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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 mine soils (RMS). The experimental sites were characterized by distinct age chronosequences of reclaimed mine soil and were located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio. These sites are owned and maintained by American Electrical Power. These sites were reclaimed (1) with topsoil application, and (2) without topsoil application, and were under continuous grass or forest cover. This report presents the results from two forest sites reclaimed with topsoil application and reclaimed in 1994 (R94-F) and in 1973 (R73-F), and two forest sites without topsoil application and reclaimed in 1969 (R69-F) and 1962 (R62-F). Results from one site under grass without topsoil application and reclaimed in 1962 (R62-G) are also shown. Three core soil samples were collected from each of the experimental sites and each landscape position (upper, middle and lower) for 0-15 and 15-30 cm depths, and saturated hydraulic conductivity (Ks), volumes of transport (VTP) pores, and available water capacity (AWC) were determined.

No significant differences were observed in VTP and AWC in 0-15 cm and 15-30 cm depths among the sites R94-F and R73-F reclaimed with topsoil application and under continuous forest cover ($P<0.05$). VTP and AWC did also not differ among upper, middle and lower landscape positions. However, saturated hydraulic conductivity in 0-15 cm depth at R73-F was significantly lower at the lower compared to the upper landscape position. No significant differences were observed for Ks among landscape positions at R94-F. No significant differences were observed in VTP and AWC among landscape positions and depths within R69-F, R62-F and R62-G. However, saturated hydraulic conductivity was higher in 0-15 cm depth at R62-F than at R69-F and R62-G. At the latter site, Ks was higher in the upper compared to the lower

landscape position whereas Ks did not differ among landscape positions at the other sites. Statistical analyses indicated that the number of random samples taken was probably not sufficient to properly consider distribution of VTP and AWC in 0-15 cm and 15-30 cm depths across the sites, in particular for the sites without topsoil application.

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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.

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 its 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 forest). All these sites are characterized by distinct age chronosequences of reclaimed mine soil, and sites are located in Guernsey, Morgan, Noble, and Muskingum Counties of Ohio, and are maintained and owned by American Electrical Power.

Three core soil samples were collected in 0-15 cm and 15-30 cm depths at upper, middle and lower landscape positions from each of the experimental sites and saturated hydraulic conductivity (Ks), volumes of transport (VTP) pores, available water capacity (AWC) were determined on soil cores. The results of the study from sites reclaimed with topsoil and under forest (R94-F and R73-F) indicate that VTP and AWC did not differ among landscape positions and sites for 0-15 cm and 15-30 cm depths. Saturated hydraulic conductivity was also not different among sites but the lower landscape position at R73-F had significantly lower Ks compared to the upper landscape position. Among the sites reclaimed without topsoil (R69-F, R62-F and R62-G), VTP and AWC did not differ significantly in 0-15 cm and 15-30 cm depths. This was also the case among landscape positions. However, saturated hydraulic conductivity in 0-15 cm depth was higher at R62-F than at R69-F and R62-G. Furthermore, Ks at the upper landscape position at R62-G was higher than at the lower landscape position. Statistical analysis indicated that in particular at the reclaimed mine sites without topsoil application the number of random samples taken was not sufficient to properly consider spatial distribution of VTP and AWC.

2.0 Experimental

2.1 Experimental Sites:

The experimental sites were: (1) reclaimed prior to the 1972 Ohio Mineland Reclamation Act or the 1977 surface mining reclamation and control act (SMRCA), under continuous grass or 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 or forest. The sites Tilton's Run, Mt. Carmel, Spencer, Campsite D and Singer 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 grass and two under continuous forest cover, and (ii) two sites reclaimed with topsoil application and under continuous forest cover. The sites 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 Sample

Three core samples were collected at each landscape position (upper, middle, and lower) using 6 cm long and 6 cm diameter stainless steel cores from each of the experimental sites reclaimed in 1994 (Tilton's Run: R94-F) and 1973 (Mt. Carmel: R73-F) with topsoil application and under continuous forest cover from 0-15 and 15-30 cm depths. Similarly, three core soil samples were collected from each of the sites reclaimed in 1969 (Spencer: R69-F) and 1962 (Campsite D: R62-F) both under continuous forest cover, and from a site reclaimed in 1962 (Singer: R62-G) under continuous grass cover without topsoil application. For saturated hydraulic conductivity, two core samples were collected at each landscape position and 0-15 cm depth using 7.5 cm long and 7.5 cm diameter stainless steel cores from each of the experimental sites.

2.3 **Analysis of Soil Samples**

2.3.1 **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).

2.3.2 **Saturated Hydraulic Conductivity**

The saturated hydraulic conductivity (K_s) was determined in the laboratory for intact soil cores by the constant head permeameter method (Klute and Dirkson, 1986).

2.4. **Statistical Analysis**

The analysis of variance (ANOVA) was computed for depth x landscape position interactions using the Statistical Package for the Social Sciences (SPSS Inc., 2005), separately for soils reclaimed with topsoil application and without it for each treatment. The least significant differences (LSD) for mean separation were calculated for chronosequence within: (i) topsoil, and (ii) no topsoil, separately for each depth for $P \leq 0.05$. Descriptive statistics including mean, median, standard deviation, skewness, kurtosis, minimum, and maximum were obtained to characterize the distribution of VTP and AWC among 9 sampling positions for 0-15 and 15-30 cm depths at each site. For the normal distribution, skewness = 0 and kurtosis = 3 (Lozán, 1992).

3.0 **Results and Discussion**

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

The test for least significant difference (LSD) and ANOVA indicated that volume of transport (VTP) pores and available water capacity (AWC) was not different among landscape positions and depths within R94-F and R73-F (Table 1). Furthermore, VTP and AWC were not different among sites for each landscape position and 0-15 cm or 15-30 cm depths (ANOVA). Both sites were reclaimed with topsoil and were under continuous uniform and dense forest cover. Thus, water transport characteristics, which were mainly influenced by root density, were similar among sites.

Saturated hydraulic conductivity in 0-15 cm depth was not different among landscape positions at R94-F as indicated by the LSD test, but differed between the upper and the lower landscape position at R73-F (Table 1). Saturated hydraulic conductivity was higher at R73-F than at R94-F but also highly variable.

Mean, median, standard deviation, kurtosis, skewness, minimum and maximum of VTP and AWC in 15-30 cm depth at R94-F, and in 0-15 cm depth at R73-F indicated that data were not normally distributed (Table 3). The number of random samples taken was probably not sufficient to properly consider the distribution of VTP and AWC across the sites. However, taking nine samples seems to be sufficient to consider VTP and AWC data distribution in 0-15 cm depth at R94-F, and in 15-30 cm depth at R73-F for AWC.

3.2 **Sites Reclaimed Without Topsoil Application**

No significant differences were observed in VTP and AWC among landscape positions and depths within R69-F, R62-F and R62-G (Table 2). VTP and AWC were also similar among sites for each landscape position and 0-15 cm or 15-30 cm depths (ANOVA). Two sites were under continuous uniform and dense forest cover, and one under dense grass cover. Thus, water transport characteristics, which were mainly influenced by root density, were similar among sites.

The saturated hydraulic conductivity in 0-15 cm depth at the sites under forest without topsoil application was not significantly different among landscape positions at R69-F and R62-F (Table 2). However, Ks was higher for R62-G at the upper compared to the lower landscape position. ANOVA indicated that saturated hydraulic conductivity was lowest at R62-G and highest at R62-F, with R69-F having intermediate values.

Mean, median, standard deviation, kurtosis, skewness, minimum and maximum of VTP and AWC for R69-F, R62-F and R62-G indicated that data were not normally distributed in 0-15 and 15-30 cm depths (Table 3). The number of random samples taken was probably not sufficient to properly consider distribution of VTP and AWC for both depths at each site.

4.0 **Conclusion**

The volume of transport (VTP) pores and available water capacity (AWC) were not different among landscape positions and depths. The sites were under dense forest or grass cover. Thus, water transport characteristics, which were mainly influenced by root density, were similar among sites. Saturated hydraulic conductivity was higher at the sites under forest than at the site covered with grass, but also more variable.

5.0 **Tasks to be performed in the next Quarter (April- June 2006)**

We will continue to complete laboratory analyses:

1. Determine Soil Texture
2. Determine Soil pH and Electrical Conductivity
3. Statistical Analysis of Data on Soil Physical and Chemical Properties

6.0 **References**

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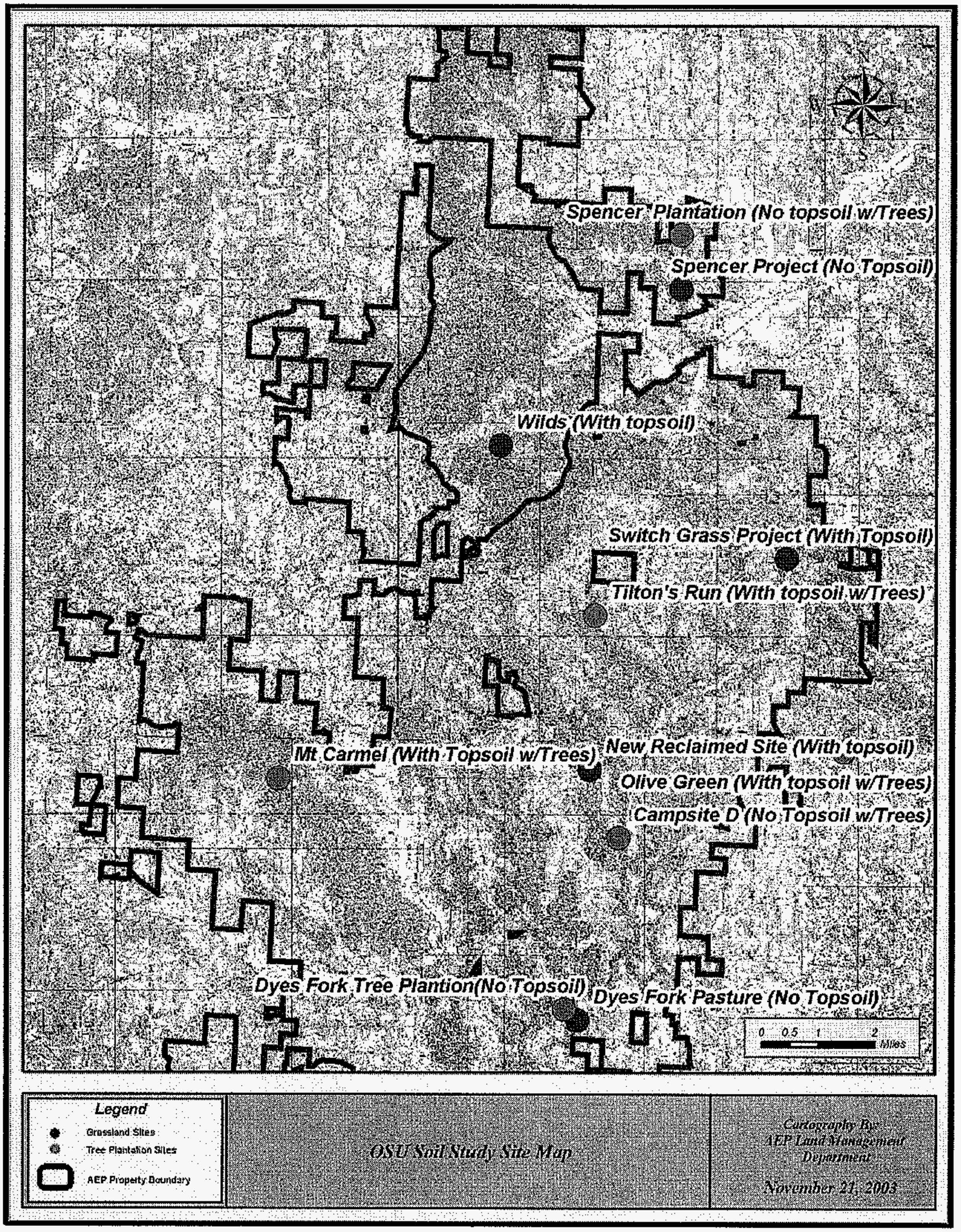

Figure 1. Location map of the experimental sites.

Table 1. Soil physical properties in an age chronosequence of reclaimed mine soils with topsoil application under continuous forest cover

Treatment	R94-F			LSD (0.05)	R73-F			LSD (0.05)
	US	MS	LS		US	MS	LS	
		0-15 cm				0-15 cm		
VTP (cm^{-3} cm^{-3})	0.08	0.09	0.05	NS	0.10	0.09	0.08	NS
AWC (cm^{-3} cm^{-3})	0.30	0.25	0.30	NS	0.31	0.35	0.37	NS
Ks (cm min^{-1})	2.00	2.93	2.53	NS	8.79	3.10	0.51	8.3
		15-30 cm				15-30 cm		
VTP (cm^{-3} cm^{-3})	0.05	0.05	0.05	NS	0.08	0.05	0.04	NS
AWC (cm^{-3} cm^{-3})	0.23	0.18	0.22	NS	0.26	0.31	0.32	NS

VTP are volumes of transport pores, AWC is available water capacity, and K_s is saturated hydraulic conductivity

Table 2. Soil physical properties in an age chronosequence of reclaimed mine soils without topsoil application under continuous forest and grass cover

Treatment	R69-F			LSD (0.05)	R62-F			LSD (0.05)	R62-G			LSD (0.05)
	US	MS	LS		US	MS	LS		US	MS	LS	
	0-15 cm				0-15 cm				0-15 cm			
VTP (cm^{-3} cm^{-3})	0.09	0.09	0.12	NS	0.18	0.15	0.16	NS	0.06	0.07	0.08	NS
AWC (cm^{-3} cm^{-3})	0.32	0.29	0.24	NS	0.16	0.27	0.24	NS	0.22	0.25	0.21	NS
Ks (cm min^{-1})	1.49	0.28	1.65	NS	3.16	4.12	1.65	NS	0.28	0.26	0.25	0.02
	15-30 cm				15-30 cm				15-30 cm			
VTP (cm^{-3} cm^{-3})	0.09	0.09	0.11	NS	0.13	0.12	0.14	NS	0.07	0.07	0.08	NS
AWC (cm^{-3} cm^{-3})	0.15	0.18	0.16	NS	0.16	0.23	0.21	NS	0.07	0.12	0.12	NS

VTP are volumes of transport pores, AWC is available water capacity, and K_s is saturated hydraulic conductivity

Table 3. Summary statistics for water transport characteristics in 0-15 and 15-30 cm Saturated hydraulic conductivity depths (N=9)

	R94-F		R73-F		R69-F		R62-F		R62-G	
	VTP	AWC	VTP	AWC	VTP	AWC	VTP	AWC	VTP	AWC
					0-15 cm					
Mean	0.07	0.28	0.09	0.35	0.10	0.28	0.17	0.22	0.07	0.23
Median	0.08	0.29	0.08	0.34	0.11	0.27	0.18	0.19	0.06	0.24
Std Dev	0.02	0.05	0.03	0.07	0.02	0.05	0.04	0.11	0.02	0.04
Skewness	-0.03	-0.05	0.14	-0.42	0.38	0.68	-0.38	1.64	0.49	-1.18
Kurtosis	-1.06	-1.59	-1.05	-0.69	1.58	-0.30	-0.99	2.19	-1.74	0.22
Minimum	0.04	0.22	0.06	0.22	0.07	0.21	0.10	0.13	0.05	0.16
Maximum	0.10	0.34	0.13	0.44	0.14	0.38	0.22	0.46	0.10	0.27
					15-30 cm					
Mean	0.05	0.21	0.06	0.30	0.10	0.16	0.13	0.20	0.07	0.10
Median	0.05	0.22	0.04	0.31	0.10	0.17	0.14	0.20	0.07	0.09
Std Dev	0.01	0.05	0.03	0.10	0.02	0.03	0.02	0.09	0.01	0.04
Skewness	0.90	-1.98	0.66	-0.07	-0.65	1.28	-0.52	-0.74	0.19	0.71
Kurtosis	2.14	4.71	-0.79	-0.81	0.60	2.48	0.62	-0.49	-2.13	0.00
Minimum	0.04	0.09	0.02	0.15	0.06	0.13	0.09	0.05	0.06	0.05
Maximum	0.06	0.25	0.12	0.44	0.13	0.24	0.16	0.31	0.09	0.17