MINE SOIL MAPPING, CLASSIFICATION, AND CHARACTERIZATION IN ILLINOIS

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Abstract

Surface mining for coal completely disturbs the soils and geologic materials overlying the coal. The soils and landscapes left after surface mining are a result of what the miners did with the materials they encountered. At one time, the spoil was left as it was deposited by the mining activities, but through the years, increasing attempts have been made to purposely place materials to accommodate reclamation requirements. If mined areas are to be used, a soil survey is needed to describe the landscape to guide wise land use decisions. Existing mine soil series and map units in Illinois, as elsewhere, are insufficient to describe their diversity adequately. Most of these soil series were developed before reclamation requirements took full effect and others were too broadly defined. The official series descriptions did not adequately recognize soil attributes, such as compaction, produced by new techniques of material handling and placement. The purpose of this study was to address these shortcomings by developing new soil series and by refining existing soil series. Proposed soil series were characterized in the field and existing series were redefined to reflect field conditions better. Standard soil survey techniques were used. In addition, depth to compaction was estimated with a recording cone penetrometer. Alterations of existing soil series were proposed to restrict them to a better range of sod properties and recognize important soil features. The descriptions, along with the existing mine soil series, will be used as a guide to map reclaimed mine sods in Illinois.

Introduction

Surface mining for coal entirely disrupts a landscape, sometimes to a depth as great as 170 feet. While many surface mines are not that deep, they all disturb the entire soil profile and the portion of the underlying geologic profile above the coal regardless of depth. Reclamation methods used in Illinois range from none at all, to a variety in response to "intermediate" legislation, to the standards in place today, under which a reclaimed soil must have equal or greater productivity than the pre soil. Mined lands need an accurate soil survey to guide post mining land use decisions. However, soil series descriptions have not kept pace with the strides made in reclamation technology. Consequently, many mine soils are mapped improperly, if at all. There is a need for a more refined system of mine soil classification and mapping in Illinois as elsewhere today to rectify these problems.

History of Surface Coal Mining and Reclamation

Surface mining for coal over the last one hundred fifty years has affected approximately 257,000 acres in forty counties in Illinois (Table 1, Fig. 1) (IDMM 1995). The distribution throughout the state clearly indicates the geologic spoon shaped Illinois coal basin. Surface mines are confined to the margins where the coal is shallow. Deep mines occupy the center of the basin. Slightly over two-fifths of the surface mined area was never reclaimed and the remainder was reclaimed to meet the regulation standards of the day (Table 1). Regulations have changed a great deal over time; consequently, so have the post-mine soils. Both reclaimed and nonreclaimed mine soils present problems to a soil classifier and mapper. Over the years, surface mined land has undergone more careful consideration, but the mapping and classification of mine soils has not been conducted with the care given to unmined areas.

Coal mine reclamation in Illinois has taken on many forms over the years. Mine soil reclamation in Illinois is now conducted to meet the standards set forth in the Surface Mining Control and Reclamation Act (SMCRA, PL 95-87) (United States, 1977). This act mandates the replacement of a minimum of four feet of soil after mining. This includes all of the original topsoil to a minimum of 6 in. of surface soil, and a rooting media of equal or better quality than the original subsoil. The methods by which these soil materials are placed can create large differences in the post-mine soils.

Compaction is a common consequence of soil placement. Soil materials placed with scrapers or end-dump trucks driving on the surface become densely compacted (Jansen, 1982). This greatly reduces the exploitable root volume for plants, leading to reduced nutrient and moisture availability. This method of replacement was common for years in Illinois, causing many acres of compacted soils that are not recognized in the existing series. Compaction can be avoided or ameliorated by more careful material handling methods or the use of deep tillage (Dunker et al., 1995). Deep tillage of compacted reclaimed soils can result in corn and soybean yields equal to native soils (McSweeney et al., 1987; Dunker and Jansen, 1987). Soils that have been carefully placed or deep-tilled are also not accounted for by the current soil series.

History of Mine Soil Classification and Mapping

Soil maps have not shown much detail m areas that have been surface mined. Originally, mined areas were identify ed as MD (Mine Dump), SM (Surface Mine), or NE (Made Land) (Table 2). From about 1960 through 1982, mine soils were mapped with the generic Orthent or Udorthent labels. Ironically, in the quest to apply a taxonomic name to these soils, the counties mapping them as Orthents lumped them with other disturbed soils as well as natural Orthents. Valuable information about the soils' formation that the strip mine label indicated was lost. Beginning in 198 1, five soil series were used to describe mine soils. In Illinois there are two series into which an unreclaimed surface mined soil may be placed, Lenzburg and Morrisstown. There are currently three soil series, Swanwick, Schuline, and Rapatee, which may be used in Illinois to identify reclaimed surface mined soils.

These five soils are all classified into mixed, mesic families of Entisols. However, there has been debate about the higher categories into which these soils should be placed. Lenzburg and Morristown are well drained and are classified as Typic Udorthents. They are composed of cast overburden with no or minimal reclamation (Fig. 2). The main difference between these two soils is at the family level; Morristown is loamy-skeletal, while Lenzburg is fine-loamy. The three series representing reclaimed mine soils differ mainly in terms of soil materials replaced. The parent materials for Schuline are topsoil replaced over cast overburden. There is no root media replaced, as Schuline is an intermediate reclamation law soil. Swanwick and Rapatee both have root media and topsoil replaced. Rapatee soils have a dark colored surface horizon, while Swanwick and Schutine soils have a light colored epipedon. Schuline and Rapatee are both classified as Typic Udorthents, while Swanwick is classified as an Oxyaquic Udorthent. Swanwick and Rapatee are in the fine-silty family, and Schuline is in the fine-loamy family.

Mapping and classification of these soils are difficult. Mine soils are inherently heterogeneous which complicates classification and mapping. In addition, there is no natural soil-landscape model which one can apply across a mined landscape as is done to map natural soils. Premine soil(s), mining method(s), reclamation method(s), and the premine geologic column must be used to map these soils (Indorante and Jansen, 1984). The field researcher must be careful to determine whether a particular soil property is inherited from the premine soil, or is an actual indicator of pedogenesis experienced by the soil in place. This is especially important when interpreting subsurface colors. There may be relict materials and colors that would lead a researcher to believe there were reduction-oxidation processes associated with excessive wetness in the soil. These soils also may not exhibit the natural trend of decreasing organic matter with increasing depth, due to relict concentrations of organic matter (Ammons and Sencindiver, 1990). Perhaps the most easily identifiable feature of these soils is the erratic nature of curves plotted from physical data for the soils.

Reclaimed soils present unique challenges to classification as well. They may retain the materials from their original horizons, but without their original structure, which is a very important physical property of a soil. They also may show layering effects and abrupt boundaries that are due to placement of the materials. The physical property of compaction and the disturbance of the entire profile are reasons enough to warrant new series for these soils.

Problems With Existing Soil Series

The existing soil series are extremely broad in scope and do not adequately describe the diversity of mine soils. There are some very different soils that must be included in the same mapping unit because of the limited suite of soil series from which to choose. In southern Illinois, reclaimed mine soils with light colored surface horizons must be mapped as Swanwick if root media was replaced; if not, they must be mapped as Schuline. Currently, reclaimed mine soils with dark surface horizons must be mapped as Rapatee. Alternatively, a new soil series must be developed to allow for additional soils. When comparing profile descriptions from one county to another, it becomes evident that very different soils have been mapped the same because of lack of alternatives (Elmer and Zwicker, 1996; Walker, 1992; Windhom, 1986).

There is a need for soil series that will include more recent reclamation techniques and recognize the materials used. Modem reclamation places topsoil on root media on graded cast overburden (Fig. 2). Topsoil and root media are taken from the premining soil A horizon and the B or C horizons and are of Pleistocene age. Cast overburden is generally Pennsylvanian in age, although it can be any material removed in the process of mining, dumped, then leveled. Replacing 48 in. of root media on top of graded cast overburden often greatly increases the volume of soil available for root exploitation and water storage. This practice is required for all reclamation since the SMCRA took effect, but only two of the current soil series recognize this.

Unrecognized in existing soil series is compaction. Compacted soils, or soils with densic layers, have massive structure, high soil strength, and high bulk density. Compaction slows water flow, and root growth is restricted to fractures between large fragments of compacted soil. This causes poor crop growth. A penetrometer can be used to detect densic soil layers (Fig. 3). These devices measure the resistance of a soil to penetration. Densic layers occurring within 50 cm of the surface can be detected with a hand-held penetrometer; deeper ones require a tractor or truck mounted penetrometer. Densic layers are now recognized in soil taxonomy (Soil Survey Staff, 1996) as Cd horizons. The label Cd was not available when the existing reclaimed mine soil series were established. Consequently, the official series descriptions for these soils do not include Cd horizons, although compaction was indicated by the consistent descriptions.

Another shortcoming of the existing soil series lies in the lack of recognition of lithologic discontinuities. The topsoil and underlying root media are of Pleistocene age, while the cast overburden is a mixture of predominantly Pennsylvanian age materials. The Pleistocene materials are typically neutral to slightly acidic and lack coarse fragments; the Pennsylvanian materials are typically calcareous and contain a large percentage of coarse fragments. The Pennsylvanian age cast overburden should be recognized as a second parent material and indicated with an Arabic number two (2) in front of the horizon designation (Soil Survey Staff, 1996).

Mine Soil Characterization

Characterization of these soils involves studying the soil properties that make them unique. These soils usually have very similar chemical characteristics to the premine soils, since they are usually made from them (Snarski et al., 1981). Reclaimed mine soils differ from premine soils primarily in physical properties. Structure is destroyed during material handling, and a dense, massive structure may be imparted during material replacement (Thomas and Jansen, 1985; Dunker, et al., 1995). These dense layers have high soil strength.

Soil Strength

Soil strength is an important property of mine soils. Roots cannot enter soils with excessive strength, and crop yields consequently suffer (Dunker et al., 1995). There are many measurements of soil strength, including bulk density, shear strength, compressive strength, and resistance to penetration, among others. Bulk density is the most commonly reported measurement, but it does not adequately describe the strength of reclaimed mine soils.

We sampled selected horizons at seven locations to determine bulk density by the coated clod method (Blake and Hartge, 1986). Included were samples from densic Cd horizons and non-densic C horizons (Soil Survey, Staff, 1996). Clod bulk densities were not consistently higher in the Cd horizons (Table 3). Field differentiation between densic and non-densic horizons was based, in part, on ped size. Horizons labeled densic were composed of large, dense clods of replaced compacted soil. The non-densic horizons originally were similar, but were modified by deep tillage that shattered the clods into smaller pieces. The result of deep tillage is that roots are able to penetrate between the smaller pieces to a greater depth and extent than through the original material, even though the clod bulk density of the material was not altered.

Based on these findings, we believe that clod bulk density should not be used to separate densic (Cd) horizons from non-densic C horizons in reclaimed mine soils. We feel that a much better indicator of root penetration is the penetrometer. Penetrometer resistance can be used to determine depth of tillage and is correlated with crop yields on reclaimed mine soils (Dunker et al., 1995; Thompson et al., 1987). Penetrometer resistance can also be used to determine topsoil this root media thickness, or depth to cast overburden (Fig. 3). Cast overburden is composed mainly of impenetrable shale fragments that increase penetrometer resistance.

Proposed and Revised Series

New soil series are needed to encompass the diversity of mine soils in Illinois sufficiently (Indorante et al., 1992). We have refined existing soil series and proposed five new series to accommodate reclaimed mine soils now found in Illinois.

Unreclaimed mine soils are adequately covered by the existing soil series with the exception of wet Lenzburg soils. Lenzburg is defined as a well-drained soil; however, they include areas that are not well drained. These have been mapped as inclusions within the Lenzburg map unit. There needs to be a wet phase of Lenzburg recognized for these areas. They have similar profiles to a typical Lenzburg, but occupy landscape positions that cause poor drainage.

Changes are also needed in the existing reclaimed mine soil series official descriptions to narrow their range in characteristics. Because of root media and topsoil replacement, Rapatee soils have a very dense layer starting at about 18 in. (Windhorn, 1986). Swanwick soils have a very hard layer starting at 27 in. (Miles, 1988). These should be recognized as Cd horizons. Recognition of these Cd horizons will separate the early, non deep-tilled soils from the more recent, carefully placed or deep-tilled soils.

Proposed mine soil series include three soils with light colored surface horizons: Pyatts, Burningstar, and Captain (Fig. 4). These soils were formed in areas where Alfisols were the dominant premine soils. In these soils, the original light colored surface horizons have been replaced over root media for a total of 48 in. of replaced material. Two of them do not have densic contacts within the top 50 cm. They are the fine-silty Captain and the fine-loamy Burningstar. The third proposed light colored surface soil is Pyatts, which has a fine-loamy texture with a densic contact. Pyatts is a loamy analogue of Swanwick.

There are also two proposed soils with dark colored surface horizons (Fig. 4). These soils were formed in areas where Mollisols were the dominant premine soil type. The original dark colored surface horizons have been replaced, almost re-creating a mollic epipedon. These two soils both have fine-silty textures. Fairview is a proposed series that is similar in most respects to Rapatee, although it also does not have a densic contact within 50 cm, because of better material placement methods or deep tillage. Rupp is an intermediate-la* sod, similar to Schuline, but with a dark colored surface replaced directly on top of cast overburden. Soils that meet the criteria for Rupp have been mapped in Stark and Peoria counties as Rapatee (Elmer and Zwicker, 1996; Walker, 1992).

Future of Illinois Mine Soil Mapping

There is still much work to be completed before mine soils in Illinois are mapped adequately. The five soil series and revisions to existing series proposed will allow much greater accuracy in assigning soil series to these disturbed lands. Soils will be classified more accurately than they are by the five existing soil series, but there are still limitations.

Counties will need to re-map areas that have already been mined. As part of this objective, more studies will be needed to determine approximate crop yields for both the proposed series and the revised existing ones. This could have a significant effect on the tax base for the more effectively reclaimed sites whose productivity should be far superior to that of the earlier attempts at reclamation. As areas of compacted mine soils, such as Rapatee, are deep tilled to improve crop yields, re-mapping of the areas, as Fairview, will be necessary. Deep tillage is an expensive, high energy input event with persistent effects (Dunker et al., 1995). It permanently and significantly changes soil properties throughout the solum.

Soil scientists will need to use a penetrometer to detect densic contacts to identify compacted soils. One possibility is to mount a penetrometer on an all-terrain vehicle to assist the mapper. There are also hand-held constant rate recording cone penetrometers that are suitable for detecting densic contacts within 50 cm. Mappers will also need to become accustomed to the fact that unlike natural soils, many mine soil mapping units will have regular boundaries as a direct result of the reclamation methods and mining permit boundaries.

Conclusion

Surface coal mining dramatically alters soils and landscapes. Some areas were reclaimed to various extent over the years, while others were not. There is a need for more soil series to describe the variability found in mine soils adequately. New technology and approaches, such as measurement of penetration resistance, will aid in detecting soil compaction, the most important crop yield limiting property of mine soils. Soils already mapped will need to be reexamined to place them into the most suitable series. More work needs to be done to characterize specific soil properties of mine soil series in Illinois.

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Table 1. Acreage disturbed by surface coal mining in Illinois.

County	Acreage Affected: Prior to '62 Law	Acreage Affected: 1/1/62 - 6/30/93	Acreage Affected: % Pre Law	Acreage Affected: Total	Area Affected %	Acres in County
Adams	177	51	78	228	0.04	556,160
Brown	19	761	2	780	0.40	196,480
Bureau	2,910	225	93	3,135	0.56	558,720
Clark	3	0	100	3	0.00	322,560
Crawford	4	17	19	21	0.01	282.880
Edgar	51	450	10	501	0.17	296,160
Fulton	25,293	28,016	47	53,309	9.53	559,360
Gallatin	208	3,460	6	3,668	1.74	211,200
Greene	50	6	89	56	0.02	349,440
Grundy	6,162	1,128	85	7,290	2.66	273,920
Hancock	101	0	100	101	0.02	510,080
Henry	2,676	0	100	2,676	0.51	528,640
Jackson	4,080	5,168	44	9,248	2.40	385,920
Jefferson	72	3,435	2	3,507	0.94	373,120
Jersey	1	0	100	1	0.00	241,280
Johnson	1	81	1	82	0.04	220,800
Kankakee	2,097	63	97	2,160	0.49	437,760
Knox	11,434	10,359	52	21,793	4.73	460,800
LaSalle	1,213	0	100	1,213	0.16	737,920
Livingston	46	0	100	46	0.01	668,800
Madison	7	0	100	7	0.00	476,160
Marshall	1	0	100	1	0.00	255,360
McDonough	6	2,057	0	2,063	0.55	372,480
Menard	0	6	0	6	0.00	202,240
Mercer	25	0	100	25	0.01	364,160
Morgan	4	0	100	4	0.00	366,080
Peoria	1,265	8,413	13	9,678	2.40	403,840
Perry	13,084	37,506	26	50,590	17.84	283,520
Pike	1	0	100	1	0.00	540,160
Pope	0	53	0	53	0.02	238,080
Randolph	2,387	12,913	16	15,300	3.96	386,560
St. Clair	5,948	8,330	42	14,278	3.24	440,960
Saline	5,584	12,032	32	17,616	7.11	247,680
Scott	1	0	100	1	0.00	161,280
Schuyler	1,327	3,039	30	4,366	1.57	277,760
Stark	239	2,447	9	2,686	1.45	184,960
Vermilion	4,208	1,152	79	5,360	0.93	575,360
Wabash	6	4	60	10	0.01	145,280
Will	4,698	1,624	74	6,322	1.17	540,800
Williamson	7,792	11,377	41	19,169	6.79	282,240
Total	103,181	154,172	40	257,353		

Source: Illinois Department of Mines and Minerals, 1995 Annual Report.

Table 2. Soil map used on Illinois mine soils.

Map Unit					
Number	Name	Established	Texture	Reaction	Classification
MD, ML, SM	Strip Mine	Pre 1978	*Undifferentiated strip mined and other made land*		
801	Orthents	1978	silty	--	Udorthent
802	Orthents	1978	loamy	--	Typic Udorthent
803	Orthents	1978	--	non-acid	Udorthent
804	Orthents, acid	1978	loamy-skeletal	acid	Udorthent
821	Morristown	1978	loamy-skeletal	(calcareous)	Typic Udorthent
871	Lenzburg	1981	fine-loamy	(calcareous)	Typic Udorthent
823	Schuline	1983	fine-loamy	(calcareous)	Typic Udorthent
824	Swanwick	1983	fine-silty	non-acid	Oxyaquic Udorthent
872	Rapatee	1983	fine-silty	non-acid	Typic Udorthent
806	Orthents	1988	clayey-skeletal	--	Udorthent
825	Lenzburg	1988	871, *Acid sub-stratum phase*		Typic Udorthent

Note: All taxa are members of mixed, mesic families of their respective subgroups.

Table 3. Bulk density of selected horizons of Illinois mine soils.

Pedon	Horizon	Depth (cm)	Bulk Density (g/cc)
S72	C	17-49	2.08
S72	Cd1	49-100	2.14
S72	2Cd2	100-110+	2.00
S74	C2	35-75	1.97
S74	Cd1	75-107	1.97
S74	2Cd2	107-112+	1.99
S75	C2	46-80	2.00
S75	Cd4	138-160+	2.05
S76	C1	21-51	2.08
S76	Cd1	91-121	1.95
S77	C	25-74	1.95
S77	Cd1	74-122	1.90
S77	2Cd2	122-140+	2.07
S78	Cd1	56-99	2.08
S79	C1	18-68	1.75
Mean	Cd		2.02†
Mean	C		1.97

†No difference at =0.05

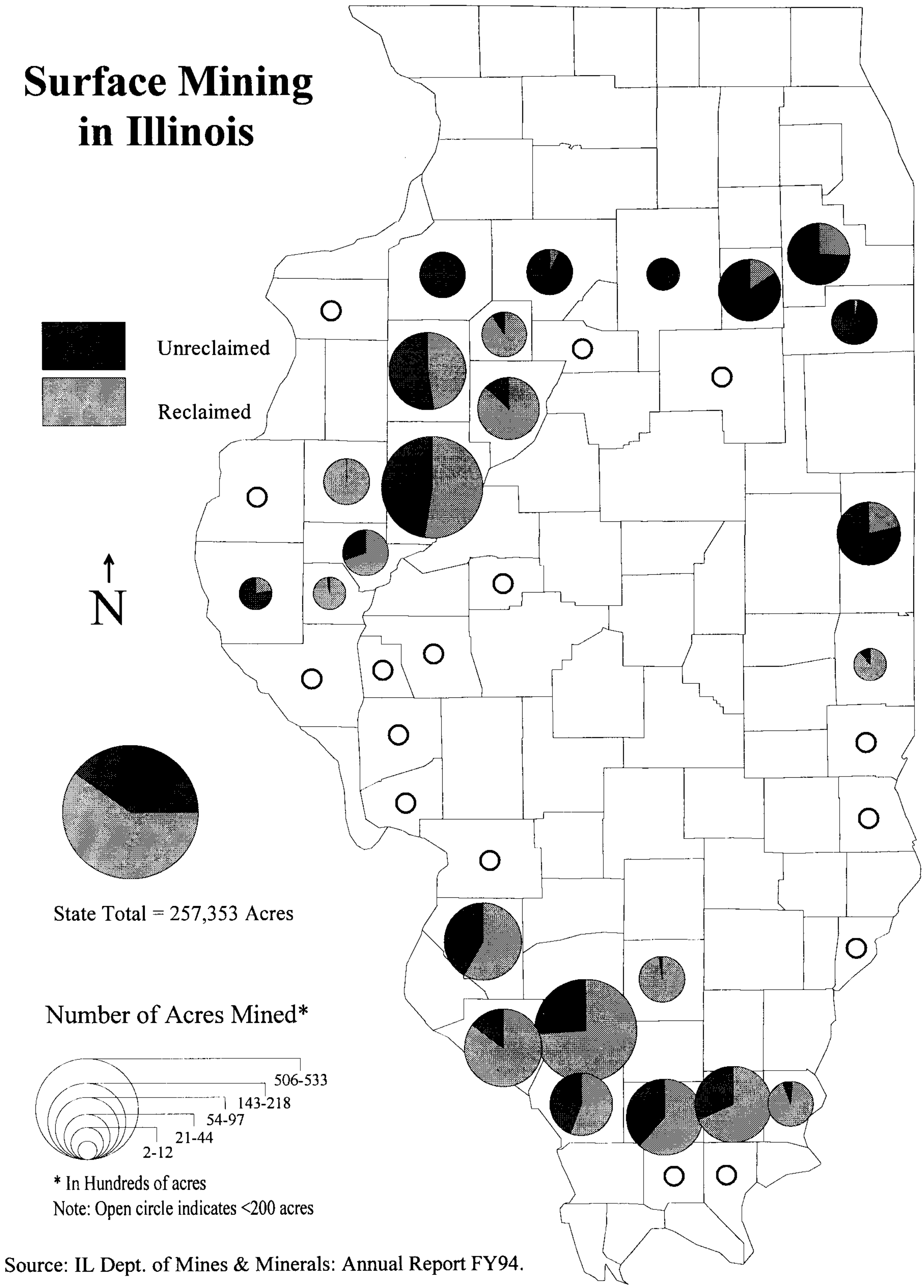

Figure 1. Distribution of surface mining in Illinois.

Soil mapping unit names			
MD, ML, SM	Schuline	Rapatee	Burningstar*
Orthents	Rupp*	Swanwick	Captain*
Lenzburg		Pyatts*	Fairview*
Morristown			

* Proposed.

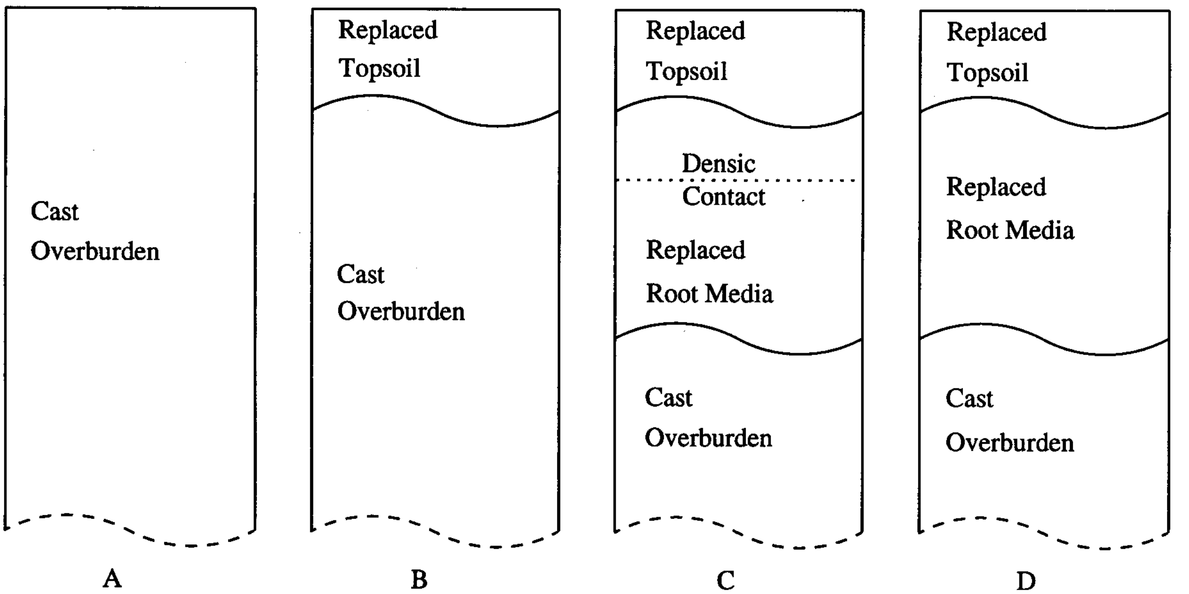

Figure 2. Idealized post-mine material placement profiles showing soil mapping unit names.

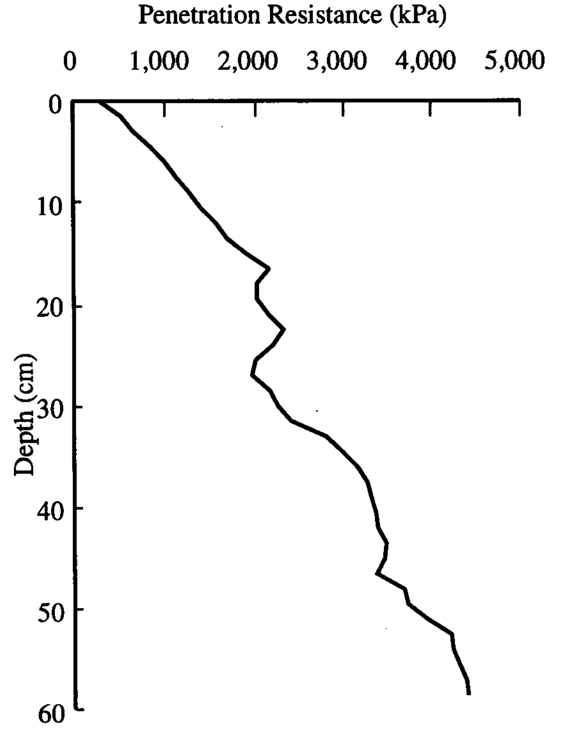

Figure 3. Penetration resistance in a soil mapped as Rapatee, 30 cm topsoil replaced over rocky cast overburden. This soil meets the guidelines for the proposed Rupp series.

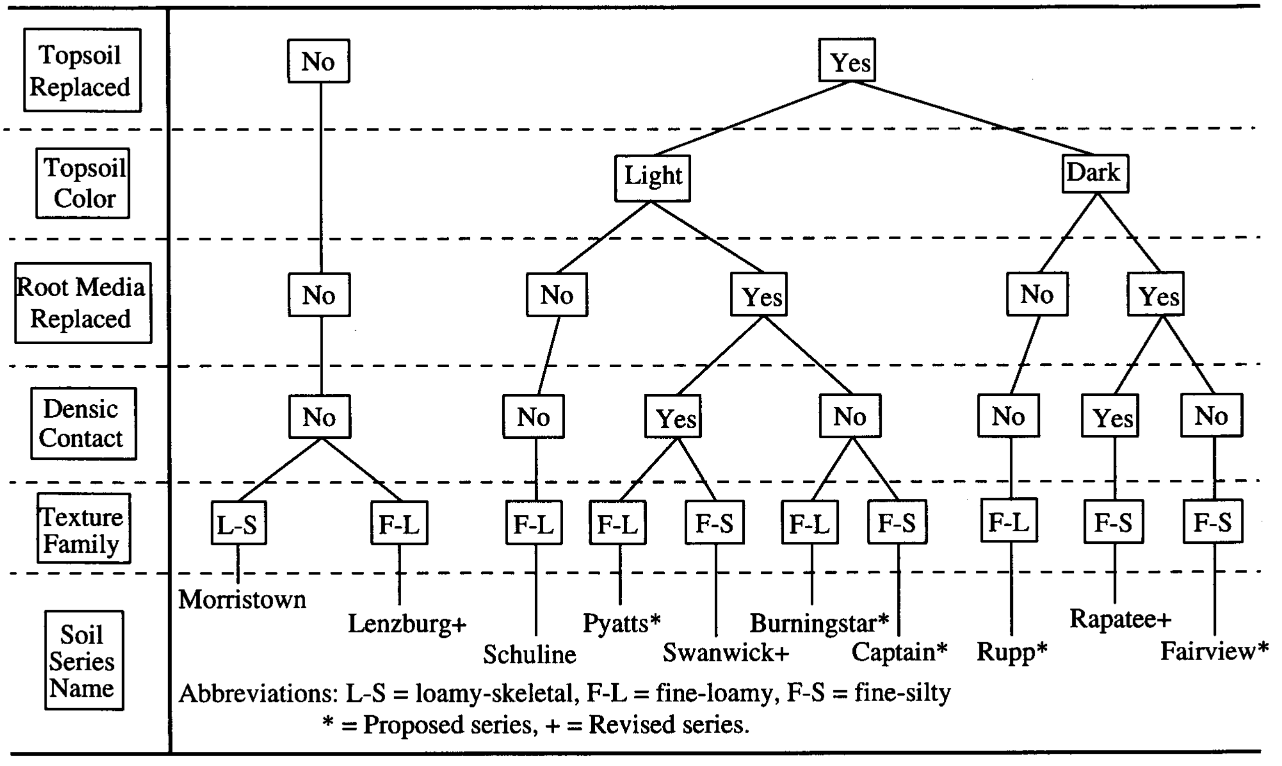

Figure 4. Key for Illinois minesoils including proposed and revised series.