CHARACTERIZATION OF RECLAIMED SOILS IN SOUTHWESTERN INDIANA AFTER SURFACE MINING FOR COAL, PART II.[1]

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Abstract: The study is the second part of an earlier paper to document some physical soil properties and morphological characteristics of soils reclaimed after surface mining for coal in southwestern Indiana. All sites except Daviess 001 were reclaimed using scraper placement. Daviess 001 used shovel-truck placement during reclamation. All the soils were fine-silty Alfisols before they were disturbed for mining. The reclaimed soils classify as either fine-silty or loamy Udarents. Four of the undisturbed soils had fragipans and aquic or oxyaquic conditions, which are indicated, in their classification. All reclaimed soils were reclaimed using prime farmland rules and regulations developed by the State Regulatory Authority as set forth in the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Both the bulk density and soil strength indicate that these reclaimed soils are shallower to a root restrictive soil layer than the premined soils. Gravimetric water content and bulk density explains 73 percent of the variation in soil strength. The restrictive layers in these reclaimed soils reduce the available water capacity to the extent that crop yields are reduced as compared to the premined soils. The reclamation of the soils in this study ranged from 6 to 17 years before present. These soils have been in cropland or hayland during this period of time.

Additional Key Words: Land Capability-Classification, penetrometer, water retention difference (WRD), proof of productivity, Code of Federal Regulations.

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Introduction

This paper provides information for using soil strength data to evaluate the quality of soils reclaimed after surface mining. These data support the conclusions in an earlier paper entitled “Characterization of Reclaimed Soils in Southwestern Indiana after Surface Mining for Coal” by Sinclair et al. (2004). It further substantiates that some laboratory soil properties, the soil taxonomic classifications, and selected soil morphological characteristics of the premined soils, described in the earlier paper, were more favorable for plant growth than those of the reclaimed soils. The earlier paper explained how the differences in soil classifications (unlimited compared to shallow soil depth classes), some soil properties (available water capacity and bulk density), and some selected soil morphological characteristics (strong to moderate blocky structure compared to weak or no soil structure) of the soils before mining and after mining affected soil productivity. Fig. 1 shows the sampling sites.

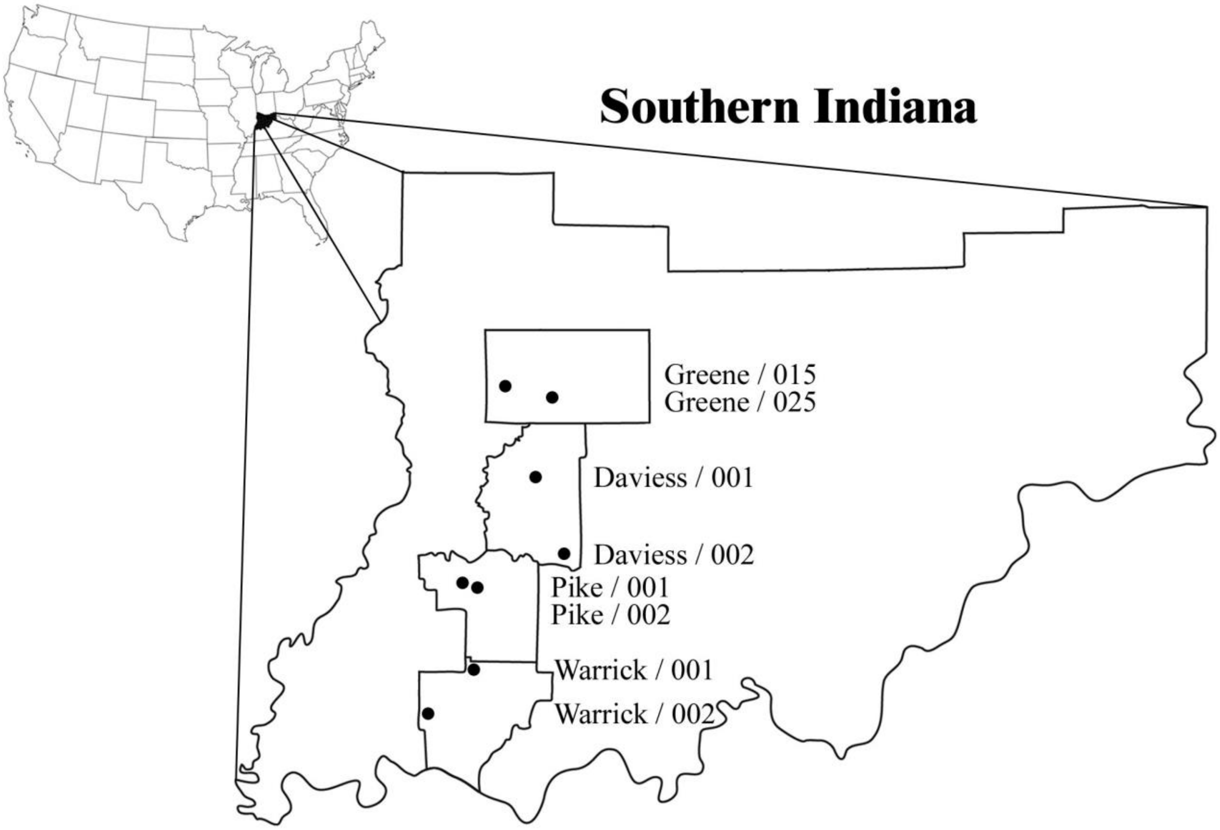

Figure 1. Sampling Sites in Southwestern Indiana.

Soil properties of the reclaimed soils were compared to soil properties of soils before mining (Sinclair et al., 2004). All data are similar except for structure and bulk density. The higher bulk density in the reclaimed soils is a deterrent to roots. In addition, the lowest horizons of some of the reclaimed soils are higher in channery rock fragments. The pH values of reclaimed soils and premined soils are similar. If a significant difference exists, it is in some subhorizons in the reclaimed soils. These subhorizons have a higher pH values than the premined soils. The water retention differences (WRD) of the reclaimed soils are similar or often higher than the soils before mining. These numerical WRD values are deceiving because the reclaimed soils have high bulk densities (root-limiting) and weak or no structure which restricts roots and water from entering these soil horizons. Bulk densities in the reclaimed soils are significantly higher than those in all but three of the premined soils. But, even in these three soils, root-limiting bulk densities are at a shallower depth than those in the premined soils.

Table 1 shows the soil taxonomic classification of each soil before mining and after reclamation and indicates the years reclaimed (Sinclair, et al., 2004). All soils in this study had a rooting depth of 71 to 203 cm before mining. The rooting depth of reclaimed soils ranges from 25 to 99 cm. Five of the reclaimed soils are classified in a shallow soil depth class, less than 50 cm from the soil surface to a root limiting layer. None of the premined soils are classified as shallow.

Soil structure and consistence are important in determining movement of air, water, and roots in the soil (McSweeney and Jansen, 1984; Grossman et al., 1992; Fehrenbacher et al., 1982; Fehrenbacher and Rust, 1956; Fehrenbacher and Snider, 1954; Fehrenbacher et al., 1960; Dunker and Barnhisel, 2000). Layers that have organization (structure, consistence, etc.) such that roots cannot enter except in cracks are considered “root limiting” layers as long as the cracks that roots can enter are 10 cm or more apart (Soil Survey Staff, 1999). Layers with physical root restrictions in these soil profiles are human made. They formed during the placement of soil rooting media, especially during scraper placement.

Soil depth to a structureless (non granular and non blocky) layer ranged from 76 to more than 203 cm in premined soils (Kelly et al., 1974; McCarter et al., 1988; Shively et al., 1979; Struben et al., 1987). Soil depth to a structureless layer ranged from 25 to 76 cm in reclaimed soils (Sinclair, et al., 2004). The soil depth to a structureless layer with a friable or firm consistency ranged from 34 to 132 cm in reclaimed soils (Sinclair et al., 2004). One conclusion that can be made is that scraper placement soils are shallower to a root limiting layer than the premined soils (Dunker et al., 1992; Hooks et al., 1992; Caldwell et al., 1992; Chong et al., 1992, and Wells and Barnhisel, 1992).

Seybold et al. (2004) evaluated the soil quality of the near surface and soil profile for the six reclaimed coal mine soils in this paper. The near-surface properties (typically from the surface to 3 or to about 20 cm depending on soil property) of bulk density, soil strength, aggregate stability and the particulate-organic-matter carbon are within limits observed for cultivated surface horizons. However, in general, the cultivated surface horizons of the reclaimed mined soils have poor soil quality compared to their natural or no-till managed counter parts. The morphology of the reclaimed soils lacked pedogenic B horizons. The general horizonation of the reclaimed soils was an Ap-C horizonation. The profile soil quality was lower on all eight reclaimed sites compared to their respective reference condition before mining. The soil quality index scores ranged from 68 to 87 on a scale from 0 to 100. The properties that were a major factor in lowering the soil quality of the reclaimed soils were poor or massive soil structure, lower available water capacity, and increased bulk density of the subsoil. Organic C, CEC, and soil pH on most sites were generally comparable to the condition before mining. The poor structure, higher bulk density, and lower AWC of the reclaimed soils in the subsoil could result in water stress and/or lower productivity, especially under droughty conditions.

Crop productivity is the criterion on which the success of prime farmland reclamation is evaluated (Howard, 1980; Mavrolas, 1980; Reybold and McCormack, 1980). An alternative that has been proposed is to use selected soil survey characterization data (Soil Survey Staff, 2004) as a measure of prime farmland reclamation success (Smith, unknown date). Crop production as a measure of prime farmland reclamation success is explained in 30 CFR., 2002. Olson (1992) explains the difference in methods and procedures used in the 1977 Surface Mining Control and Reclamation Act and those used by the University of Illinois to determine long term crop yields.

Research by Dunker et al. (1992), Dunker and Barnhisel (2000), Hooks et al. (1992), Underwood and Sutton (1992), Vance et al. (1992), and Caldwell et al. (1992) explain that deep tillage is a specification and condition to get a positive response in crop yield after reclaiming surface mined soils. Dunker et al. (1991) explains methods for alleviation of soil compaction and how reducing the compaction in the subsurface horizons increases crop yields. Dunker and Barnhisel (2000) and Hooks (1998) show the relationship among bulk density to average root length density and crop yield. Hooks et al. (1992) determined rooting media for plant growth using shovel-truck placement is typically less compacted and usually results in higher crop yields.

The partnership between the coal companies, USDI's Office of Surface Mining, State Regulatory Authority, researchers, and NRCS is improving reclamation technology. Today, the new reclamation technology that is being used by the coal companies is reclaiming prime farmland soils to achieve premined productivity (Dunker et al., 1992).

Methods

Six of the eight original sites were selected for this paper (Greene 015, VGA and Warrick 002, HoB-2 were excluded from this study). They were typical of the soils reclaimed 6 to 17 years ago. Scraper placement reclaimed all sites except the Daviess 001 site, which used shovel-truck placement during reclamation. Five of the six soils in this paper in southwestern Indiana were reclaimed to meet Indiana prime farmland rules and regulations. Pike 002 was not prime farmland before mining, but the area was reclaimed to meet prime farmland criteria. The soils were sampled for laboratory characterization in November 2002.

All measurements for soil strength were made using a calibrated Dickey-John penetrometer tipped with a 1.3 cm cone. At each of the above sites a hole was bored into the center of each horizon using a 5.4 cm bucket auger. This depth was measured. Since the angle of the penetrometer tip is 2.5 cm from the point, a point on the shaft was marked 2.5 cm above the ground surface. The dial reading was recorded when the instrument penetrated to the mark on the shaft while pushing the penetrometer into the hole. A total of three replications were recorded at each site. The replications ranged from 4 to 8 inches apart. Samples for each soil strength measurement were collected for the laboratory to determine soil water tension.

Results and Discussion

Soil Classification and Years Reclaimed

Table 1 shows the soil taxonomic classification of each soil before mining and after reclamation and indicates the years reclaimed (Sinclair, et al., 2004). All of the soils in this study had a rooting depth of 71 to 203 cm before mining. The rooting depth of the reclaimed soils ranges from 25 to 99 cm. Five of reclaimed soils are classified as shallow, less than 50 cm rooting depth. None of the premined soils are classified as shallow.

Bulk Density

The values for nonlimiting, critical, and root-limiting bulk densities for each family particle-size class are presented in Table 2 (Pierce et al., 1983). Subsurface horizons of the reclaimed soils above 122 cm are predominately fine silty (Sinclair, et al., 2004). The depth to the first layer with a bulk density of more than 1.54 (critical bulk density by Pierce et al., 1983) and/or 1.65 (root-limiting by Pierce et al., 1983) is above 50 cm for seven of the soils listed in Table 1. The WRD values, though lower than expected for the soil textures, are not reflected in the available water capacity shown in table 5 because the bulk density in many layers is root-limiting. Therefore, since roots cannot enter these layers, even this reduced soil moisture cannot by used by the growing plants commonly grown in the area, e.g., corn.

Table 2 Nonlimiting, critical, and root limiting bulk densities for each family texture class (Pierce et al., 1983).

Family Texture Class	Nonlimiting Bulk Density g cm^{-3}	Critical Bulk Density g cm^{-3}	Root-Limiting Bulk Density g cm^{-3}
Sandy	1.60	1.69	1.85
Coarse loamy	1.50	1.63	1.80
Fine loamy	1.46	1.67	1.78
Coarse silty	1.43	1.67	1.79
Fine silty	1.34	1.54	1.65
Clayey: 35-45%	1.40	1.49	1.58
Clayey: 45-100%	1.30	1.39	1.47

Table 1. Soil classification of pre- and post-mined soils and years reclaimed (Sinclair et al., 2004).

County / Soil (Soil Symbol)	Years Reclaimed	Name for Pre-Mined Soil	Premined Soil Classification[1]	Post-Mining Soil Classification[2]
Daviess 001 (AlB2)	14	Alford silt loam, 2 to 6 percent slopes, eroded	fine-silty, mixed, superactive, mesic Ultic Hapludalf	fine-silty, mixed, active, acid, mesic Alfic Udarent
Daviess 002 (HoB2)	6	Hosmer silt loam, 2 to 6 percent slopes, eroded	fine-silty, mixed, active, mesic Oxyaquic Fragiudalf	fine-silty, mixed, active, acid, mesic Ultic Udarent
Greene 015 (VgA) [3]	16	Vigo silt loam, 0 to 2 percent slopes	fine-silty, mixed,superactive, mesic Aeric Glossaqualf	loamy, mixed, active, nonacid, mesic, shallow Alfic Udarent
Greene 025 (ScA)	17	Shakamak silt loam, 0 to 2 percent slopes	fine-silty, mexed, active, mesic Aquic Fragiudalf	loamy, mixed, active, nonacid, mesic, shallow Alfic Udarent
Pike 001 (HoB2)	12	Hosmer silt loam, 2 to 6 percent slopes, eroded	fine-silty, mixed, active, mesic Oxyaquic Fragiudalf	loamy, mixed, active, nonacid, mesic, shallow Alfic Udarent
Pike 002 (PpD3)	10	Pike silt loam, 12 to18 percent slopes, severely eroded	fine-silty, mixed, superactive, mesic Ultic Hapludalf	loamy, mixed, active, nonacid, mesic, shallow Alfic Udarent
Warrick 001 (HoB-1)	15	Hosmer silt loam, 2 to 6 percent slopes	fine-silty, mixed, active, mesic Oxyaquic Fragiudalf	loamy, mixed, superactive, nonacid, mesic, shallow Alfic Udarent
Warrick 002 (HoB-2) [3]	13	Hosmer silt loam, 2 to 6 percent slopes	fine-silty, mixed, active, mesic Oxyaquic Fragiudalf	fine-silty, mixed, active, acid, mesic Alfic Udarent

[1] Soil Survey Staff, 1999. [2] Robert J. Engel, personal communications, 2003.

[3] Soil strength data were not collected for these sites for this paper.

Soil Strength

Dunker and Barnhisel (2000) show penetrometer resistance and mean yields for various deep tillage treatments on scraper placed mine soils. Corn yields were reduced from about 8 Mg/ha with about 1 MPa of penetrometer resistance to about 4 Mg/ha with about 3 MPa of penetrometer resistance. Soybean yields were reduced from about 2 Mg/ha with about 1 MPa of penetrometer resistance to about 0.8 Mg/ha with about 3 MPa of penetrometer resistance.

Table 3 shows the soil strength and bulk densities for the six reclaimed soils in this study. Table 4 shows the soil water tension for the six reclaimed soils in this study. All six soils have root limiting horizons within 50 cm of the surface of the soil based on soil strength and/or bulk density data. With root limiting layers at these depths, it will probably be difficult to meet the "proof of productivity" in the rules and regulations of 30 CFR, 2002.

Soil strength was highly correlated to the bulk density ($r = 0.76$) and inversely correlated to the gravimetric water content ($r = -0.79$). The correlation coefficient was slightly lower between soil strength and volumetric water content ($r = -0.71$). Error associated with the conversion from gravimetric to volumetric water content could be the cause for the lower correlation. The bulk density and gravimetric water content were then used to predict soil strength using General Linear Models. The soil strength prediction equation is:

Soil strength = [(717 x 1/3 bar bulk density) – (16.6 x gravimetric water content)] - 444

Bulk density and gravimetric water content explained 73% of the variation in the soil strength (R^2 – 0.73; n = 75). The standard deviation (root mean square error) about the regression line was about 85.

Table 3. Soil Strength and Bulk Density (A, B. and C designates replicate samples)

County/Soil	Soil Horizon	Soil Depth cm	Soil Strength MPa A	Soil Strength MPa B	Soil Strength MPa C	Bulk Density g cm^{-3}
Daviess/001	Ap1	10	2.4	2.9	2.4	1.54
	B/A	31	3.5	3.5	3.5	1.64
	C1	50	4.1+	3.5	4.1	1.64
	C2	62	4.1	2.9	2.4	1.70
	C3	77	3.5	2.9	1.8	1.64
Daviess/002	Ap	12	1.2	1.2	1.2	1.45
	C1	29	1.8	2.4	1.2	1.61
	C2	45	4.1	3.5	2.4	1.67
	C3	75	4.1	4.1	4.1	1.73
Greene/025	Ap	10	1.8	2.4	2.4	1.54
	AC	24	3.5	2.9	4.1	1.61
	C1	30	4.1	3.5	4.1+	1.6
	Cd1	55	4.1+	4.1+	4.1+	1.86
Pike/001	AP1	7	1.2	1.8	1.8	1.49
	Ap2	19	2.4	2.9	2.9	1.66
	C1	39	2.4	2.4	2.9	1.69
	C2	75	3.5	2.9	3.5	1.67
Pike/002	Ap1	5	0.6	1.2	0.6	1.48
	Ap2	17	2.9	2.4	2.4	1.55
	Bg	33	4.1	3.5	4.1	1.6
	C1	59	4.1	4.1	4.1+	1.73
Warrick/001	Ap	7	0.6	0.6	0.6	1.46
	A/C	23	2.9	3.5	2.4	1.56
	Cd1	47	4.1+	4.1+	4.1+	1.77
	Cd2	75	4.1+	3.5	4.1+	1.73

Table 4. Soil Water Tension of Soil Strength Samples (A, B. and C designates replicate samples)

County/Soil	Soil Horizon	Layer Depth - top (cm)	Layer Depth - bottom (cm)	tension (bars) A	tension (bars) B	tension (bars) C
Daviess/001	Ap1	8	12	0.41	0.51	0.1
	B/A	29	33	0.57	1	0.51
	C1	48	52	5	6	2
	C2	60	64	1.3	0.9	0.33
	C3	75	79	0.4	0.4	0.6
Davies/002	Ap	10	14	0.31	0.1	0.1
	C1	27	31	0.01	0.05	0.03
	C2	43	47	1	0.33	0.33
	C3	73	77	0.09	0.33	2
Greene/025	Ap	8	12	0.4	0.1	0.33
	AC	22	26	0.85	0.75	0.8
	C1	28	32	1	1	1.2
	Cd1	53	57	2	2	10
Pike/001	Ap1	5	9	0.22	0.18	0..2
	Ap2	17	21	0.05	0.06	0.06
	C1	37	41	0.05	0.05	0.22
	C2	73	77	0.33	0.4	0.5
Pike/002	Ap1	3	7	0.01	0.01	0.08
	Ap2	15	19	0.2	0.1	0.3
	Bg	31	35	0.2	0.1	0.1
	C1	57	61	0.01	0.01	0.1
Warrick/001	Ap	5	9	0.08	0.01	0.01
	A/C	21	25	0.3	0.31	0.31
	Cd1	45	49	0.33	0.33	0.33
	Cd2	73	77	0.8	0.33	0.33

1/ A, B, and C designates samples.

Land-Capability Classes of Soils Before and After Reclamation

Table 5 shows the AWC for the rooting media and land capability classes for the reclaimed soils and soils before mining (Sinclair, et al., 2004). The USDA-NRCS Land-Capability Classification classifies soils according to their hazards and limitations (Klingebiel, 1958; Klingebiel and Montgomery, 1961). The land capability classes include an AWC criterion as follows: Class I - 22.5 cm or more of water; Class II - 15.0 to 22.5 cm of water; Class III - 7.5 to 15 cm of water; and Class IV - 7.5 cm or less water available for plant growth. All reclaimed soils have less AWC for plant growth than the soils before mining except for one site (Warrick 002).

Land Capability Classes I, II, and III are considered suitable for cropland and class IV is hayland. The changes in the land capability classes in table 5 are due to lower AWC in the reclaimed soils as compared to the higher AWC in the premined soils. This lower AWC in the reclaimed soils would indicate that reclaimed soils probably would not have the same long-term average yield as the premined soils.

Table 5. Land capability classes (LCC) assigned by Available Water Capacity (AWC) for reclaimed soils and premined soils (Sinclair et al., 2004).

County / Soil	AWC of Reclaimed Soils cm	Reclaimed LCC	Premined LCC
Daviess 001	10.9	III	I
Daviess 002	10.6	III	II
Greene 015	6	IV	II
Greene 025	6.8	IV	II
Pike 001	3.4	IV	II
Pike 002	9.9	III	II
Warrick 001	6.6	IV	II
Warrick 002	16.8	II	II

Summary and Overall Conclusions

Soil strength is an indicator of the quality of the rooting media for plant growth. Soil strength measurements are usually made in the spring, when soils are uniformly moist in the corn belt, and when minor differences in soil moisture would not occur within an area. The soil strength data collected in the spring before planting the crop are considered to be made at field capacity. Soils that have a value in excess of 1 MPa will probably have some reduction in crop yields. Soils with a value of 3 MPa have a significant reduction of crop yields and have a reduced chance of meeting proof of productivity as written in the rules and regulations of 30 CFR, 2002.

All six soils have root limiting horizons within 50 cm of the surface of the soil based on numerical values for soil strength and/or bulk density data shown in table 3. With these root limiting layers at these depths, it will probably be difficult to meet the “proof of productivity” in the rules and regulations of 30 CFR, 2002.

The quality of soils reclaimed after surface mining in recent years is better than those reclaimed in the past. Reclamation using scraper placement is seldom used by the more progressive mining companies. Shovel-truck placement is replacing the scraper placement (Sinclair, et al., 2004).

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