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ABSTRACT

Assessment of soil organic carbon (SOC) sequestration potential of reclaimed minesoils (RMS) is important for preserving environmental quality and increasing agronomic yields. The mechanism of physical SOC sequestration is achieved by encapsulation of SOC in spaces within macro and microaggregates. The experimental sites, owned and maintained by American Electrical Power, were characterized by distinct age chronosequences of reclaimed minesoils and were located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio. These sites were reclaimed both with and without topsoil application, and were under continuous grass or forest cover. In this report results are presented from the sites reclaimed in 1994 (R94-F), in 1987 (R87-G), in 1982 (R82-F), in 1978 (R78-G), in 1969 (R69-F), in1956 (R56-G), and from the unmined control (UMS-G). Three sites are under continuous grass cover and three under forest cover since reclamation. The samples were air dried and fractionated using a wet sieving technique into macro (> 2.0 mm), meso (0.25-2.0 mm) and microaggregates (0.053 - 0.25 mm). The soil C and N concentrations were determined by the dry combustion method on these aggregate fractions. Soil C and N concentrations were higher at the forest sites compared to the grass sites in each aggregate fraction for both depths. Statistical analyses indicated that the number of random samples taken was probably not sufficient to properly consider distribution of SOC and TN concentrations in aggregate size fractions for both depths at each site. Erosional effects on SOC and TN concentrations were, however, small. With increasing time since reclamation, SOC and total nitrogen (TN) concentrations also increased. The higher C and N concentrations in each aggregate size fraction in older than the newly reclaimed sites demonstrated the C sink capacity of newer sites.

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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) evaluating 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) establishing 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 that were reclaimed with or without topsoil application, out of which three are under forest and three under continuous grass cover. All sites reclaimed before 1972 without topsoil application under forest have steep and abrupt landscape and are not easily accessible. Soil samples were collected during December 2003 to August 2004 from 0-15 cm and 15-30 cm depths. In this report results are presented from the sites reclaimed in 1994 (R94-F), 1987 (R87-G), 1982 (R82-F), 1978 (R78-G), 1969 (R69-F) and 1956 (R56-G). Bulk soil samples were collected from each site from thirty sampling grid positions for 0-15 cm depth, and from four sampling grid positions for 15-30 cm depth. At the hilly sites, three bulk soil samples were collected from three landscape positions (upper, middle, and lower) for 0-15 cm and 15-30 cm depths. The soil C and N concentrations were determined by the dry combustion method on these aggregate fractions. Soil C and N concentrations were higher at the forest sites compared to the grass sites in each aggregate fraction for both depths. However, more random samples should be taken to properly consider distribution of SOC and TN concentrations in aggregate size fractions for each depth and site. Erosional effects on SOC and total nitrogen (TN) concentrations were small. With increase in time since reclamation, SOC and TN concentrations also increased. The higher C and N concentrations in each aggregate size fraction in older than the newly reclaimed sites demonstrated the high sequestration potential of newer sites.

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. This report includes the analysis of soil data from seven sites, two of them reclaimed without topsoil application (one each under grass and forest) and four with topsoil application (two each under grass and forest). The sites under continuous forest were reclaimed in 1994 (R94-F), 1982 (R82-F) and 1969 (R69-F), and the sites under grass cover were reclaimed in 1987 (R87-G), 1978 (R78-G), and 1956 (R56-G). The sites R94-F, R69-F and R56-G were hilly and, therefore, soil samples were collected from three landscape positions (upper, middle and lower) for each site and depth.

2.2 Collection of Soil Samples

Bulk soil samples were collected from each site from thirty sampling grid positions for 0-15 cm depth, and from four sampling grid positions for 15-30 cm depth. At the hilly sites, three bulk soil samples were collected from each landscape position (upper, middle, and lower) at each site and depth. These samples were air-dried in the lab at temperatures $<60^0$C.

2.3 Soil Organic Carbon and Nitrogen in Aggregate Fractions

Total carbon (TC) and total nitrogen (TN) concentrations were determined for aggregate fractions retained after wet sieving on 2.0 mm (macroaggregate), 0.25 mm (mesoaggregate) and 0.053 mm (microaggregate) sieves by the dry combustion method at 900^{o}C (Elementar, GmbH, Hanau, Germany). The aggregates were finely ground using a ball mill and sieved through 0.25 mm sieve before the C and N analyses. The carbonate concentration as determined by the acid drop-test on ground soil showed no effervescence. Therefore, TC was assumed equal to total soil organic carbon (SOC) concentration of aggregates.

2.4. Statistical Analysis

Descriptive statistics including mean, median, standard deviation, skewness, kurtosis, minimum, and maximum were obtained to characterize the distribution of SOC and TN concentrations among 30 sampling grid positions (0-15 cm depth) or among 4 sampling grid positions (15-30 cm depth) at each site using the Statistical Package for the Social Sciences (SPSS Inc., 2005). The mean should be calculated with data collected by random sampling sufficient numbers of sampling grid positions to properly consider the data distribution across the experimental site (Lozán, 1992). Calculation of the mean is, however, only reasonable if the values at the sampling grid positions are in the range of (i) the mean plus, and (ii) the mean minus the standard deviation. Otherwise, skewness and kurtosis characterize the data distribution relative to the normal distribution. For the normal distribution, skewness = 0 and kurtosis = 3. Any deviation in skewness and kurtosis in the data set is another indication that more random samples are required to properly consider the data distribution at a site. However, if the number of random samples is insufficient, the median is appropriate for comparing the data.

The analysis of variance (ANOVA) was computed for landscape position x sample within each site, and site x sample interactions among sites separately for each land use and depth. Significant mean interactions and the least significant differences (LSD) for mean separation were calculated using LSD multiple comparison method for $P \leq 0.05$ (SPSS Inc., 2005).

3.0 Results

3.1 **The Variability of Carbon and Nitrogen Concentrations in Aggregate Fractions**

Table 1 lists the descriptive statistics of the SOC and TN concentrations in aggregate fractions in 0-15 cm depth from the unmined control (UMS-G), and from the reclaimed sites Switch Grass (R87-G), Cumberland (R82-F) and Wilds (R78-G) including mean, median, standard deviation, skewness, kurtosis, minimum, and maximum values, respectively.

Minima and maxima SOC concentrations in aggregate fractions for UMS-G, R87-G, R82-F and R78-G were much lower or higher than calculated according to equations (i) or (ii) (Table 1). Furthermore, skewness and kurtosis indicated that the data were not normally distributed. Taking more than 30 random soil samples in 0-15 cm depth at each site is therefore required for proper characterization of SOC concentrations in aggregate fractions. However, the median values for SOC were higher in the > 2.0 mm, 0.25-2.0 mm and 0.053-0.25 mm aggregate fractions for R82-F (28.47 g kg^{-1}; 28.28 g kg^{-1}; 21.57 g kg^{-1}) than for the sites under continuous grass cover. The median values for SOC in > 2.0 mm aggregate fraction (macroaggregates), 0.25-2.0 mm fraction (mesoaggregates), and 0.053-0.25 mm fraction (microaggregates) were lowest for the unmined control (5.93 g kg^{-1}; 5.67 g kg^{-1}; 3.85 g kg^{-1}). In general, median SOC concentrations decreased with decrease in aggregate size but differences between > 2.0 mm aggregate fraction and 0.25-

2.0 mm fraction for R82-F and R78-G were small (28.47 g kg^{-1} and 17.50 g kg^{-1} vs. 28.28 g kg^{-1} and 18.05 g kg^{-1}, respectively).

Comparable to SOC, mean, median, standard deviation, kurtosis, skewness, minimum, and maximum values for TN concentrations in aggregate fractions in 0-15 cm depth indicated that data were not normally distributed (Table 1). The number of random samples was not sufficient to characterize TN concentrations for each site properly. However, the median values for TN were highest for R82-F in > 2.0 mm aggregate fraction, 0.25-2.0 mm fraction, and 0.053-0.25 mm fraction (1.83 g kg^{-1}; 1.82 g kg^{-1}; 1.28 g kg^{-1}). Median TN concentrations decreased with decrease in aggregate size but were equal in > 2.0 mm fraction and 0.25-2.0 mm fraction for R82-F.

Table 2 lists the descriptive statistics of the SOC and TN concentrations in aggregate fractions in 15-30 cm depth from the unmined control (UMS-G), and from the reclaimed sites Switch Grass (R87-G), Cumberland (R82-F) and Wilds (R78-G) including mean, median, standard deviation, skewness, kurtosis, minimum, and maximum values, respectively.

Compared to aggregate SOC concentrations in 0-15 cm depth, taking 4 random samples was more appropriate to characterize aggregate SOC fractions in 15-30 cm depth (Table 2). This was indicated by smaller differences between mean plus standard deviation, and between mean minus standard deviation, and minima and maxima. However, the data were not normally distributed as indicated by skewness and kurtosis. More than 4 random samples should therefore be taken in 15-30 cm depth to characterize SOC concentrations in aggregates size fractions properly.

However, the median values for SOC in > 2.0 mm aggregate fraction, 0.25-2.0 mm fraction, and 0.25-0.053 mm fraction were highest for R82-F (13.02 g kg^{-1}; 13.19 g kg^{-1}; 10.32 g kg^{-1}). Whereas SOC concentrations were lower in all aggregate fractions for UMS-G, R87-G and R78-G. The median values for SOC decreased for UMS-G with decrease in aggregate size (7.57 g kg^{-1}, 4.69 g kg^{-1}, and 3.38 g kg^{-1} for > 2.0 mm fraction, 0.25-2.0 mm fraction, and 0.053-0.25 mm fraction, respectively). For the other sites, median values for SOC were highest in the mesoaggregate fraction (0.25-2.0 mm).

The summary statistics for TN concentrations in aggregate size fractions in 15-30 cm indicated a more statistically sound characterization of each site compared to 0-15 cm depth, but data were not normally distributed (Table 2). More than 4 random samples should therefore be taken in 15-30 cm depth to properly characterize TN concentrations in aggregate size fractions. The median values for TN at R82-F and R78-G, however, were higher in all aggregate size fractions than UMS-G and R87-G. Median values for TN decreased for UMS-G with decrease in aggregate size (0.48 g kg^{-1}, 0.43 g kg^{-1}, and 0.41 g kg^{-1} for > 2.0 mm fraction, 0.25-2.0 mm fraction, and 0.053-0.25 mm fraction, respectively), but was highest in the mesoaggregate fractions for R87-G, R82-F and R78-G.

3.2 **Carbon and Nitrogen Concentrations in Aggregate Fractions**

3.2.1 Landscape position versus sample interactions in each site

For 0-15 cm and 15-30 cm depths, the SOC concentrations for R94-F and R69-F did not vary among different landscape positions for > 2.0 mm aggregate fractions (macroaggregate) as well as for 0.25-2.0 mm fractions (mesoaggregate) (Table 3). However, in the 0.053-0.25 mm fractions (microaggregate) for both depths for R69-F, SOC concentration was higher for MS (45.60 g kg^{-1} and 36.27 g kg^{-1}) than LS (28.57 g kg^{-1} and 18.14 g kg^{-1}) position. In R94-F and R69-F, SOC concentrations in microaggregates in 15-30 cm depth were higher for US than LS positions.

For 0-15 cm and 15–30 cm depths, TN concentrations did not vary for R94-F and R69-F among landscape positions for any aggregate fraction (Table 4). For R94-F, however, TN concentrations in 0-15 cm depth in 0.25-2.0 mm factions were higher for US (0.82 g kg^{-1}) than for MS (0.62 g kg^{-1}) positions.

3.2.2 Site versus sample interaction

Among forest sites, in general, SOC and TN concentrations increased with increase in duration since reclamation for all three aggregate size fractions for both depths (Tables 3 and 4). The SOC and TN concentrations in all three aggregate fractions were much higher in R69-F than R94-F for both depths.

4.0 **Discussion and Conclusions**

The forest sites had relatively higher SOC concentrations than the grass sites in all three aggregate size fractions for both depths. With increase in time since reclamation, SOC concentrations for R94-F, R82-F and R69-F, and for R87-G and R78-G increased in all three aggregate size fractions for both depths. Statistical analyses indicated that more random samples need be taken to properly consider the data distribution. However, the effects of erosion on SOC concentrations for R94-F and R69-F in all three aggregate size fractions for both depths were small. Comparable to SOC, TN concentrations increased with increase in time since reclamation in all three aggregates size fractions for both depths at the forest and grass sites. The effects of erosion on TN concentrations were, however, negligible for R94-F and R69-F in all three aggregate size fractions for both depths. The higher SOC and TN concentrations in older sites demonstrated the sequestration potential of younger sites.

5.0 **Tasks to be performed in the next Quarter (January - March 2006)**

We will continue to complete laboratory analyses:

1. Determine Saturated Hydraulic Conductivity
2. Determine Soil Moisture Characteristic Curves
3. Statistical Analysis of Data on Soil Physical and Chemical Properties

6.0 **References**

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Table 1. Summary statistics for SOC and TN concentrations in aggregate fractions in 0-15 cm depth (N=30)

	UMS-G			R87-G			R82-F			R78-G		
	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm
	---g SOC kg^{-1}---											
Mean	6.57	5.91	4.27	10.03	7.14	5.61	26.68	27.02	20.80	18.22	19.10	11.72
Median	5.93	5.67	3.85	9.17	7.10	5.57	28.47	28.28	21.57	17.50	18.05	10.46
Std Dev	2.95	2.67	2.32	4.58	2.14	1.78	8.72	9.17	7.49	6.68	6.47	4.38
Skewness	1.33	0.21	1.82	1.91	0.36	-0.10	-0.62	-0.40	-0.29	0.52	0.15	1.05
Kurtosis	2.99	-0.66	4.87	4.30	0.99	-0.58	-0.57	-0.81	-0.78	0.53	-0.73	1.26
Minimum	1.93	1.23	1.16	5.15	3.20	2.12	8.55	9.13	6.28	6.29	6.54	4.34
Maximum	16.46	11.85	12.50	25.09	13.15	9.07	40.08	40.97	33.04	36.20	32.23	24.34
	---g TN kg^{-1}---											
Mean	0.64	0.61	0.49	0.75	0.56	0.46	1.80	1.79	1.32	1.72	1.79	1.12
Median	0.62	0.59	0.45	0.71	0.54	0.43	1.83	1.82	1.28	1.77	1.69	1.07
Std Dev	0.24	0.18	0.19	0.24	0.12	0.11	0.47	0.47	0.38	0.55	0.53	0.32
Skewness	1.08	0.34	2.99	0.83	0.42	1.06	-0.33	-0.11	0.27	0.21	0.03	0.59
Kurtosis	1.35	-0.46	13.2	0.53	-0.55	1.05	-0.73	-1.19	-0.52	0.01	-0.90	0.10
Minimum	0.31	0.29	0.21	0.43	0.36	0.30	0.85	0.94	0.66	0.66	0.70	0.50
Maximum	1.36	0.97	1.33	1.42	0.79	0.78	2.58	2.58	2.12	3.04	2.68	1.84

Table 2. Summary statistics for SOC and TN concentrations in aggregate fractions in 15-30 cm depth (N=4)

	UMS-G			R87-G			R82-F			R78-G		
	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm	> 2.0 mm	0.25-2.0 mm	0.053-0.25 mm
	------------------g SOC kg^{-1}------------------											
Mean	7.51	6.00	4.98	5.14	5.77	5.43	12.53	13.43	10.06	7.05	8.66	5.50
Median	7.57	4.69	3.38	4.72	5.90	4.44	13.02	13.19	10.32	7.22	8.39	5.32
Std Dev	5.26	4.94	4.35	2.57	2.46	3.70	7.54	7.53	5.66	0.54	1.07	0.92
Skewness	-0.05	0.91	1.52	0.59	-0.16	1.22	-0.11	0.12	-0.16	-1.31	1.07	0.85
Kurtosis	-	-1.01	1.99	-2.23	-4.10	0.94	-5.26	-2.88	-3.38	-	-	-
Minimum	2.22	2.10	1.95	2.77	3.04	2.28	4.68	5.32	3.65	6.44	7.75	4.69
Maximum	12.74	12.51	11.21	8.35	8.22	10.56	19.41	22.02	15.95	7.48	9.84	6.49
	------------------g TN kg^{-1}------------------											
Mean	0.49	0.46	0.42	0.35	0.41	0.34	0.70	0.76	0.56	0.72	0.76	0.52
Median	0.48	0.43	0.41	0.33	0.38	0.31	0.60	0.73	0.56	0.68	0.81	0.51
Std Dev	0.15	0.16	0.12	0.07	0.09	0.07	0.30	0.29	0.17	0.09	0.10	0.10
Skewness	0.38	0.55	0.11	1.46	1.17	1.90	1.70	0.53	0.06	1.55	-1.63	0.53
Kurtosis	-	-2.92	-5.21	1.81	0.32	3.64	3.13	0.52	0.68	-	-	-
Minimum	0.34	0.33	0.31	0.30	0.34	0.30	0.47	0.45	0.36	0.65	0.65	0.43
Maximum	0.64	0.66	0.55	0.45	0.53	0.44	1.14	1.13	0.77	0.82	0.83	0.63

Table 3. SOC concentrations in aggregate fractions in 0-15 cm and 15-30 cm depths separated for landscape positions

Position	R94-F	R69-F	R56-G	LSD	R94-F	R69-F	R56-G	LSD
		0-15 cm				15-30 cm		
	-------------------g kg^{-1}-------------				-------------------g kg^{-1}----------------			
> 2.0 mm								
US	10.03	42.83	48.65	32.95	5.73	45.04	30.87	39.31
MS	11.99	58.86			4.76	48.37		
LS	12.99	44.55			4.43	34.22		
LSD	NS	NS			NS	NS		
0.25-2.0 mm								
US	11.17	57.03	46.75	35.58	5.82	46.48	28.15	40.66
MS	9.87	60.33			4.72	42.97		
LS	9.72	40.89			4.87	24.70		
LSD	NS	NS			NS	NS		
0.053-0.25 mm								
US	12.32	40.94	41.73	28.62	5.71	25.06	24.06	18.35
MS	6.38	45.60			3.33	36.27		
LS	7.66	28.57			3.47	18.14		
LSD	NS	17.03			2.24	6.92		

Table 4. TN concentrations in aggregate fractions in 0-15 cm and 15-30 cm depths separated for landscape positions

Position	R94-F	R69-F	R56-G	LSD	R94-F	R69-F	R56-G	LSD
		0-15 cm				15-30 cm		
	-----------------g kg^{-1}------------				---------------------g kg^{-1}--------------			
> 2.0 mm								
US	1.36	2.92	3.57	1.60	0.61	1.23	1.50	NS
MS	1.16	2.76			0.53	1.44		
LS	1.24	2.39			0.89	1.51		
LSD	NS	NS			NS	NS		
0.25-2.0 mm								
US	0.90	2.99	3.13	2.09	0.60	1.38	1.31	NS
MS	0.91	2.91			0.49	1.30		
LS	0.86	2.06			0.57	1.00		
LSD	NS	NS			NS	NS		
0.053-0.25 mm								
US	0.82	1.87	2.52	1.04	0.52	0.79	1.12	0.60
MS	0.62	1.92			0.38	0.88		
LS	0.66	1.46			0.44	0.74		
LSD	0.20	NS			NS	NS		