CHARACTERIZATION OF PRIME AGRICULTURAL FARMLAND SOILS DISTURBED BY SURFACE MINING IN WESTERN PENNSYLVANIA[1]

by

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Abstract. Obtaining a plausible estimation of potential soil productivity for drastically disturbed soils is a persistent problem for regulatory agencies particularity where prime farmland soils are involved. The current practice of using crop yield data to estimate soil productivity has inherent shortcomings since many factors that are unrelated to soil productivity can contribute significantly to crop yield results. Additionally, this practice pressures landowners and mine operators to produce a crop for regulatory purposes when other land-uses may be more appropriate or desirable following mining. Criteria for identifying prime farmland soils are specified in the National Soils Handbook published by the U.S.D.A. Soil Conservation Service. An alternative approach to using crop yield data to evaluate potential soil productivity is to conduct a soil morphological investigation of the drastically disturbed soils to assess prime farmland soil criteria with possible considerations for soil disturbance. The purpose of this study was to characterize the physical, morphological, and chemical properties of reclaimed prime farmland soils and to evaluate the feasibility of using a soil morphological investigation to estimate potential soil productivity. We described and sampled 72 soil profiles at 8 surface mining sites throughout western Pennsylvania and collected crop yield data. Soil depth over spoil was generally greater than 75-cm with an observed range of 5 to greater than 200-cm. Well-expressed Ap-horizons were observed in nearly all profiles. Reclamation procedures had drastically altered soil structure below the Ap with most horizons exhibiting massive structure. Excessively compacted, soil layers within 30-cm of the surface that were restricting downward penetration of plant roots were observed at several of the mine sites. Soil horizons likely to restrict plant growth included: 1) horizons composed of spoil, 2) horizons with a >50% rock fragment content, and 3) highly compacted soil horizons. Limiting soil horizons were found within one-meter of the surface for 79% of the soil profiles described in this study and within 50-cm for 51% of the soil profiles.

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Introduction

Current surface-mining regulations in the United States require an assessment of the agricultural productivity of the native soil prior to disturbance by mining and in some cases another assessment following reclamation. The pre-mining assessment is usually based on a published soil survey or similar investigation to determine if the soils are highly productive and meet criteria established by the U.S.D.A. Soil Conservation Service defining prime agricultural farmlands. If prime farmland soils are present, then specific guidelines must be followed to insure that the soils are reconstructed such that their agricultural productivity is preserved.

Crop yields are frequently collected from recently reclaimed prime farmland soils to assess soil productivity. This approach has intrinsic shortcomings since many factors that are unrelated to soil productivity can contribute significantly to crop yield results. These extraneous factors include management practices, weather conditions, disease, pest, and various forms of pollution. The primary goal of the evaluation process is to assess the potential, long-term productivity of the reclaimed soil resource. In this scenario, crop yield data are being used as a productivity indicator of the soil resource.

An alternative to using crop yield data to infer soil productivity would be to examine the soil directly. There are many ways to test soils. Perhaps the most familiar is the fertility test used by farmers to estimate fertilizer and lime requirements. These tests are usually based on composite samples taken from the surface soil. These soil tests do not consider may other soil properties that may be related to the ability of the soil to support plant growth such as soil texture, density, depth, drainage, and rockiness. Therefore, a more holistic view of the soil is necessary to evaluate potential productivity. A soil morphological investigation can is better suited for this purpose. Soil morphology refers to the arrangement of contrasting layers or horizons of a soil. A soil morphological investigation involves the delineation of soil horizons and a field description of certain physical and chemical properties of each horizon. Selected soil horizons are frequently sampled for further laboratory analysis. Soils are observed in the field using either an auger or pit to expose a vertical exposure of the soil called a soil profile. This is the type of soils investigation that is used to describe soils in a soil survey report which is used to identify areas of prime farmland soils.

Prime farmland soil designation is based on a description of: 1) soil morphological, physical and chemical properties, 2) certain landscape and climatic features, and 3) current land-use. Crop yield measurements are not explicitly included as a criteria for prime farmland soil identification. According to the U.S. Soil Conservation Service, prime farmland soils have:

> ...the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed, including water management, according to acceptable farming methods.

Specific criteria for identifying prime farmland soils are provided in the National Soils Handbook (Soil Survey Staff, 1984). For soils in western Pennsylvania (mesic and frigid temperature regimes and udic moisture regime) these criteria include: 1) sufficient available moisture capacity in the rooting zone (upper 1 meter in most instances), 2) soil pH of 4.5 to 8.4, 3) lack of a seasonal water table in the rooting zone, 4) low soluble salt content, 5) infrequent flooding, 6) non-highly erodible soils, and 7) <10% rock fragments in the surface horizon, and 8) moderate permeability in the upper 50 cm.

Only a cursory evaluation of soil chemical characteristics is required for two main reasons. First, while mining and reclamations operations will certainly result in some alteration of soil chemical characteristics, these alterations will be minor assuming that the soil horizons were restored in the proper sequence. A soil morphological investigation is the most direct method to determine if the proper sequence of soil horizons were restored. Secondly, most soil nutrient deficiency and pH imbalance problems can be readily corrected using standard soil and crop management practices. Therefore, soil chemical properties are somewhat ephemeral in nature and do not reflect the long-term productivity of the soil resource since they can be easily altered with the exception of extremely acidic, alkaline, or toxic conditions. In comparison, the physical properties and arrangement of soil horizons in reconstructed soils are a direct function of reclamation operations and cannot be significantly altered by conventional agricultural management practices.

If soil morphological investigations are to be used to assess compliance to reclamation standards, then specific performance criteria must be established. While some of these criteria can be gleaned from the existing definitions of prime farmland soils, special considerations will be required for drastically disturbed soils. Consequently, the primary goal of this study is to gather and analyze information on the morphological, physical, and chemical properties of reclaimed prime farmland soils that have been disturbed by surface mining operations.

Objectives

1. Characterize certain morphological, physical, and chemical properties of reconstructed prime farmland soils in western Pennsylvania.

2. Identify characteristics of the restored prime farmland soils that may limit plant growth.

3. Evaluate feasibility of using a soil morphological investigation to evaluate the productivity of reclaimed prime farmland soils..

Methods

Selection of Mine Study Sites

Eight mine reclamation sites located throughout western Pennsylvania were selected for study. Pennsylvania Department of Environmental Resource personnel from the appropriate districts assisted in identifying potential reclaimed prime farmland sites. Site selection criteria included:

1. Prime farmland soils were identified on the site prior to disturbance by mining,

2. The reclamation plan within the mining permit specified that topsoil removal, storage, and replacement procedures required for mining prime farmland soils would be used, and

3. The site would be used for crop production following reclamation.

The locations of the eight selected sites are illustrated in Figure 1.

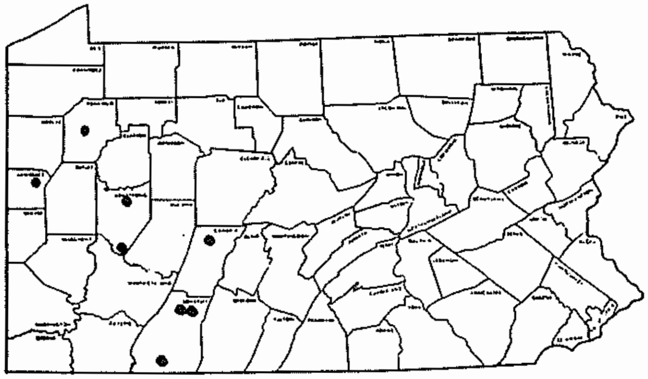

Figure 1. Location of reclaimed prime farmland mine study sites.

Soil Description and Sampling Techniques

Three sampling transects were located at each site that were approximately 100 meters in length. A soil profile was exposed by excavating three backhoe pits along each of the three transects to a depth of 2 meters or until large rock fragments impeded further excavation. For each soil horizon in the profile we described depth, texture, rock fragment content, structure, consistence, color, and rooting density using standard soil description techniques (Soil Survey Manual, 1984). We took soil samples and excavated undisturbed soil clods from the surface (Ap-horizon) and subsurface (C or Bw-horizon) soil horizons from one of the nine soil profiles described at each site for laboratory analysis. The profile selected for laboratory analysis had morphology (soil horizonation) that was representative of the majority soil profiles at that site.

The extent of soil compaction was evaluated qualitatively during the soil description process. Soil horizons were defined as compacted if all of following conditions were met: 1) the horizon was structureless and massive, 2) plant roots did not penetrate into the horizon, 3) soil consistence was firm or very firm and 4) considerable effort was required to insert a knife into the horizon. Rock fragment content was estimated by visual examination of the exposed soil profile. All mine sites were described in early spring or late fall to avoid disruption of crop production.

Crop yield data was collected from the farmers at each site on an annual basis. Since different crops were being grown at the study sites, all yield values were converted to corn equivalent yield as indicated by the footnote in Table 3. A variety of methods were used by the farmers to estimate annual crop yields on a per-field basis.

Soil Sample Analysis

Soil samples were sent to the Merkle Soil Testing Laboratory at the Pennsylvania State University for conventional fertility tests for pH, soil macro-nutrients (P, K, Mg, Ca), and cation exchange properties. Soil bulk densities of the whole soil and <2-mm fraction were determined on saran-coated clods by the method of Blake (1965). Gravimetric rock fragment (>2-mm diameter) content was determined by dry sieving. Volumetric moisture contents at 33 kPa (field capacity) and 1500 kPa (wilting point) were determined by desorption of the soil clods in a pressure plate extractor (Klute, 1965). Available water capacity was estimated from the difference in volumetric water contents at 33 and 1500 kPa. Particle size distributions were determined by the pipette method described by Day (1965). All Ap-horizons were treated with peroxide prior to particle size determination to minimize the particle binding effects of soil organic matter.

Results and Discussion

Soil Morphological Characteristics

The morphology of the reconstructed soils varied depending on pre-mining soil conditions and soil replacement techniques. Three major types of soil horizons were identified: 1) a darkened surface horizon (Ap), 2) a structureless subsurface soil horizon (C1), and 3) mine spoil horizon (C2). The general morphology of a typical reconstructed prime farmland soil profile is illustrated in Figure 2.

Figure 2. Diagram of a typical, reconstructed prime farmland soil profile.

Reconstructed Surface Soil Horizons

Reconstructed surface soil horizons are derived from the original plow layer (Ap soil horizon) that are disturbed by tillage operations in normal agricultural management practices. Soil color is typically dark brown due to the incorporation of organic material from decaying root and organic fibers from the soil surface. Colloidal organic matter binds individual soil particles together into structural aggregates. Ap-horizons in the reconstructed soils usually contained moderately expressed granular structure quite similar to Ap-horizons in undisturbed soils. Presumably, soil structure in the Ap-horizon was largely retained and/or regenerated rather quickly due to: 1) relatively high organic matter contents, and 2) exposure to wet/dry and freeze/thaw cycles at the surface. Since Ap-horizons are removed, stored, and replaced independently of other soil layers, the organic matter content is not "diluted" by mixing with subsoil materials. The Ap-horizon is considered the zone of maximum biologic activity and is frequently the major source of plant nutrients. The structure, texture, color, and consistence of the reconstructed Ap-horizons were similar to those of the undisturbed, agricultural soils of western Pennsylvania. The mean and standard deviation of Ap-horizon depths for the nine soil profiles observed on each site are depicted in Figure 3. The depths of the reconstructed Ap-horizons are relatively consistent as would be expected since the depth of the plow layers (Ap-horizons) are relatively consistent in most undisturbed soils of the region as well. Additionally, the Ap-horizon is easily distinguished from the subsoil due to an obvious change in color. During soil removal operations, the Ap-horizon can be easily identified and segregated by equipment operators.

Reconstructed Subsurface Soil Horizons.

The reconstructed subsoil is typically derived from a mixture of the B and C-horizons from the undisturbed, pre-mining soil in western Pennsylvania. Native subsoils (B and C-horizons) typically have lower organic matter contents and finer texture than the surface soils (Ap-horizon) in this region as well as some degree of structural development. While we did observe weak structural development in a few of the reconstructed subsoils, the vast majority of the reconstructed subsoils were structureless and massive. Our observations of subsurface soil structure agrees with those by McSweeney and Jansen (1984) for reconstructed prime farmland soils in Illinois. They found that subsoils replaced by scrapers were massive whereas subsoils replaced by mining wheels formed aggregates which were termed as "fritted" structure.

On certain sites, the subsoil material was excessively compacted by mining equipment during soil replacement operations. The creation of dense, massive soil layers by mining equipment and its subsequent deleterious effects on crop growth is well documented in the literature (Van Es, et al., 1988; Thompson et al., 1987; McSweeney et al., 1987; McSweeney and Jansen, 1984; Fehrenbacher et al., 1982; Bell, 1982). Soil compaction is a function of the type of equipment being used and the condition of the soil at the time of reclamation. In western Pennsylvania, large earth-moving scrapers are used for many soil moving operations with bulldozers playing a lessor role. The rubber tires and bowls of scrapers exert considerable force on the soil surface during replacement operations that can result in excessive soil compaction of shallow soil horizons, particularly if the soil is in a moist state. Forty-seven percent of the soil profiles described contained an excessively compacted soil horizon within the upper 2 meters. As shown in Figure 4, the depth to a compacted soil horizon varies considerably for the profiles described in this study. Note in Figure 4 that the means and standard deviations are calculated only for the soil profiles where a compacted soil layer was identified, not for all soil profiles at a given site. The number of soil profiles out of nine that exhibited shallow compacted is shown parenthetically after the site ID on the X-axis. Bulldozers were used for some of the soil replacement operations on sites B, D, and H instead of scrapers. Site D had only one compacted soil profile. Compacted soil layers occurred deeper, on the average, and the depth to a compacted soil layer was more variable at sites B and D.

In undisturbed soil profiles of residual soils in western Pennsylvania, the lower portion of the soil profile is usually composed of weathered bedrock material from which the surrounding soil has formed. During the surface mining operations this weathered bedrock is either incorporated into the soil material to be used as subsoil or is treated as spoil. In the reclaimed soil profiles, this weathered bedrock has been replaced by spoil which usually forms an abrupt boundary in terms of color, texture, and rock fragment content with the reclaimed subsoil. Spoils in this region are frequently dark gray shales or siltstone rock fragments ranging from a few centimeters to over one meter in diameter. Varying amounts of soil-sized material (5-50%) typically fills the interstices between the rock fragments. Spoils with a high rock fragment content were usually loose since the large fragments form a bridging network that prevents compaction of the fine particles. Conversely, lower rock fragment spoils were frequently compacted due to lack of this bridging effect. The mean depth to spoil material, or alternatively the depth of the reconstructed soil, is shown in Figure 5. Depth to spoil was in excess of 2-meters for all soil profiles at site E and little variability in depth was found on site C. Otherwise, depth to spoil varied considerably both within and among the mine sites. Upon close examination of the mining plans for site G we learned that there was a direct relationship between the distance to the soil stockpile and the depth to spoil with the deepest soils being close to the stockpile location and gradually diminishing in depth with distance. We suspect that similar circumstances on the other sites led to the variability in reconstructed soil depths as mining operators attempted to minimize haul distances during soil reconstruction. Plant roots were observed growing into the spoil material at sites C, D, F, and G when the spoil was not compacted. Several studies have previously determined

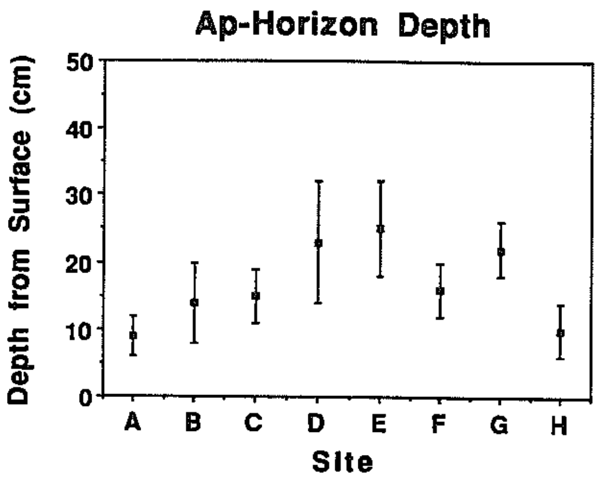

Figure 3. Mean and standard deviations for Ap-horizon depth by mine site. (n=9 observations per mine site)

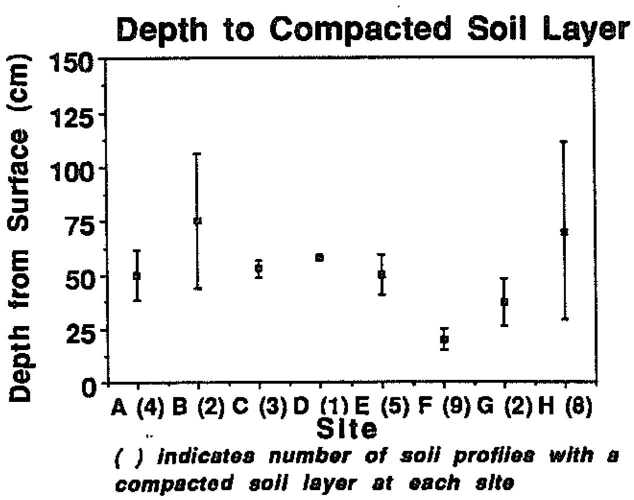

Figure 4. Mean and standard deviations for depth to a compacted soil layer by mine site. (n=9 observations per mine site)

that mine spoil material can successfully support plant growth (Roberts et al., 1988a, 1988b, 1988c, McFee et al., 1981) however, the spoil's physical and chemical properties would usually be inferior to those of native

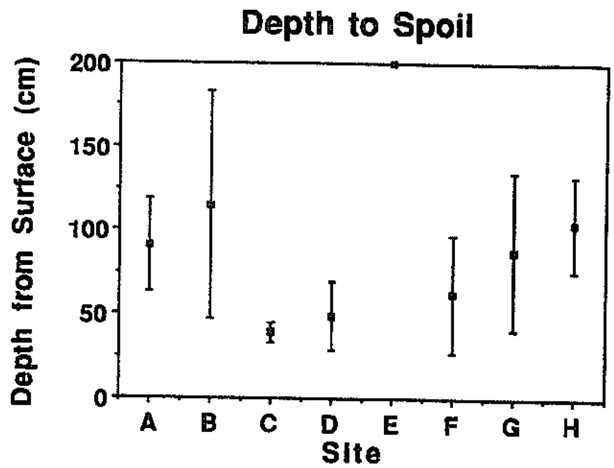

Figure 5. Mean and standard deviations for depth to spoil by mine site.

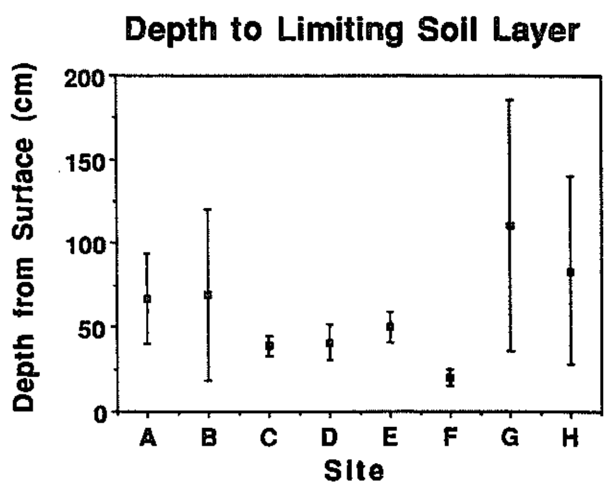

Figure 6. Mean and standard deviations for depth to a limiting soil layer by site. (n=9 observations per mine site)

prime farmland soils.

Limiting Morphological Characteristics

Soil morphological characteristics observed that would limit plant growth would include: 1) excessively compacted soil horizon, 2) horizon with a high rock fragment content, and/or 3) a horizon composed of mine spoil.

Shallow, excessively compacted soil horizons diminish the water holding capacity of the soil and increase the likelihood of saturated soil conditions in the rooting zone following periods of heavy precipitation. Soil horizons with high rock fragment contents also diminish the water holding capacity of the soil. Spoil horizons frequently have high rock fragment contents and inferior soil physical and chemical characteristics when compared to the subsoils of prime farmland soils.

A possible approach to evaluating reconstructed soil morphology would be to establish criteria based on depth to a limiting soil horizon. Figure 6 shows the mean and standard deviation for depth to a soil horizon that: 1) contains greater than 50% rock fragments by volume, 2) is excessively compacted, or 3) is composed of mine spoil material. The sites appear to fall into two general groups: 1) sites with a mean depth of less that 50 cm to a limiting horizon with low variability and 2) sites with a mean depth of greater that 50 cm to a limiting horizon with high variability. The limiting condition on sites C and D appears to be shallow depth to spoil whereas compaction of shallow soil layers is the main limiting condition on sites E and F. All nine soil profiles on both sites C and F contained limiting horizons within 50 cm of the surface whereas sites D and E each contained 2 or 3 profiles without a limiting layer in the upper meter. Of the 72 soil profiles described in this study, 79% contained a limiting layer within 1-meter of the surface, 75% contained a limiting layer within 75 cm and 51% contained a limiting layer within 50 cm.

Soil Physical and Chemical Characteristics

The physical and chemical characteristics of the reconstructed soils are based on a limited number (1 profile per site) of laboratory samples and are intended to provide some general characterization of the properties of the soils in the surface and subsurface horizons. Table 1 provides a summary of selected soil physical properties. An intact clod could not be removed from an Ap-horizon at sites A, E, G, and H and consequently available water capacity and bulk density data is not reported for the Ap-horizon at these sites. Available water capacity is related to soil structure, texture, and organic matter content. Higher organic matter contents in the Ap-horizons relative to the subsoils probably explain the slightly higher available water holding capacities in the Ap-horizons. The available water holding capacities are within the range expected for the native soils of the region. Soil bulk density samples were taken from un-compacted soil horizons with the exception of site H where a highly compacted portion of the C1 horizon was sampled. As shown in Table 1, the bulk density of the <2-mm fraction for this sample is considerably higher than other samples. Bulk densities determined by the clod method typically yield higher bulk densities than those obtained by other methods since intact soil clods are frequently denser than the soil mass in general. Consequently, large differences were not always found between the Ap and C horizons since the most dense portion of the Ap-horizon was sampled in order to obtain an intact clod. Soil textures were loams or silt loams with little difference in particle size distributions between the surface and subsurface horizons. Notable exceptions were sites F and H where the Ap-horizons had a higher silt content. High silt contents are common in many of the surface soil horizons of this region and this trait was probably inherited from the native soil.

Table 1. Soil physical characteristics of a single soil profile for each study site.

			Whole Soil		<2-mm fraction				
Site	Horizon	Depth	Available Water Capacity	Bulk Density	Bulk Density	Sand	Silt	Clay	Rock Fragments
		-- cm --	-- % --	------ Mg/m^3	-------	---------	--------- %	---------	---------
A	Ap	0 - 5	--	--	--	28.9	46.3	24.8	19.6
	C1	5 - 110	0.18	1.61	1.51	28.6	48.9	22.8	52.8
B	Ap	0 - 23	0.15	1.67	1.50	25.1	48.1	26.8	21.1
	C1	23 - 54	0.12	1.87	1.42	28.8	49.4	21.8	38.2
C	Ap	0 - 20	0.15	1.56	1.46	28.1	50.3	21.6	25.1
	C1	20 - 40	0.08	1.74	1.69	29.0	45.8	25.2	17.3
D	Ap	0 - 15	0.13	1.63	1.49	57.2	26.3	16.5	24.9
	C1	15 - 36	0.11	1.86	1.40	52.0	29.8	18.3	30.8
E	Ap	0 - 8	--	--	--	19.1	53.3	27.5	8.2
	C1	8 - 61	0.17	1.69	1.60	22.9	52.6	24.5	5.1
F	Ap	0 - 15	0.24	1.40	1.13	29.5	54.9	15.6	35.6
	C2	25 - 90	0.23	1.79	1.60	39.2	42.3	18.4	45.7
G	Ap	0 - 23	--	--	--	28.4	54.2	17.4	17.1
	Bw	23 - 40	0.20	1.79	1.56	27.0	54.9	18.1	19.1
H	Ap	0 - 10	--	--	--	17.6	58.9	23.5	8.9
	C1	23 - 48	0.13	1.89	1.81	28.8	46.6	24.6	26.0

A summary of soil chemical properties for sites E, F, G, and H is shown in Table 2. The slightly higher pH in the Ap horizons are probably a result of post-mining lime applications. Soil plant nutrients are in the low to optimum range for western Pennsylvania with the exception of Mg for the C1 horizon at site H which is in the excessive range according the agricultural recommendations provided by the Merkle Soil Testing Laboratory at the Pennsylvania State University. The sampled soil pit at site H was described as having some spoil material mixed throughout the soil profile. The high Mg could be related to the spoil component of this profile. Since spoil is composed of blasted rock which has undergone minimal mineral weathering, high levels of certain bases, such as Mg, would be expected.

Crop Yields

Crop yield data collected by the farmers at each site are shown in Table 3. Actual yields were from a variety of crops and were converted to corn equivalent yields as indicated in the footnote of Table 3. Yield data could not be obtained for site H. For comparison purposes it should be noted that the sites in this study were under different levels of agricultural management and that different procedures were used by the farmers to estimate their annual yield. Consequently, conclusions drawn from the yield data are somewhat dubious. Crop yield data was to be collected in 1988, however doughty conditions resulted in crop failures throughout the region. This data indicates that crop yields on the reclaimed prime farmland sites are somewhat lower that the yield potentials for the pre-mining soils and lower than the west central Pennsylvania average for this time period. Significant correlations were not found between the soil characterization information and farmer-estimated crop yields in this study. This may be related to the fact that soil investigations were made at specific point locations whereas crop yields represented an average value over the entire site. Additionally, as previously mentioned, many factors other than soil condition can effect crop yields.

Summary

Three major types of soil horizons were identified by the morphological investigations. These included: 1) a darkened surface horizon (Ap), 2) a structureless subsurface soil horizon (C1), and 3) mine spoil horizon (C2). The surface (Ap) soil horizons were quite similar to Ap-horizons for undisturbed agricultural soils of the region. The structure and in some cases the density of the reconstructed subsurface had been drastically changed which could alter water movement and root penetration compared to subsurface horizons in undisturbed soils. Most reclaimed subsoils were structureless and massive whereas undisturbed agricultural soils typically have some degree of structural development in the subsoil. The lower portion of the soil profile in native soils of the region is usually composed of weathered bedrock material. This has been replaced by either loose or compacted spoil in the reclaimed soils. While bulk density has probably been increased in some instances due to soil compaction, other soil chemical and physical properties appear to be within the expected range for agricultural soils of the region. The major soil alterations that are attributable to reclamation are alteration of soil horizonation (depths and type of soil horizons), subsurface soil structure and bulk density, and replacement of the weathered, native bedrock by compacted or loose spoil in the lower portion of the reconstructed profile.

Reclaimed prime farmland soil characteristics observed in this study that could potentially limit plant growth included shallow

Table 2. Soil chemical characteristics for a single soil profile at sites E, F, G, and H.

Site	Horizon	pH	P	K	Mg	Ca	CEC	Base Saturation
			- kg/ha -	--------- meq/100g ---------				- % -
E	Ap	6.9	22	0.2	0.5	8.3	8.9	100
	C1	6.1	11	0.2	0.5	7.3	11.8	67
F	Ap	6.7	59	0.3	0.4	6.3	9.0	78
	C2	5.5	26	0.3	0.7	3.5	8.6	52
G	Ap	7.5	16	0.2	0.9	10.3	11.3	100
	Bw	6.9	15	0.2	1.7	6.5	8.4	100
H	Ap	7.2	39	0.2	1.1	11.0	12.4	100
	C1	6.1	6	0.1	5.1	5.5	14.6	73

Table 3. Farmer estimated crop yields (1989-1991) for reclaimed prime farmland soils and yield potential for pre-mining soils as reported in county soil survey.

Site	Corn Equivalent Yields*					
	1989	1990	1991	Average	Potential**	Soil Series**
	---------------------------- kg/ha ----------------------------					
A	4076	5205	5456	4891	6271	Rayne/Gilpin
B	4076	3136	5832	4327	6271	Rayne/Gilpin
C	5268	1944	3888	3700	5017	Wharton
D	6271	6271	6271	6271	7525	Hazelton
E	4954	1568	2195	2884	3449	Hanover
F	Manured	5644	2696	4139	5957	Rayne
G	2195	1756	2320	2069	6271	Canfield
West Central Pennsylvania Average	5957***	7086	--	5581		

* 100 bushels corn equals 20 tons of corn silage, 79 bushels of oats, 40 bushels of wheat, 4.0 tons of alfalfa-grass hay, 3.2 tons grass-legume hay, or 7.7 animal units months of grazing tall grass pasture. 1 bushel corn equals 25 kg.

** Venango, Lawrence, Armstrong, Cambria, and Sommerset counties Pennsylvania soil surveys.

*** 1988 Average

soil horizons in the rooting zone with the following characteristics: 1) excessively compacted soil or spoil 2) high (>50%) rock fragment contents, and 3) horizons composed of mine spoil rather than native soil materials. Shallow soil horizons that are compacted or have a high rock fragment content reduce the moisture holding capacity of the soil and diminish potential productivity. Of the 72 soil horizons described in this study, 79% contained at least one of these limiting horizons in the upper 1-meter and 51% contained a limiting horizon in the upper 50 cm.

The results of our study indicate that soil morphological investigations provide a promising alternative for the evaluation of reclaimed prime farmland soils. Excavation of soil pits and subsequent descriptions of soil profiles by professional (ARCPACS certified) soil scientists provides a direct visual examination of the reconstructed soil rather that relying on inferences from crop yield data. Documentation can be provided through photographs of the soil profiles accompanied by standard soil profile descriptions. This approach also provides a certain amount of consistency in the overall evaluation process since the original designation of prime farmland soils is largely based on a soil morphological investigation. The morphological investigation seeks to establish if the reconstructed soil has similar horizonation and rooting depth as the pre-mining soil. An on-site investigation of the pre-mining soils by a professional soil scientist to document the actual morphology of the soils on-site would be of considerable benefit for comparison purposes following reclamation.

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