995 (87)	8 (16)	Olive Green	81^{o}36.43	39^{o}44.53’
3	1993-94	1994	2002	1	Tilton’s Run	81^{o}41.39	39^{o}46.56’

Table 4. Age chronosequence under continuous grass and without topsoil application

Site	Year Mined	Year Reclaimed	Year Planted	Age	Location ID	Longitude	Latitude
1	1957	1957	1957	46	Dyes fork	81^{o}42.12’	39^{o}40.56’
2	1962	1962	1962	41	Composite D	81^{o}41.09	39^{o}43.33’
3	1969	1969	1969	34	Spencer Plantation	81^{o}41.39	39^{o}52.44’

Table 5. Soil pH, electrical conductivity (EC), soil nitrogen (TN) and soil organic carbon concentration for 0 to 15 cm depth in chronosequence of topsoiled and reclaimed minesoil and unmined control under continuous grass cover

Treatment	pH	EC ($dS\ m^{-1}$)	TN ($g\ kg^{-1}$)	SOC ($g\ kg^{-1}$)
Control	7.1b	0.11c	1.25a	12.94a
Reclaimed in 1978	8.3a	0.22b	1.07a	20.41a
Reclaimed in 1987	8.2a	0.58a	0.74b	11.64ab
Reclaimed in 2003	6.3c	0.06c	0.34c	1.90b
LSD (0.5)	0.7	0.10	0.29	9.97

Table 6. Soil pH, electrical conductivity (EC), soil nitrogen (TN) and soil organic carbon concentration for 15 to 30 cm depth in chronosequence of topsoiled and reclaimed minesoil and unmined control under continuous grass cover

Treatment	pH	EC ($dS\ m^{-1}$)	TN ($g\ kg^{-1}$)	SOC ($g\ kg^{-1}$)
Control	5.8b	0.07b	0.45a	8.4a
Reclaimed in 1978	8.3a	0.63a	0.51a	10.6a
Reclaimed in 1987	8.3a	0.63a	0.51a	10.6a
Reclaimed in 2003	6.3c	0.04b	0.31b	1.2b
LSD (0.5)	1.1	0.26	0.08	5.2

Table 7. Soil pH, electrical conductivity (EC), soil nitrogen (TN) and soil organic carbon concentration for 0 to 15 cm depth in chronosequence of reclaimed minesoil without topsoil under continuous grass and tree cover (F)

Treatment	pH	EC ($dS\ m^{-1}$)	TN ($g\ kg^{-1}$)	SOC ($g\ kg^{-1}$)
Reclaimed in 1956	8.3	0.6	1.50	43.6
Reclaimed in 1969	8.2	0.35	1.93	39.01
Reclaimed in 1956-F	8.1	0.09	1.83	33.78
LSD (0.5)	NS	NS	NS	NS

Table 8. Soil pH, electrical conductivity (EC), soil nitrogen (TN) and soil organic carbon concentration for 15 to 30 cm depth in chronosequence of reclaimed minesoil without topsoil under continuous grass and tree cover (F)

Treatment	pH	EC ($dS\ m^{-1}$)	TN ($g\ kg^{-1}$)	SOC ($g\ kg^{-1}$)
Reclaimed in 1956	8.3	0.6	1.50	43.6
Reclaimed in 1969	8.2	0.35	1.93	39.01
Reclaimed in 1956-F	8.1	0.09	1.83	33.78
LSD (0.5)	NS	NS	NS	NS