CHARACTERIZATION OF RECLAIMED SOILS IN SOUTHWESTERN INDIANA AFTER SURFACE MINING FOR COAL[1]

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Abstract. The study was to document some laboratory soil properties, soil classifications, and selected morphological characteristics of soils reclaimed after surface mining for coal in southwestern Indiana. The reclamation of these soils range from 6 to 17 years. Scraper placement reclaimed all sites except Daviess 001. It used shovel-truck placement during reclamation. Seven of the eight soils sampled for laboratory characterization in southwestern Indiana 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). Since being reclaimed all the soils have been in cropland or hayland for the last 6 to 17 years. The soils were sampled for laboratory characterization in November 2002. All the soils were fine-silty Alfisols before they were disturbed for mining. The reclaimed soils classify in either fine-silty or loamy Udarents. Five of the undisturbed soils had fragipans. Six of the undisturbed soils had aquic or oxyaquic conditions, which are indicated, in their classification. Selected laboratory data for the reclaimed soils are compared to properties in the National Cooperative Soil Survey Database for the premined soils. Through current reclamation techniques, most the reclaimed soils have similar soil properties to the pre-mined soils. Soil structure and bulk density are two of the properties that will be different than the premined soils.

Additional Key Words: Available water capacity, bulk density, Land-Capability Classification, National Cooperative Soil Survey Database, Public Law 95-87, soil morphological properties, structureless, and water retention difference.

[1] Paper was presented at the 2004 National Meeting of the American Society of Mining and Reclamation and The 25th West Virginia Surface Mine Drainage Task Force, April 18-24, 2004. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2004 pp 1674-1699
DOI: 10.21000/JASMR04011674
https://doi.org/10.21000/JASMR04011674

Introduction

This paper documents some laboratory soil properties, the soil taxonomic classifications, and selected soil morphological characteristics of soils reclaimed after surface mining for coal in Southwestern Indiana. It compares selected laboratory properties of the soils before mining to the properties of the reclaimed soils. The properties of soils before mining are from the National Cooperative Soil Survey Database (NCSSD) (Soil Survey Staff, 2003). The taxonomic classifications and selected soil morphological characteristics of the soils before mining are compared to the same items for the reclaimed soils. The paper explains how the differences in the classifications, some soil properties, and selected soil morphological characteristics of the soils before mining and after mining could affect soil productivity.

The criterion on how to evaluate prime farmland reclamation success is crop productivity (Howard, 1980; Mavrolas, 1980; Reybold and McCormack, 1980). The other alternative proposed is to use soil survey properties 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. Stout (1998) explains the variability of prime farmland in meeting post-mining yield targets. In his paper, Stout (1998) reported only 41 percent of the prime fields had passed the three-year yield tests in the 10-year liability period. Stout (1998) stated that deep tillage increases the probability of prime farmland fields passing yield tests and shortens the time to passage by about one year. 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 the specifications and conditions for deep tillage to get a positive response in crop yield. Dunker (1991) explains compaction alleviation methods and how reducing compaction in the subsurface horizons increases crop yields. Dunker (2000) and Hooks (1998) show the relationship of 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 being used by the coal companies is reclaiming prime farmland soils to achieve premined productivity (Dunker et al., 1992).

Methods

The eight sites selected for this study were typical of the soils reclaimed 6 to 17 years ago. Scraper placement reclaimed all sites except Daviess 001. It used shovel-truck placement during reclamation. Seven of the eight soils sampled for laboratory characterization in southwestern Indiana were reclaimed using prime farmland rules and regulations. Pike 002 was not prime farmland before mining, but the area was reclaimed as prime farmland. Warrick 002 was prime farmland before mining, but it was grandfathered so it was not reclaimed as prime farmland. The soils were sampled for laboratory characterization in November 2002. Water Retention Difference (WRD) is the volume of water that is measured in the laboratory, inclusive of rock fragments. The Available Water Capacity (AWC) is the volume of water that should be available to plants if the soil, inclusive of rock fragments, were at field capacity. Reductions in AWC are made in the water difference for incomplete root ramification that is associated with certain soil features such as fragipans, bulk density, and other chemical and physical soil properties that are indicative of root restrictions. The amount of available water to the expected maximum depth of root penetration, commonly either 1 or 1.5m, or a physical or chemical root limitation, whichever is shallower (Soil Survey Division Staff, 1993).

The soil descriptions and samples follow the standard procedure established by the National Cooperative Soil Survey (Schoeneberger et al., 2002; Soil Survey Division Staff, 1993). The laboratory procedure for carbon is: An air-dry (80 mesh, >180µm) soil sample in a tin foil, weighted, and analyzed for total C, N. and S by an elemental analyzer. The analyzer works according to the principle of catalytic tube combustion in an oxygenated CO_2 atmosphere and high temperature. The combustion gases are freed from foreign gases. The desired measuring components (N_2, CO_2 and SO_2) are separated from each other with the help of specific absorption columns and determined in succession with a thermal conductivity detector, with helium as the flushing and carrier gas (Burt, 2004). The laboratory procedure for particle-size analysis is: A 10-g sample of <2-mm, air-dry soil is pretreated to remove organic matter and soluble salts. The sample is dried in the oven to obtain the initial weight, dispersed with a sodium hexametaphosphate solution, and mechanically shaken. The sand fraction is removed from the suspension by wet sieving and then fractionated by dry sieving. The clay and fine silt fractions are determined by using the suspension remaining from the wet sieving process. This suspension is diluted to 1 L in a sedimentation cylinder, stirred, and 25-mL aliquots removed with a pipet at calculated, predetermined intervals based on Stokes' law. The aliquots are dried at 105^{o} C and weighed. Coarse silt is the difference between 100 percent and the sum of the sand, clay, and fine silt percentages. The laboratory procedure for bulk density is: Natural clods are collected from the face of an excavation. One coat of plastic lacquer is applied in the field. Additional coats of plastic lacquer are applied in the laboratory. The clod is desorbed to 33 kPa. After equilibration, the clod is weighed in air to measure its mass and in water to measure volume. After the clod is dried in the oven at 105^{o} C, its mass and volume are determined again. A correction is made for the mass and volume of rock fragments and for the plastic coatings. The laboratory procedure for Water Retention Difference (WRD) is: The WRD is the calculated value that denotes the volume fraction for water in the whole soil that is retained between 1500 kPa suction and 33 kPa suction. The 33 and 1500 kPa gravimetric water contents are converted to a whole soil volume basis. The pressure desorption method is used. A sample of <2-mm (sieved), air-dry soil is placed in a retainer ring sitting on a porous ceramic plate in a pressure-plate extractor. The plate is covered with water to wet the samples by capillarity. The sample is equilibrated at pressures of 33 and 1500 kPa. The pressure is kept constant until equilibrium is obtained. The gravimetric moisture content is determined. The laboratory procedure for pH is: A 20-g soil sample is mixed with 20 mL of distilled water with occasional stirring. The sample is allowed to stand 1 hour with occasional stirring. The sample is stirred for 30 seconds, and the pH is measured. The laboratory procedures used for the laboratory data in this paper follow the standard procedure established by the National Soil Survey Laboratory (Soil Survey Staff, 1996).

Results and Discussion

Soil Classification and Years Reclaimed

Table 1 shows the soil taxonomic classification of each soil before mining and after reclamation (Engel, 2003; Soil Survey Staff, 1999) and indicates the years reclaimed. 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.

Table 1. Soil classification of pre- and post-mined soils and years reclaimed.

County / Soil (Soil Symbol)	Years Reclaimed	Name for Pre-Mined Soil	Reclaimed 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)	16	Vigo silt loam, 0 to 2 percent slopes	fine-silty, mexed, 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-sily, 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)	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.

Soil Morphological Properties

Soils reclaimed after surface mining for coal are pedogenically young soils developing on landscapes altered by human activities. They have properties that differ from the unmined soils. Initially, most mine soils are devoid of soil horizonation (Sencindiver and Ammons, 2000).

Soil descriptions for the reclaimed soils are presented in Table 2. Soil structure and consistence are important in determining the 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 so 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 manmade. They formed during the placement of soil rooting media, especially during scraper placement. Such layers are designated as Cd in the soil profile descriptions. Layers designated as Cr in the soil profile description consist of graded cast overburden. The graded cast overburden consists of weakly cemented sandstone or shale.

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

Selected Laboratory Soil Properties

The laboratory data for soil separates (sand, silt, clay, and very fine sand), rock fragments, organic matter, pH, bulk density, and water retention difference (WRD) are contained in Table 3 and 4. The reclaimed soils have more sand and rock fragments than expected for a soil formed in loess (Kelly et al., 1974; McCarter et al., 1988; Shively et al., 1979; Struben et al., 1987). The organic matter content in the reclaimed soil profiles decreases irregularly with depth (Table 4).

Table 2. Soil descriptions of reclaimed soils.

Daviess 001. Site ID: 02IN027001

Ap1--0 to 20 cm; brown (10YR 4/3), silt loam; moderate fine subangular blocky parting to weak fine granular structure; friable; common fine roots; abrupt wavy boundary.

BA--20 to 43 cm; 10 percent dark yellowish brown (10YR 4/4) and 90 percent yellowish brown (10YR 5/6), silt loam, silty clay loam; 10 percent light gray (10YR 7/2) mottles; moderate coarse subangular blocky parting to weak coarse subangular blocky structure; firm; few fine roots; abrupt smooth boundary.

C1--43 to 56 cm; 20 percent light gray (10YR 7/2) and 80 percent yellowish brown (10YR 5/6), silt loam, silty clay loam; massive; firm; few fine roots in cracks; clear wavy boundary.

C2--56 to 69 cm; 5 percent dark gray (10YR 4/1) and 10 percent strong brown (7.5YR 5/6) and 15 percent gray (10YR 6/1) and 70 percent brownish yellow (10YR 6/6), silty clay loam; massive and weak thin platy; firm; few fine roots in cracks; abrupt wavy boundary.

C3--69 to 99 cm; yellowish brown (10YR 5/4) and yellowish brown (10YR 5/6) and 10 percent light brownish gray (10YR 6/2), silt loam, silty clay loam; massive; firm.

C4--99 to 122 cm; yellowish brown (10YR 5/4) and yellowish brown (10YR 5/6) and 10 percent light brownish gray (10YR 6/2), silt loam, silty clay loam; massive; firm; abrupt smooth boundary.

2Cr--122 to 150 cm; C is thin layers of Sic material 1/8 inch thick sandwiched between Cr.

Davies 002. Site ID: 02IN027002

Ap--0 to 25 cm; brown (10YR 4/3); moderate medium and coarse subangular blocky parting to weak fine granular structure; friable; many fine roots; clear wavy boundary.

C1--25 to 33 cm; 10 percent light brownish gray (10YR 6/2) and 30 percent brown (7.5YR 4/4) and 60 percent yellowish brown (10YR 5/6); weak coarse subangular blocky structure; firm; few fine roots; 1 percent; clear wavy boundary.

Table 2. Continued.

C2--33 to 58 cm; 20 percent strong brown (7.5YR 5/8) and 20 percent light brownish gray (10YR 6/2) and 60 percent yellowish brown (10YR 5/6), 5 percent gray (10YR 6/1) and 95 percent brownish yellow (10YR 6/6), dry; weak thick platy structure; firm; few fine roots; 1 percent; clear smooth boundary.

C3--58 to 97 cm; 25 percent dark gray (10YR 4/1) and 25 percent yellowish brown (10YR 5/8) and 50 percent yellowish brown (10YR 5/6); weak thick platy structure; firm; 2 percent; clear smooth boundary.

C3--97 to 132 cm; 25 percent dark gray (10YR 4/1) and 25 percent yellowish brown (10YR 5/8) and 50 percent yellowish brown (10YR 5/6); weak thick platy structure; firm; clear smooth boundary.

Cr--132 to 158 cm; dark gray (10YR 4/1); massive; firm.

Greene 015. Site ID: 02IN055015

Ap--0 to 20 cm; silt loam; moderate coarse granular structure; friable; many very fine roots; clear wavy boundary.

AB--20 to 28 cm; silt loam; weak medium subangular blocky structure; friable; common fine roots; 1 percent; clear wavy boundary.

CB--28 to 43 cm; 5 percent brown (7.5YR 4/4) and 10 percent light gray (10YR 7/1) and 85 percent yellowish brown (10YR 5/6), silty clay loam; weak medium and coarse subangular blocky structure; firm; common fine roots; 1 percent; gradual wavy boundary.

Cd--43 to 84 cm; 10 percent light gray (10YR 7/1) and 20 percent light brownish gray (10YR 6/2) and 70 percent yellowish brown (10YR 5/8), silty clay loam; massive; very firm; few fine roots in cracks; 2 percent; clear wavy boundary.

C1--84 to 107 cm; 5 percent strong brown (7.5YR 5/6) and 20 percent yellowish brown (10YR 5/6) and 75 percent brown (10YR 4/3), silt loam, silty clay loam; massive; firm; 3 percent; abrupt smooth boundary.

C2--107 to 145 cm; dark gray (10YR 4/1) and 70 percent yellowish brown (10YR 5/8), clay loam; massive; firm; 6 percent; abrupt smooth boundary.

Table 2. Continued.

C3--145 to 183 cm; 5 percent black (10YR 2/1) and 15 percent gray (10YR 6/1) and 80 percent yellowish brown (10YR 5/8), clay loam; massive; firm; 2 percent 150 to 380 millimeter sandstone fragments and 5 percent and 18 percent coal fragments; clear smooth boundary.

C4--183 to 200 cm; 5 percent gray (10YR 6/1) and 10 percent gray (10YR 5/1) and 85 percent strong brown (7.5YR 5/8), clay loam; massive; firm.

Greene 025. Site ID: 02IN055025

Ap--0 to 20 cm; dark yellowish brown (10YR 4/4), silt loam; weak very coarse platy and moderate coarse subangular blocky parting to moderate medium granular structure; friable; common fine roots; abrupt wavy boundary.

AC--20 to 27 cm; 5 percent gray (10YR 6/1) and 10 percent strong brown (7.5YR 4/6) and 20 percent dark grayish brown (10YR 4/2) and 65 percent light brownish gray (10YR 6/2), silt loam; weak medium platy structure; friable; common fine roots; clear wavy boundary.

C1--27 to 34 cm; 15 percent strong brown (7.5YR 5/6) and 15 percent gray (10YR 6/1) and 70 percent yellowish brown (10YR 5/6), silt loam; weak medium subangular blocky structure; friable; common fine roots; clear wavy boundary.

Cd1--34 to 76 cm; light brownish gray (10YR 6/2) and brown (7.5YR 5/2) and 25 percent light brownish gray (10YR 6/2) and 75 percent strong brown (7.5YR 5/6), silt loam; strong very coarse angular blocky structure; very firm; common fine roots in cracks; clear wavy boundary.

Cd2--76 to 117 cm; 5 percent gray (10YR 6/1) and 95 percent yellowish brown (10YR 5/6), silty clay loam; very firm; few fine roots in cracks; abrupt smooth boundary.

Cr--117 to 135 cm; greenish gray (10Y 6/1), extremely channery silty clay; very firm.

Pike 001. Site ID: 02IN125001

Ap1--0 to 13 cm; yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky parting to moderate fine granular structure; friable; many fine roots; neutral, pH 6.8; gradual smooth boundary.

Table 2. Continued.

Ap2--13 to 25 cm; yellowish brown (10YR 5/4) and 10 percent yellowish brown (10YR 5/6), silt loam; weak coarse platy parting to moderate fine and medium subangular blocky structure; friable; common fine roots; neutral, pH 6.8; abrupt wavy boundary.

C1--25 to 58 cm; brownish yellow (10YR 6/6) and light gray (10YR 7/2) and yellowish brown (10YR 5/8), silty clay loam; massive; firm; few fine roots between peds; slightly acid, pH 6.4; clear wavy boundary.

C2--58 to 112 cm; yellowish brown (10YR 5/6) and pale brown (10YR 6/3), silty clay loam; massive; firm; moderately acid, pH 5.8; abrupt smooth boundary.

C2--58 to 112 cm; yellowish brown (10YR 5/6) and light yellowish brown (10YR 6/4) and light brownish gray (10YR 6/2), silty clay loam; massive; firm; moderately acid, pH 5.8; abrupt smooth boundary.

2C--112 to 142 cm; gray (10YR 5/1), silty clay loam; massive; firm; neutral, pH 6.8.

Pike 002. Site ID: 02IN125002

Ap1--0 to 10 cm; brown (10YR 5/3), silt loam; moderate medium subangular blocky parting to moderate fine and medium granular structure; friable; many fine and medium roots throughout; gradual smooth boundary.

Ap2--10 to 23 cm; pale brown (10YR 6/3), silt loam; light brownish gray (10YR 6/2) mottles; moderate fine and medium subangular blocky structure; friable; many fine and medium roots throughout; clear smooth boundary.

Bg--23 to 43 cm; light brownish gray (10YR 6/2), silt loam; strong brown (7.5YR 5/8) and pale brown (10YR 6/3) mottles; weak medium and coarse subangular blocky structure; friable; many fine and medium roots throughout; clear smooth boundary.

C1--43 to 76 cm; yellowish brown (10YR 5/6), silt loam; light brownish gray (10YR 6/2) mottles; massive; firm; common fine roots; yellowish brown (10YR 5/4) clay films; clear wavy boundary.

Table 2. Continued.

C2--76 to 124 cm; gray (10YR 5/1) and yellowish brown (10YR 5/4) and pale brown (10YR 6/3), silt loam, silty clay loam, clay; strong brown (7.5YR 5/8) mottles; massive; firm; common very fine and fine roots; gray (10YR 5/1) clay films; clear smooth boundary.

2Cr--124 to 137 cm; dark gray (10YR 4/1); massive; firm.

Warrick 001. Site ID: 02IN173001

Ap--0 to 15 cm; brown (10YR 5/3), silt loam; weak fine and medium subangular blocky parting to moderate fine and medium granular structure; very friable; many fine and medium roots; slightly acid, pH 6.4; abrupt smooth boundary.

A/C--15 to 30 cm; 20 percent brownish yellow (10YR 6/6) and 80 percent yellowish brown (10YR 5/4), silt loam; moderate medium subangular blocky parting to weak medium granular structure; friable; common very fine and fine roots; neutral, pH 6.8; gradual wavy boundary.

Cd1--30 to 66 cm; 30 percent brownish yellow (10YR 6/8) and 70 percent brownish yellow (10YR 6/6), silty clay loam; massive; very firm; few very fine and fine roots in cracks; 10 percent light brownish gray (10YR 6/2) clay films; 2 percent; moderately acid, pH 5.8; gradual smooth boundary.

Cd2--66 to 102 cm; 30 percent brownish yellow (10YR 6/8) and 70 percent brownish yellow (10YR 6/6), silty clay loam; massive; very firm; few very fine and fine roots in cracks; 10 percent light brownish gray (10YR 6/2) clay films; 2 percent; moderately acid, pH 5.8; abrupt smooth boundary.

2C--102 to 152 cm; 5 percent light brownish gray (10YR 6/2) and 10 percent brownish yellow (10YR 6/6) and 85 percent dark gray (10YR 4/1), channery clay loam, clay loam; massive; firm; neutral, pH 7.2.

Warrick 002. Site ID: 02IN173002

Ap--0 to 9 cm; yellowish brown (10YR 5/4), silt loam; weak fine subangular blocky parting to weak fine granular structure; friable; common fine roots and few medium roots; slightly acid, pH 6.2; clear smooth boundary.

Table 2. Continued.

C1--9 to 28 cm; yellowish brown (10YR 5/6), silt loam; weak medium and coarse subangular blocky structure; friable; light gray (10YR 7/2) clay films and 3 percent dark yellowish brown (10YR 4/6) and yellowish brown (10YR 5/4) clay films; very strongly acid, pH 4.8; gradual smooth boundary.

C2--28 to 58 cm; 10 percent yellowish brown (10YR 5/6) and 90 percent light yellowish brown (10YR 6/4), silt loam; weak thick platy parting to weak medium subangular blocky structure; friable; light gray (10YR 7/2) clay films and yellowish brown (10YR 5/4) clay films and yellowish brown (10YR 5/4) pressure faces; strongly acid, pH 5.6; abrupt smooth boundary.

C3--58 to 76 cm; yellowish brown (10YR 5/6), silt loam; weak medium and coarse subangular blocky structure; friable; light gray (10YR 7/2) clay films and strong brown (7.5YR 4/6) clay films; extremely acid, pH 4.4; abrupt smooth boundary.

2C--76 to 152 cm; gray (5Y 5/1), very channery clay loam; massive; firm; neutral, pH 7.3.

Table 3. Laboratory data for selected soil separates and rock fragments.

County / Soil	Depth cm	Horizon	Soil Texture	Clay %	Silt %	Sand %	SandVF %	Rock Fragment of Whole Soil % by weight
Daviess 001	0-20	Ap	silt loam	16.6	78.2	5.2	2.5	1
	20-43	B/A	silt loam	24.5	69.9	5.6	2.6	0
	43-56	C1	silt loam	26.3	69.3	4.4	2.4	0
	56-69	C2	silt loam	21.9	65.7	12.4	4.4	1
	69-99	C3	silt loam	20.9	62.8	16.3	5.5	0
	99-122	C4	silt loam	21.0	66.3	12.7	4.7	2
	122-150	2Cr	channery silt loam	25.1	61.3	13.6	5.0	40
Daviess 002	0-25	Ap	silt loam	20.0	73.8	6.2	2.2	3
	25-33	C1	silt loam	24.6	63.0	12.4	2.7	2
	33-58	C2	silt loam	24.1	61.3	14.6	3.2	11
	58-97	C3	silt loam	25.0	68.9	6.1	2.2	0
	97-132	C3	silt loam	26.7	68.4	4.9	1.9	0
	132-158	Cr	channery Silty clay loam	34.9	54.5	10.6	5.2	39
Greene 015	0-20	Ap	silt loam	20.9	70.9	8.2	2.6	0
	20-28	AB	silt loam	22.6	64.9	12.5	3.7	5
	28-43	CB	silt loam	26.3	55.1	18.6	4.8	7
	43-84	Cd	silty clay loam	27.6	53.0	19.4	4.3	3
	84-107	C1	silty clay loam	28.8	56.8	14.4	4.5	0
	107-145	C2	clay loam	30.3	45.4	24.3	6.4	1
	145-183	C3	silty clay loam	35.8	48.4	15.8	4.2	0
	183-200	C4	clay loam	31.4	45.1	23.5	4.4	1
Greene 025	0-20	Ap	silt loam	19.7	72.1	8.2	2.3	2
	20-27	AC	silt loam	19.7	72.4	7.9	2.1	0

	27-34	C1	silt loam	23.3	66.2	10.5	3.4	0
	34-76	Cd1	silt loam	25.8	58.5	15.7	5.0	2
	76-117	Cd2	silt loam	26.5	62.9	10.6	3.8	5
	117-135	Cr	channery silty clay loam	27.7	62.0	10.3	5.4	38
Pike 001	0-13	Ap1	silt loam	20.6	69.8	9.6	3.4	0
	13-25	Ap2	silt loam	25.8	59.5	14.7	4.4	0
	25-58	C1	clay loam	27.4	52.5	20.1	5.1	0
	58-112	C2	silt loam	24.8	71.0	4.2	1.9	0
	58-112	C2	silt loam	21.6	72.0	6.4	2.6	4
	112-142	2C	silty clay loam	34.8	52.4	12.8	7.1	0
Pike 002	0-10	Ap1	silt loam	18.2	71.6	10.2	5.8	0
	10-23	Ap2	silt loam	15.4	75.9	8.7	5.4	0
	23-43	Bg	silt loam	16.6	75.9	7.5	4.9	0
	43-76	C1	silt loam	20.5	67.6	11.9	6.6	0
	76-124	C2	silt loam	22.0	70.3	7.7	4.2	0
	76-124	C2	silty clay	49.3	42.9	7.8	2.9	0
	124-137	Cr	very channery silty clay loam	35.7	54.5	9.8	4.9	68
Warrick 001	0-15	Ap	silt loam	18.3	75.6	6.1	2.7	3
	15-30	A/C	silt loam	19.5	75.4	5.1	2.3	2
	30-66	Cd1	silt loam	24.8	64.5	10.7	5.5	2
	66-102	Cd2	silt loam	25.5	65.3	9.2	4.9	8
	102-152	2C	channery loam	23.9	48.9	27.2	10.2	35
Warrick 002	0-9	Ap	silt loam	20.0	77.8	2.2	1.4	tr
	9-28	C1	silt loam	22.3	74.3	3.4	2.2	1
	28-58	C2	silt loam	19.6	77	3.4	2.3	0
	58-76	C3	silt loam	22.4	74.7	2.9	1.6	1
	76-152	2C	very channery silty clay loam	28.9	62.7	8.4	5.7	64

Table 4. Selected soil chemical and physical laboratory properties.

County / Soil	Depth cm	Horizon	Soil Texture	Organic Matter %	Soil Reaction pH	Bulk Density g/cm3	WRD cm/cm
Daviess 001	0-20	Ap	silt loam	2.27	6.8	1.54	0.24
	20-43	B/A	silt loam	0.41	5.5	1.64	0.17
	43-56	C1	silt loam	0.43	5.0	1.64	0.17
	56-69	C2	silt loam	0.45	5.7	1.7	0.17
	69-99	C3	silt loam	0.62	6.0	1.64	0.19
	99-122	C4	silt loam	0.46	6.0	1.66	0.19
	122-150	2Cr	channery silt loam	0.84	7.4	1.71	0.12
Daviess 002	0-25	Ap	silt loam	2.27	6.3	1.45	0.22
	25-33	C1	silt loam	0.43	4.4	1.61	0.16
	33-58	C2	silt loam	0.19	4.4	1.67	0.15
	58-97	C3	silt loam	0.28	4.6	1.73	0.12
	97-132	C3	silt loam	0.38	4.7	1.60	0.16
	132-158	Cr	channery silty clay loam	5.57	5.6	1.76	0.09
Greene 015	0-20	Ap	silt loam	2.31	7.0	1.48	0.23
	20-28	AB	silt loam	1.00	6.7	1.57	0.18
	28-43	CB	silt loam	0.46	5.6	1.71	0.12
	43-84	Cd	silty clay loam	0.34	5.0	1.78	0.10
	84-107	C1	silty clay loam	0.81	5.3	1.63	0.14
	107-145	C2	clay loam	0.52	5.2	1.62	0.14
	145-183	C3	silty clay loam	2.40	4.8	1.52	0.07
	183-200	C4	clay loam	0.81	5.2	1.64	0.13
Greene 025	0-20	Ap	silt loam	2.05	5.6	1.54	0.21
	20-27	AC	silt loam	1.05	5.2	1.61	0.20

	27-34	C1	silt loam	0.64	6.1	1.60	0.17
	34-76	Cd1	silt loam	0.91	7.3	1.86	0.08
	76-117	Cd2	silt loam	0.31	5.0	1.71	0.12
	117-135	Cr	channery silty clay loam	2.65	5.6	1.95	0.07
Pike 001	0-13	Ap1	silt loam	1.75	7.0	1.49	0.16
	13-25	Ap2	silt loam	0.62	7.5	1.66	0.11
	25-58	C1	clay loam	0.19	7.4	1.69	0.09
	58-112	C2	silt loam	0.28	5.6	1.67	0.13
	58-112	C2	silt loam	1.72	7.0	1.67	0.16
	112-142	2C	silty clay loam	8.82	6.6	1.91	0.07
Pike 002	0-10	Ap1	silt loam	1.20	6.9	1.48	0.22
	10-23	Ap2	silt loam	0.69	7.0	1.55	0.22
	23-43	Bg	silt loam	0.29	6.9	1.60	0.19
	43-76	C1	silt loam	0.24	7.3	1.73	0.12
	76-124	C2	silt loam	1.00	7.4	1.74	0.10
	76-124	C2	silty clay	0.24	7.3	-	-
	124-137	Cr	very channery silty clay loam	2.94	6.6	1.50	0.10
Warrick 001	0-15	Ap	silt loam	2.75	6.9	1.46	0.23
	15-30	A/C	silt loam	1.39	7.2	1.56	0.21
	30-66	Cd1	silt loam	0.26	6.3	1.77	0.13
	66-102	Cd2	silt loam	0.24	5.9	1.73	0.13
	102-152	2C	channery loam	3.94	6.6	1.58	0.15
Warrick 002	0-9	Ap	silt loam	2.36	5.1	1.32	0.23
	9-28	C1	silt loam	0.41	4.8	1.53	0.21
	28-58	C2	silt loam	0.21	5.1	1.50	0.24
	58-76	C3	silt loam	0.21	4.7	1.42	0.20
	76-152	2C	very channery silty clay loam	2.60	6.9	1.79	0.05

The irregular decrease of organic matter with depth is in contrast to the regular decrease in organic matter for soils before mining. The pH will be discussed later in this paper. The bulk density values for the soils reclaimed by scraper placement are higher at a shallower depth than expected for soils in these loessial landscapes. The values for nonlimiting, critical, and root-limiting bulk densities for each family particle-size class are presented in Table 5 (Pierce et al., 1983). The subsurface horizons above 122 cm of the reclaimed soils are predominately fine silty. The depth to the first layers with bulk densities of 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 4. The WRD values, though lower than expected for the soil textures, are not available for use by plants because the bulk densities are 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.

Comparison of Soil Properties of the Reclaimed Soils to the Properties of the Soils Before Mining

The soil properties of the reclaimed soils are presented in Tables 3 and 4 and the soil properties of the soils before mining in Table 6. The data are similar except in bulk density. The difference bulk density results in the reclaimed soils having a less desirable rooting media. The organic matter contents in the reclaimed soils are typically within the range of those in the NCSSD for soils before mining. The exceptions are the lower horizons in the reclaimed soils are usually somewhat higher in organic matter than the NCSS data for soils before mining. In addition, the lowest horizons of the reclaimed soils are usually higher in channery rock fragments. The pH for 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 than the premined soils. The WRD in the reclaimed soils are similar or often higher than the soils before mining. These numerical WRD values in Table 4 are deceiving since as discussed earlier, the root-limiting bulk densities and absence of moderate to strong blocky structure restricts roots from entering these soil horizons. The bulk densities in the reclaimed soils are significantly higher than in all but three of the premined soils. But, even in these three soils, the root-limiting bulk densities are shallower than in the premined soils.

Table 5. Nonlimiting, critical, and root limiting bulk densities for each family texture class (Pierce et al, 1983).

Family Texture Class	Nonlimiting Bulk Density g/cm3	Critical Bulk Density g/cm3	Root-Limiting Bulk Density g/cm3
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

Crop Productivity

The decision to use crop production as a measure of prime farmland reclamation success was a win-win for everyone (30 CFR. 2002). AWC is the limiting factor that determines plant growth and crop yield in these soils. Many prime farmland soils before being mined have 7.6 to 30.0 cm of AWC. Some reclaimed soils have, at the very most, 6.8 cm of AWC and some much less (Tables7). The reclaimed soils have less AWC if they contain appreciable amounts of rock fragments. Most of the upland soils in Indiana, before mining, formed in loess which is the most desirable parent material for growing crops if no root limiting layer is present in the soil profile.

Corn is the commonly grown crop in Indiana on prime farmland soils. With a lower AWC, reclaimed soils require above normal precipitation during July and August than the premined soils to get equal or higher yields. Typically, at least one year out of every ten, the months of July and August will have what farmers refer to as a wet July and August. The year with a wet July and August is the year that corn yields are reported to the State Regulatory Authority for bond release in some states. Olson (1992) explains the difference in methods and procedures used in the 1977 Surface Mining Control and Reclamation Act and by the University to determine long term crop yields.

Table 6. Selected soil properties from the National Cooperative Soil Survey Database.

County / Soil	Depth cm	Horizon	Clay %	Silt[1] %	Sand[1] %	Very Fine Sand[1] %	Rock Fragments volume %	Bulk Density g/cm3	WRD cm/cm	Soil Reaction pH	Organic Matter %	Passing Sieve #10 weight %
Daviess 001	0-33	H1	12-20	79	5	2	0	1.30-1.60	0.22-.024	4.5-7.3	1.0-3.0	100
	33-127	H2	22-32	70	3	1	0	1.40-1.60	0.18-0.20	4.5-6.5	0.5-1.0	100
	127-152	H3	8-20	81	5	2	0	1.40-1.60	0.20-0.22	5.1-6.5	0.0-0.5	100
Daviess 002	0-30	H1	10-17	80	7	3	0	1.20-1.50	0.18-0.24	4.5-6.5	1.0-3.0	100
	30-84	H2	24-30	66	7	3	0	1.30-1.50	0.15-0.22	4.4-5.5	0.5-1.0	100
	84-203	H3	16-26	66	10	4	0	1.60-1.80	0.06-0.08	4.5-6.0	0.0-0.5	100
Greene 015	0-20	H1	10-16	72	15	3	0	1.30-1.60	0.18-0.24	4.5-7.3	1.0-3.0	100
	20-46	H2	12-24	70	12	3	0	1.40-1.60	0.17-0.26	4.5-5.5	0.5-1.0	100
	46-203	H3	24-35	59	10	2	0	1.40-1.60	0.16-0.20	4.5-6.0	0.0-0.5	100
Greene 025	0-25	H1	12-22	69	14	2	0	1.20-1.50	0.18-0.24	4.5-7.3	1.0-3.0	100
	25-71	H2	24-32	67	4	1	0	1.40-1.60	0.18-0.22	4.5-6.0	0.5-1.0	100
	71-145	H3	20-27	63	14	3	0	1.60-1.80	0.06-0.08	4.5-5.5	0.0-0.5	100
	145-203	H4	12-25				0-9	1.40-1.60	0.06-0.19	4.5-5.5	0.0-0.5	85-100
Pike 001	0-20	H1	10-17	80	7	3	0	1.20-1.50	0.18-0.24	4.5-6.5	1.0-3.0	100
	20-79	H2	24-30	66	7	3	0	1.30-1.50	0.15-0.22	4.4-5.5	0.5-1.0	100
	79-203	H3	16-26	66	10	4	0	1.50-1.80	0.06-0.08	4.5-6.0	0.0-0.5	100

Pike 025	0-20	H1	18-25	71	5	2	0	1.30-1.60	0.18-0.24	5.1-7.3	1.0-2.0	100
	20-152	H2	22-30	69	3	1	0-3	1.30-1.50	0.18-0.22	4.5-5.5	0.0-0.5	95-100
	152-203	H3	18-30	40	36	3	3-6	1.50-1.70	0.12-0.18	4.5-5.5	0.0-0.5	90-95
Warrick 001	0-23	H1	10-17	80	7	3	0	1.20-1.50	0.18-0.24	4.5-6.5	1.0-3.0	100
and 002	23-76	H2	24-30	66	7	3	0	1.30-1.50	0.15-0.22	4.4-5.5	0.5-1.0	100
	76-165	H3	16-26	66	10	4	0	1.60-1.80	0.06-0.08	4.5-6.0	0.0-0.5	100

[1] Representative values.

Table 7. Land capability classes assigned by Available Water Capacity (AWC) for reclaimed soils and premined soils.

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

The comparison of the laboratory soil properties, the soil taxonomic classifications, and selected soil morphological characteristics indicates that the reclaimed soils are less desirable for cropland than the premined soils. A conclusion that can be made is scraper placement soils are shallower to root limiting layer than the premined soils. Soil Structure and bulk density are the two of the properties that are less desirable in the reclaimed soils than the premined soils. Thus, the thickness and quality of the rooting media result in reclaimed soils that are more droughty than the premined soils.

The reclamation of soils reclaimed after surface mining is continuing to improve. Reclamation using scraper placement after surface mining for coal is just about the thing of the past by the more progressive mining companies. Shovel-truck placement is replacing the scraper placement.

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

Acknowledgements

The authors would like to thank Robert J. Engel, Soil Scientist, USDA-NRCS, Lincoln, Nebraska, for classifying the reclaimed soils and his technical suggestions during the preparation of this paper. However, Robert is not responsible for errors of fact or interpretation; the authors bear that responsibility.

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