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Report Title: Carbon Sequestration in Reclaimed Mined Soils of Ohio

Type of Report: Progress Report for 5th Quarter

Reporting Period Start Date: 1 January 2005

Reporting Period End Date: 31 March 2005

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Date Report was issued: Month [April] Year [2005]

DOE Award No: DE-FC26-03NT41903

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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 SOM 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 2003 (R03-G), in 1973 (R73-F), in 1969 (R69-G), in 1962 (R62-G and R62-F) and in1957 (R57-F). Three sites are under continuous grass cover and the three under forest cover since reclamation. Three bulk soil samples were collected from each site from three landscape positions (upper; middle, and lower) for 0-15 and 15-30 cm depths. The samples were air dried and using wet sieving technique were fractionated into macro (> 2mm), meso (2-0.25 mm) and microaggregate (0.25-0.053 mm). These fractions were weighted separately and water stable aggregation (WSA) and geometric mean (GMD) and mean weight (MWD) diameters of aggregates were obtained. The soil C and N concentrations were also determined on these aggregate fractions. Analysis of mean values showed that in general, WSA and MWD of aggregates increased with increasing duration since reclamation or age of reclaimed soil for all three landscape positions and two depths in sites under continuous grass. The forest sites were relatively older than grass sites and therefore WSA or MWD of aggregates did not show any increases with age since reclamation. The lower WSA in R57-F site than R73-F clearly showed the effect of soil erosion on aggregate stability. Higher aggregation and aggregate diameters in R73-F than R62-F and R57-F also showed the importance of reclamation with topsoil application on improving soil structure. Soil C and N concentrations were lowest for the site reclaimed in year 2003 in each aggregate fraction for both depths. The higher C and N concentrations each aggregate size fraction in older sites than the newly reclaimed site demonstrated the sequestration potential of younger 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 reclaimed 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 2003 (R03-G), in 1973 (R73-F), in 1969 (R69-G), in 1962 (R62-G and R62-F) and in1957 (R57-F). Three core and three bulk soil samples were collected from each site from three landscape positions (upper; middle, and lower) for 0-15 cm and 15-30 cm depths. In general, water stable aggregation and diameters of aggregates increased with increasing duration since reclamation or age of reclaimed soil for all three landscape positions and two depths in sites under grass cover. The sites under forest cover were relatively older than grass sites and therefore water stable aggregation or diameters did not show any increases with age. The lower aggregation in R57-F site clearly showed the effect of soil erosion on aggregate stability. Higher aggregation and aggregate diameters in R73-F than R62-F and R57-F also showed the importance of reclamation and topsoil application on improving soil structure. Soil C and N concentrations in each aggregate fraction were the lowest for site reclaimed in year 2003. Higher C and N concentrations in older sites than newly reclaimed site demonstrated the sequestration potential of younger 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 (Fig. 1). This report includes the analysis of soil data from six sites, four of them reclaimed without topsoil application (Two under grass and two under forest) and two with topsoil application (one each under grass and forest). The sites under continuous forest, were reclaimed in year 1973 (R73-F), 1962 (R62-F) and 1957 (R57-F and the sites under grass cover were reclaimed in 2003 (R03-G), 1969 (R69-G), and 1962 (R62-G). All these sites were hilly and therefore, three soil samples were collected from each landscape position (upper, middle and lower) in each site and depth.

2.2 Collection of Soil Sample

Bulk samples were collected in triplicates from each of the experimental sites from 0-15 and 15-30 cm depths for three landscape positions. These samples were air-dried in the lab at temperatures $<60^0$C.

2.3 Analysis of Soil Samples

2.3.1 Water Stable Aggregation

The air-dried bulk soil samples were first passed through wooden rollers to break down clods. Subsequently, they were passed through nested sieves of 5 mm and 2 mm diameters to separate aggregates from the remaining soil. The portion passing through 5 mm sieve but retained on 2 mm sieve was stored separately. About 50 g of dry aggregates between 5 and 2 mm size were placed on the 2 mm sieve and were allowed to saturate by capillary rise before wet-sieving. The weights retained on 2 mm, 0.25 mm and 0.053 mm sieves were air dried and stones and gravels were removed before weighing. The water stable aggregation (WSA), geometric (GMD) and mean weight (MWD) diameters of aggregates were determined by using the procedure of Yoder (1936) and Youker and McGuinness (1957).

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 mm (macro aggregate), 0.25 mm (meso aggregate) 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: N analysis. The carbonate content 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

The analysis of variance (ANOVA) was computed for landscape position x sample within each site, and site x sample interactions among sites using Statistical Analysis System (SAS Institute, 1989) separately for each land use and depth. Significant mean interactions and the least significant differences (LSD) for mean separation were calculated using Bonferroni multiple comparison method for $P \leq 0.05$.

3.0 Results

3.1 **Water Stable Aggregation and Aggregate diameters**

3.1.1 Landscape position versus sample interactions in each site

For 0-15 cm depth in sites under grass cover, WSA in R03-G was higher on US (67.59%) than MS (43.19%) or LS (42.65%) positions (Table 1). The GMD did not differ significantly among landscape positions but MWD of aggregates was higher on US (1.1 mm) than MS (0.64 mm) or LS (0.53 mm) in R03-G. In R69-G, WSA was higher for LS (81.22%) than MS (66.17%) position. The GMD did not differ and MWD was higher for LS (2.21 mm) than MS (1.75 mm) in R69-G. No significant differences were obtained in WSA, GMD or MWD among different landscape positions in R62-G. For 15-30 cm depth in sites under grass cover, no significant differences were obtained in WSA, GMD or MWD values among different landscape positions in R03-G, R69-G or R62-G (Table 1). However, WSA, GMD and MWD values were higher for 0-15 than 15-30 cm depth for all landscape positions and sites.

For sites under forest cover, no significant differences in WSA, GMD and MWD were obtained in three landscape positions in R73-F, R62-F or R57-F for either depth (Table 2). However, WSA values were consistently higher for 0-15 than 15-30 cm for all three landscape positions in each of the forested site. Most GMD and MWD values were also higher for 0-15 than 15-30 cm depth across landscape position.

3.1.2 Site versus sample interaction

For 0-15 cm depth in sites under grass cover, WSA increased with increasing duration since reclamation for all landscape positions and depths. The WSA was significantly higher for R62-G (81.37% in US and 83.7% in MS) than R69-G (70.61% and 66.17%) than R03-G (67.59% and 43.19%). For LS, significant differences in WSA, GMD and MWD varied in the order R62-G = R69-G > R03-G (Tables 1; 3). The GMD and WMD also increased with increasing duration since reclamation for all landscape positions and depths and varied in the order R62-G = R69-G > R03-G. For 15-30 cm depth, no significant differences were obtained in WSA or MWD among various sites. The GMD was significantly higher in R62-G and R69-G than R03-G for MS only (Tables 1; 3).

For 0-15 cm depth in sites under forest cover, no differences were obtained in WSA, GMD or MWD among sites for US position. The WSA varied in the order R73-F = R69-F > R69-F for MS and LS positions. No significant differences were obtained in GMD among sites and landscape positions. The MWD varied in the order R73-F = R69-F > R69-F for LS position only. For 15-30 cm depth, significant differences were obtained for WSA in US and MS positions and MWD for MS only (Tables 2; 3). Among forest sites, only R73-F was reclaimed with topsoil application and had higher WSA, GMD or MWD than R57-F. The R73-F and R62-F were under denser forest cover than R57-F. Therefore, aggregate breakdown due to rainfall seem to be less pronounced in R73-F and R62-F than R57-F.

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

3.2.1 Landscape position versus sample interactions in each site

For 0-15 cm depth, the SOC concentration did not vary among different landscape positions in R03-G for > 2 mm aggregate fractions (macroaggregate) as well as for 2-0.25 mm fraction (mesoaggregate) (Table 4). However, in 0.25-0.053 mm fraction (microaggregate), SOC concentration was higher for LS (2.03 g kg^{-1}) than US (1.40 g kg^{-1}) or MS (1.44 g kg^{-1}) position. In R69-G, SOC concentrations in macro and microaggregates were always higher for US than LS positions. However, in R62-G, SOC concentrations in macro and microaggregates were higher in LS than MS position (Table 4). For 15-30 cm depths, no significant differences in SOC concentrations were obtained in R03-G among three landscape positions for macro, meso or microaggregate fractions (Table 5). The SOC concentrations were higher for macro and mesoaggregates for MS than US in R69-G and MS and LS for microaggregate fractions only in R62-G (Table 5).

Among the three forests sites, no significant differences in SOC concentrations were obtained within landscape positions for R73-F and R62-F for either aggregate size fraction or depth. However, US and LS positions had higher SOC concentration than MS position in meso and microaggregate fractions in R57-F for 0-15 cm depth only (Table 5).

For 0-15 cm depth, TN concentrations did not vary in R03-G and R62-G among landscape positions for any aggregate fraction (Table 6). In R69-G, significant differences in TN concentrations were observed between US and MS for microaggregate fraction only. For 15-30 cm depth, TN concentrations were higher for LS than MS position for all three aggregate fractions in R03-G (Table 7). The TN concentrations were higher for MS than US or LS for all macro and meso aggregate fractions in R69-G. However, no significant differences in TN concentrations were obtained in R62-G for either aggregate fraction or depth.

Among forest sites, TN concentrations did not vary among landscape positions for either depth or aggregate fraction in R73-F and R62-F. However, they did for 0-15 cm depth only in R57-F with higher TN concentration in US than MS or LS for all size fractions.

3.2.2 Site versus sample interaction

Among grass sites, the SOC concentration was always least for R03-G for all three landscape positions and both depths (Tables 4; 5). Few significant differences in SOC concentrations were obtained between R69-G and R62-G for either aggregate fraction or depth (Tables 4; 5). In general higher SOC concentration was obtained for macro and meso aggregate than microaggregate fractions for both depths. Among forest sites, in general, SOC concentrations increased with increasing duration since reclamation for all three aggregate size fractions for both depths (Tables 5; 6; 8). The SOC concentrations in all three aggregate fractions were much higher in R57-F than R73-F or R62-F for both depths.

Among grass sites, TN concentrations in aggregate fractions followed the same trend as that for the SOC concentration with lowest TN concentrations being obtained for R03-G in each fraction and depth (Tables 6; 7). Few significant differences in TN concentrations were obtained between R69-G and R62-G. Among forest sites, Very few differences in TN concentrations were obtained in MS position across aggregate fractions for both depths (Tables 6; 7; 8). In general TN concentrations were higher in R73-F than R57-F in macroaggregate fraction and lower in microaggregate fractions for both depths and landscape positions.

4.0 **Discussion and Conclusions**

Water stable aggregation and diameters of aggregates increased with increasing duration since reclamation or age of reclaimed soil for all three landscape positions and two depths in sites under grass cover. The low aggregation and aggregate diameters, and small soil organic C and soil nitrogen concentrations in each of the macro, meso and microaggregate fraction for recently reclaimed site (R03-F) showed the drastic effects of surface mining on soil structure. The forest sites were relatively older than grass sites and therefore water stable aggregation or diameters of aggregates did not show any increases with age since reclamation. The lower aggregation in R57-F site indicated to the effects of rainfall impact and associated soil erosion, other climatic effects such as freeze thaw cycles etc. on aggregate stability. Higher aggregation and aggregate diameters in R73-F than R57-F showed the importance of reclamation and topsoil application on improving soil structure. The SOC and soil N concentrations were lowest for the site reclaimed in year 2003. The higher SOC and soil N concentrations in older sites demonstrated the sequestration potential of younger sites.

5.0 **Tasks to be performed in the next Quarter (April- June 2005)**

We will continue to perform laboratory analysis on determining:

1. Continue collecting core and bulk soil samples from experimental plots
2. Conduct water infiltration tests on plots
3. Determine SOC and soil N concentrations using bulk soil samples

6.0 **References**

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(A) R03-G

(B) R69-G

(C) R56-F

(D) R69-F

Fig. 1. Map of the experimental sites reclaimed without topsoil application (A) in 1956 under grass cover (R56-G), (B) in 1969 under grass cover (R69-G), (C) in 1956 under forest cover (R56-F), and (D) in 1969 under forest cover (R69-F)

Table 1. The mean water stable aggregation (WSA, %), geometric mean (GMD, mm) and mean weight (MWD, mm) diameters of aggregates for upper (US), middle (MS) and lower (LS) landscape positions in age chronosequence of reclaimed minesoils under grass cover

Position	R03-G	R69-G WSA	R62-G (%)	R03-G	R69-G GMD	R62-G (mm)	R03-G	R69-G MWD	R62-G (mm)
				0-15 cm depth					
US	67.59	70.61	81.37	0.98	1.39	1.53	1.10	1.94	2.53
MS	43.19	66.17	83.70	0.95	1.35	1.51	0.64	1.75	2.52
LS	42.65	81.22	84.18	0.85	1.39	1.55	0.53	2.21	2.61
LSD	17.12	13.50	NS	NS	NS	NS	0.21	0.45	NS
				15-30 cm depth					
US	37.61	67.05	64.64	0.98	1.22	1.21	0.53	1.58	1.51
MS	48.09	57.30	68.99	0.74	1.17	1.18	0.50	1.31	1.55
LS	48.54	58.93	65.98	0.89	1.15	1.20	0.60	1.28	1.43
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS

R03-G, R69-G, and R62-G are sites reclaimed in 2003, 1969 and 1962 and are under grass cover,

Table 2. The mean water stable aggregation (WSA, %), geometric mean (GMD, mm) and mean weight (MWD, mm) diameters of aggregates for upper (US), middle (MS) and lower (LS) landscape positions in age chronosequence of reclaimed minesoils under tree cover

Position	R73-F	R62-F WSA (%)	R57-F	R73-F	R62-F GMD (mm)	R57-F	R73-F	R62-F MWD (mm)	R57-F
				0-15 cm depth					
US	93.49	84.77	71.65	1.54	1.30	1.36	2.81	2.14	1.78
MS	91.87	91.43	77.45	1.48	1.39	1.34	2.62	2.48	2.00
LS	91.85	93.34	69.49	1.46	1.47	1.23	2.61	2.63	1.52
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
				15-30 cm depth					
US	83.37	85.24	64.88	1.22	1.37	1.11	1.87	2.27	1.27
MS	88.57	84.78	63.70	1.12	1.22	1.13	1.64	2.00	1.25
LS	79.63	82.65	66.47	1.22	1.02	1.12	1.68	1.50	1.33
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS

R73F, R62-F, and R57-F are sites reclaimed in 1973, 1962 and 1957 and are under forest cover

Table 3. The least square deviations (LSD, 0.05) values for aggregates properties under different fields under grass and forest cover for treatment x sample interaction for each landscape position

		Grass			Forest	
Position	US	MS	LS	US	MS	LS
			0-15 cm depth			
WSA (%)	9.55	9.86	22.32	NS	7.03	7.51
GMD (mm)	0.20	0.32	0.23	NS	NS	NS
MWD (mm)	0.57	0.59	0.72	NS	NS	0.73
			15-30 cm depth			
WSA (%)	NS	NS	NS	11.36	5.70	NS
GMD (mm)	NS	0.25	NS	NS	NS	NS
MWD (mm)	NS	NS	NS	NS	0.55	NS

Table 4. SOC concentration in aggregate fractions in 0-15 cm depth

Position	R03-G	R69-G	R62-G	R73-F	R62-F	R57-F
	---------------------------g kg^{-1} ----------------------------------					
> 2 mm						
US	2.50	44.37	28.78	21.97	29.39	38.60
MS	1.91	32.99	24.77	19.42	33.41	26.85
LS	2.52	29.05	39.19	22.67	13.72	38.65
LSD	NS	14.83	13.19	NS	NS	NS
2 - 0.25 mm						
US	2.22	45.57	27.31	14.13	25.99	37.03
MS	2.50	32.54	27.29	13.18	32.77	22.98
LS	3.02	30.38	32.82	12.42	13.98	33.67
LSD	NS	NS	NS	NS	NS	12.70
0.25 - 0.053 mm						
US	1.40	34.05	25.72	14.70	22.45	26.63
MS	1.44	25.69	20.25	12.90	24.24	21.29
LS	2.03	24.87	32.24	12.64	10.52	38.05
LSD	0.49	6.40	10.41	NS	NS	10.55

Table 5. SOC concentration in aggregate fractions in 15-30 cm depth

Position	R03-G	R69-G	R62-G	R73-F	R62-F	R57-F
	---------------------------g kg^{-1} ----------------------------------					
> 2 mm						
US	1.37	13.76	31.21	15.55	24.53	30.26
MS	0.72	49.97	41.35	22.43	14.07	32.95
LS	7.79	29.24	33.06	13.06	19.53	40.95
LSD	NS	24.11	NS	NS	NS	NS
2 - 0.25 mm						
US	1.35	13.63	29.33	6.76	23.77	30.81
MS	1.41	49.30	37.86	12.04	16.45	38.56
LS	7.90	34.80	30.68	9.95	13.58	46.38
LSD	NS	19.78	NS	NS	NS	NS
0.25 - 0.053 mm						
US	1.34	12.17	31.22	7.22	21.81	23.91
MS	1.25	36.95	35.58	12.31	10.46	31.35
LS	4.68	24.97	27.58	7.33	9.57	36.37
LSD	NS	NS	7.83	NS	NS	NS

Table 6. Nitrogen concentration in aggregate fractions in 0-15 cm depth

Position	R03-G	R69-G	R62-G	R73-F	R62-F	R57-F
	---------------------------g kg^{-1} -----------------------------------					
> 2 mm						
US	0.37	2.88	1.48	1.92	1.14	2.54
MS	0.29	1.63	1.45	1.64	0.64	1.15
LS	0.32	1.66	1.86	2.10	0.59	1.46
LSD	NS	NS	NS	NS	NS	1.01
2 - 0.25 mm						
US	0.37	2.63	1.20	1.18	1.17	2.46
MS	0.31	1.42	1.37	1.15	0.83	1.11
LS	0.35	1.62	1.47	1.05	0.95	1.49
LSD	NS	NS	NS	NS	NS	1.01
0.25 - 0.053 mm						
US	0.33	1.96	0.86	1.02	0.67	1.63
MS	0.25	0.99	1.01	1.04	0.66	0.85
LS	0.30	1.40	1.15	1.05	0.69	1.18
LSD	NS	0.79	NS	NS	NS	0.73

Table 7. Nitrogen concentration in aggregate fractions in the 15-30 cm depth

Position	R03-G	R69-G	R62-G	R73-F	R62-F	R57-F
	---------------------------g kg^{-1} -----------------------------------					
> 2 mm						
US	0.30	0.81	1.18	1.51	1.26	1.46
MS	0.20	3.16	2.32	1.96	1.03	1.62
LS	0.43	1.19	1.27	1.15	1.26	1.34
LSD	0.19	1.51	NS	NS	NS	NS
2 - 0.25 mm						
US	0.32	0.80	1.01	0.70	1.33	1.65
MS	0.26	2.86	1.81	1.02	1.22	2.02
LS	0.47	1.48	0.94	0.91	1.01	1.93
LSD	0.16	1.76	NS	NS	NS	NS
0.25 - 0.053 mm						
US	0.30	0.69	0.79	0.81	0.94	1.20
MS	0.22	2.15	1.32	0.95	0.81	1.36
LS	0.38	0.98	0.63	0.74	0.73	1.18
LSD	0.16	NS	NS	NS	NS	NS