LONG-TERM EFFECTS OF DEEP TILLAGE

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Abstract

The effects of seven tillage treatments ranging in depth from 9 to 48 inches applied to a reconstructed surface mine soil were evaluated over a ten year period beginning in 1988. The southern Illinois mine soil consisted of 8 inches of scraper-placed topsoil over 40 inches of scraper-placed rooting media. The pre-tillage physical condition of this mine soil is described as compact and massive. A nearby tract of Cisne silt loam (fine, montmorillonitic, mesic Mollic Albaqualf) was used as an unmined comparison. Significant differences in corn and soybean yield, soil strength, and net water extraction were observed among tillage treatments. Depth of tillage needed on the mine soil to achieve productivity comparable to permit target yields were found to be affected by initial levels of soil strength. Soil strength and depth of tillage were highly correlated to long-term yields.

Introduction

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils (Fehrenbacher et al., 1982). Newly constructed soils commonly lack a continuous macropore network necessary for water movement, aeration, and root system extension. Also, plant root growth is often severely inhibited by excessively high soil strength (Thompson, et al., 1987; Meyer, 1983).

There are two sources of the physical condition problem in man-made soils. One is the use of severely compacted, high strength soil materials that are naturally present in the lower horizons of many southern Illinois soils. If this is not adequately disrupted in the excavation process, the soil may maintain high strength. This "transportation" of compaction is generally associated with scraper placed subsoils. In that process, large monoliths of intact subsoil are sheared out and folded into the scraper pan. The resulting subsoil is largely massive with interfaces between the monoliths and where they were broken and folded together. Mottling and other characteristics of the original soil remain detectable with varying degrees of distortion. Secondly, and more common with all placement methods, is compaction induced by earth moving equipment in the process of moving, placing, and grading the soil material.

In natural soils, a physical condition problem can be improved by growing forage legumes for an extended period or at least within a crop rotation. Illinois has completed two experiments over the last ten years to evaluate its efficacy in solving the deep compaction problem of reconstructed soils. The practice, though having some merit, has proven inadequate. Soil strengths are commonly just too high to allow diffuse distribution of even alfalfa root systems. The roots tend to form mats in desiccation cracks and leave much of the soil volume largely unaffected. Physical improvement is slow, if detectable, especially in the lower horizon. Perhaps that should not be surprising, as severely compacted glacial till layers in some natural soils have also remained intact, even after one or two centuries of agriculture.

A logical approach would be to reduce compaction by limiting the moving of soil materials to periods when they are dry. This approach has some merit, but is also inadequate. The reality is that the mines simply do not have that option. Experience has also shown that, even though moving materials dry does help substantially, the finished product still has excessive soil strength and bulk density. Research should continue to be directed towards finding soil construction methods that will prevent the problem, but meanwhile, means for amelioration of deeply compacted soils must be investigated.

There are many tillage options that have been proven effective to 12 to 15 inches depth for ameliorating wheel traffic effects of farm machinery on undisturbed soils. Standard agricultural tillage equipment cannot reach the depths of the compaction problem in reconstructed soils. A deep ripper, the Kaeble Gmeinder TLG-12, which has an effective depth of 32 inches, has been tested in preliminary studies in southern Illinois (Hooks, et al. ,1987) and western Illinois (Dunker, et al., 1989). Results from both studies were very encouraging with significantly increased yields and reductions in soil strength to the depth of tillage. This experiment was designed to continue and expand the investigations of the effects of deep tillage.

Objective

The objective of this experiment was to determine the effectiveness and longevity of deep soil tillage methods for improving soils with poor physical condition.

Materials and Methods

The Site

The site for this experiment was at the Consolidation Coal Company Burning Star #2 Mine located near Pinckneyville in Perry County, Illinois. The agricultural soils disturbed by surface mining for coal in this permit area primarily belong to the Ava, Bluford, and Blair soil series. The Alfisols of this region are formed on thin loess overlying silty sediments and/or Illinoian glacial till. Most of these soils have highly weathered acidic subsoils which are high in clay, highly plastic, and poorly aerated when wet. These subsoils tend to be only slowly permeable and, when dry, restrictive to root penetration. The C horizon consists of calcareous loess and calcareous glacial till and is chemically suitable for supporting plant growth.

The mine soil at this site was constructed in 1983 using a scraper-haul system to replace 40 inches of rooting media and 8 inches of topsoil. Texture of rooting materials ranged from silt loam to clay loam, but clay content never exceeded 30%. Physical characteristics of this mine soil can best be described as compact and massive. Preliminary soil samples were taken to determine levels of soil fertility. Required amounts of inorganic fertilizer and limestone were applied prior to the application of deep tillage treatments.

Experimental Design and Layout

A randomized complete block experimental design providing for six replications of seven treatments was prepared for the site. The plots were surveyed and staked out in April, 1987. Experimental plots have two rows of three blocks each, aligned in roughly a north-south direction. Each of the 42 plots is 50 feet wide and 250 feet long, to provide two 50 foot by 100 foot subplots for corn and soybeans, separated by a 50 foot turn strip.

Pre-treatment Evaluation of Soil Strength

A deep-profile penetrometer (Hooks and Jansen, 1986) was used to measure soil strength to a depth of 44 inches prior to the application of tillage treatments (Table 1). Soil strength was highly variable, but the pattern did not compromise the experiment. Analysis of this pre-tillage penetrometer data revealed that while there was no soil strength difference between pre-treatment plot means, there were significant differences in soil strength between blocks. Soil strength levels of the west three blocks (1-3) are significantly higher (0.05 level) than soil strength levels of the three east blocks (4-6) for each depth segment of the soil profile.

The difference in soil strength between the east and west sides was initially unexplainable with limited reclamation history available. There was a time difference in grading. There was a one year delay in grading of the cast overburden between the east and west sides, but all of the root medium and topsoil materials were placed during the June-August period of 1983. Aerial photography from early June 1983 indicated a scraper haul road along the west side of the site.

Application of the Deep Tillage Treatments

The plot areas at the site were sprayed in early August 1987 with one quart of Roundup and one pint of 2,4-D per acre to kill the dense, foot-tall stand of the initial crop of legumes. This was done to reduce the amount of plugging with green trash during tillage and to reduce control problems in the row crops to be planted in 1988.

Five of the tillage treatments were completed during the next month in 1987. Additional treatments were completed in 1988 and 1990. The treatment descriptions are as follows:

TLG Kaelble Gmeinder TLG-12. The TLG uses a cut-lift operation to shatter the soil to a depth of about 36 in. A wide, moving foot is attached to each of the three shanks to cut and lift the soil as the machine moves forward.

RM1 RM1 Processor by Harry Jones. The RM1 Processor has four curved, vibrating shanks cut from 1.5 in. steel. The shanks do not have expanded points or wings. Two hydraulic vibrators are used each operating two of the four shanks. It has an effective tillage depth of about 36 in.

DM1 DMI, Inc., Deep Ripper (DMI) (prototype). This machine is a two-lift, solid shank ripper. Two "Turbo" chisel shanks are used to fracture the soil to an 18 in. depth ahead of the main shank. The main shank is cut from 4 in. steel. It is parabolic and has a winged point, 32 in. wide with a 7 in. lift. The point of the main shank is designed to run 50 in. deep. The machine incorporates a hydraulic trip/reset mechanism to prevent breakage. Successive passes are separated by 48 in. Under favorable moisture/tilth conditions, the floor of the tilled zone shears nearly horizontally, yielding a minimum tilled depth of 48 in. Moisture content at that depth was a bit high at the time of treatment, and a pronounced ridge of unloosened material was left between shank passes.

DM2 The final prototype of the DMI treatment. It incorporates a new design point and tongue to improve draft control. A larger tractor is used to increase ground speed and allow more consistent depth control.

DM3 A static-shank ripper similar to the DMI in point design but smaller. It tills to a depth of 36 to 38 in. and is pulled by a rubber-tracked tractor.

TG2 Tiger-two chisel by DMI, Inc. This is a commercially available chisel used in commercial agriculture for tillage in the 12 to 18 in. depth range. It is not really considered adequate for the needed loosening in reclaimed soils because of its depth limitations. It was included for comparison since its tillage depth should at least include the topsoil/root media interface, which can be a problem with water movement and root growth.

CHS Standard agricultural chisel plow with an effective depth of 9 to 10 in. This treatment is considered the tillage control treatment.

Table 1. 1987 Soil Strength Before Tillage at Burning Star #2.

	Soil Strength (PSI) by Depth Segment			
Treatment	**9 - 18"**	**18 - 27"**	**27 - 36"**	**36 - 44"**
1	332.5 a [1/]	369.9 a	327.9 a	260.6 c
2	365.7 a	420.0 a	350.4 a	319.9 ab
3	358.6 a	391.8 a	335.5 a	314.2 ab
4	336.5 a	391.9 a	352.4 a	327.2 a
5	348.1 a	411.2 a	338.2 a	283.6 bc
6	316.0 a	386.3 a	350.5 a	322.3 ab
7	353.0 a	396.9 a	307.4 a	301.3 abc
LSD (0.05)	59.9	61.9	62.5	41.2
Block				
1	435.0 a	571.3 a	477.1 a	432.1 a
2	498.8 a	574.2 a	440.8 ab	393.0 a
3	477.1 a	478.5 b	378.5 b	322.1 b
4	246.5 b	236.4 c	208.8 c	195.8 c
5	217.5 b	272.6 c	281.3 c	239.3 c
6	191.4 b	240.7 c	237.8 c	230.6 c
LSD (0.05)	71.1	87.0	71.1	58.0

[1/] Values followed by the same letter within a segment are not significantly different at the 0.05 level.

Tillage treatments were applied to plot areas only once, except for fall tillage in which the chisel plow is applied across all treatments. Consequently, both initial tillage effectiveness and longevity of tillage effects can be evaluated.

A nearby tract of Cisne silt loam (Mollic Albaqualf) was used as an unmined comparison. This is a prime soil compared to the high capability soils of the mine area. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation in the area. Corn (*Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental design. A minimum tillage management system was used to minimize traffic on the plots. Soil moisture was monitored during the growing season of the first two years of the experiment using a neutron probe.

Grain yield samples for corn were harvested after black-layer formation indicated physiological maturity, and soybeans were harvested when all pods were brown. Grain yield estimates were based on the amount of shelled grain after adjusting for variation in moisture content of grain to 15.5% for corn and 12.5% for soybeans.

Results and Discussion

Effects of Deep Tillage on Soil Strength

Soil strength measurements using the deep-profile penetrometer were taken prior to planting in 1988, 1989, 1991, and 1993 to evaluate tillage effects. Analysis of these data are presented in Table 2. Soil strength measurements taken in April 1991 indicate that tillage effects remain consistent to initial post-tillage soil strengths 42 months after application of tillage treatments. In summary, using the chisel treatment (CHS) as the control treatment, the Tiger II (TG2) was successful in lowering soil strength down to Segment 2 (9 to 18 inches). The TLG and RM1 significantly lowered soil strength to Segment 3 (18 to 27 inches) and was numerically lower than the CHS or TG2 in Segment 4 (27 to 36 inches). Both the DM1 and DM2 deep plows were successful in significantly lowering soil strength to the 44 inch depth. First year measurements of the DM3 treatment show it had similar effects to the RM1 and TLG treatments.

It is important to note that even though the magnitude of soil strength values are different for 1988, 1989, 1991, and 1993 results, the significant groupings of treatments are essentially the same for all years. This is probably due to differences in soil moisture content at the time data was collected.

Figure 1 shows graphically the effects of tillage on soil strength over the entire soil profile to a depth of 45 inches in 1993. The plotted curves data reveal that the effective tillage depth of each treatment is representative of the designed depth of tillage for each piece of tillage equipment. These soil strength curves represent the average curve across the six replications of each treatment. The pronounced high strength peak on the soil strength curve for the conventional chisel plow (CHS) is probably due to traffic induced compaction by scrapers from the topsoil replacement operation. The Tiger II (TG2) treatment has successfully eliminated this effect, but the soil strengths of the TG2 and CHS treatments remain high throughout the soil profile. Soil strength profiles of the RM1 and TLG are similar to the DMI deep plow treatments to a depth of about 30 inches. Below this depth soil strength increases with depth until resistance levels are comparable to the TG2 and CHS treatments. Both the DM1 and DM2 deep plow (48 in. effective depth) show relatively low soil strength throughout the soil profile.

Rowcrop Yields

Tillage treatments significantly influenced corn and soybean yields in all years (Table 3). Significant block differences have occurred for both corn and soybeans. In general, the three blocks on the west side of the experiment (Blocks 1-3) yielded lower than the three blocks on the east side (Blocks 4-6).

Grain yields from 1988 through 1997 growing seasons indicate a consistent trend over time. The DMI deep plow treatments produced corn yields significantly higher than any of the other mine soil tillage treatments for the ten years studied. The DM3, TLG, and RM1 corn yields were comparable, while the Tiger II (TG2) and conventional chisel (CHS) treatments yielded the lowest. Corn yields from the DMI Super Tiger deep plow (DM2) treatment were comparable to those obtained on the nearby tract of undisturbed Cisne soil in most years

Table 2. Soil Strength from BS#2 plots after tillage.

Soil Strength (PSI) by Depth Segment

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	9-18"	**18-27"**	**27-36"**	**36-44"**
		1988		
Spare B1/	804.1 a2 /	603.6 a	417.1 a	446 4 a
Spare C	768.8 a	584.4 a	415.8 a	432.8 ab
CHS	712.8 a	554.6 a	405.9 ab	434.5 ab
TG2	568.7 b	582.3 a	416.4 a	379.0 b
DM1	235.9 c	193.6 b	180.7 c	210.6 c
RM1	218.7 c	266.7 b	345.0 b	387.9 ab
TLG	193.4 c	219.1 b	338.9 b	390.2 ab
LSD (0.05)	99.5	123.9	67.1	61.5
		1989		
Spare B	521.9 a	515.8 a	419.7 a	381.6 a
CHS	457.4 ab	433.4 a	374.5 ab	350.5 a
TG2	400.4 b	457.7 a	394.5 ab	350.6 a
RM1	200.1 c	195.3 b	320.9 b	346.3 a
TLG	192.0 c	181.3 b	323.5 b	388.5 a
DM1	188.9 c	160.2 b	148.0 c	176.4 b
DM2	151.8 c	179.5 b	173.2 c	138.3 b
LSD (0.05)	71.0	135.6	87.3	62.9
		1991		
CHS	402.5 a	459.5 a	423.6 a	369.4 a
TG2	343.6 b	448.9 a	411.0 ab	349.9 a
DM3	218.8 c	231.4 b	290.6 c	370.3 a
RM1	210.4 c	240.2 b	320.0 bc	355.2 a
TLG	203.7 c	189.5 b	382.8 abc	427.0 a
DM1	188.9 c	211.0 b	179.4 d	159.6 b
DM2	181.1 c	175.1 b	156.5 d	140.2 b
LSD (0.05)	56.3	109.0	96.3	91.6
		1993		
CHS	406.0 a	453.9 a	411.8 a	349.5 a
TG2	381.4 a	430.7 a	349.5 ab	311.8 a
DM3	216.1 b	184.2 b	262.5 b	329.2 a
RM1	194.3 b	255.2 b	375.6 ab	342.2 a
TLG	192.9 b	214.6 b	361.1 ab	311.8 a
DM1	152.3 b	146.5 b	130.5 c	146.5 b
DM2	114.6 b	114.5 b	129.1 c	146.4 b
LSD (0.05)	103.0	161.0	113.1	69.6

1/ Soil treatments are: Spare, nontilled plot held in reserve for future application; CHS, conventional chisel plow, 8" tillage depth; TG2, DMI Tiger II Coulter, 16" depth; RM1, Harry Jones RM1 soil processor, 32" depth; TLG, Kaeble-Gmeinder TLG ripper, 32" depth; DM1, DMI deep plow (first design prototype, 48" depth; DM2, DMI deep plow (second design), 48" depth; DM3, DMI deep plow, 38" depth.

2/ Values followed by the same letter within a segment are not significantly different at the 0.05 level.

which indicates prime yield levels from reclaimed high capability soils. Significant differences have occurred between treatments within and across years. Significant differences across treatments between years due to weather variations are also apparent. Soybean yields for the DMI deep plow treatments were significantly higher than the other mine soil tillage treatments in most years. Few soybean yield differences occurred on the other tillage treatments.

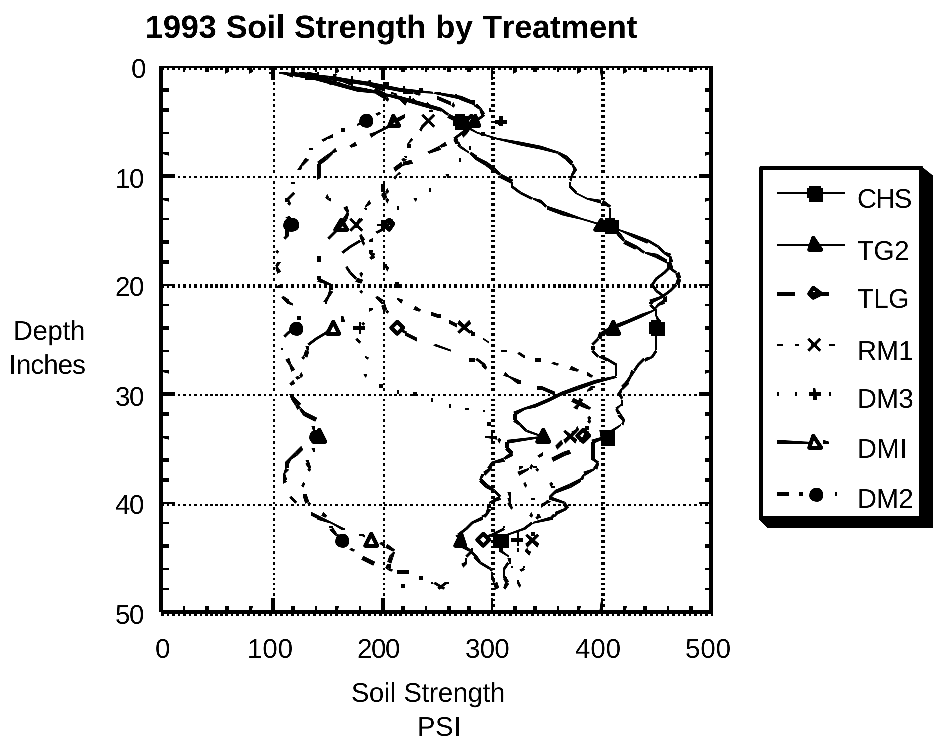

Figure 1. Soil Strength Profiles

Measurement of agronomic variables for corn indicate significant 1988-1997 mean differences among tillage treatments for % barren plants, shelling percentage (ratio of shelled grain per total ear weight), average ear weight, and test weight (a measure of grain density). Corn planted on the DMI deep plow treatments (DM1, DM2) produced a significantly lower percentage of barren plants, greater average ear weight, and grain with significantly higher test weights than the other tillage treatments.

Subsoil Differences and Productivity

Significant differences in yields of the experimental blocks have occurred. Blocks 1 to 3 on the west side have yielded lower than blocks 4 to 6 on the east side. Pre-tillage evaluation with the cone penetrometer showed significant initial differences in soil strength between the east and west sides of the plots. Soil strength levels of the west side were significantly greater than the east blocks for each depth segment. Post-tillage penetrometer data shows similar trends. The relationship of soil strength and tillage depth is consistent on both sides. Reduction of soil strength with increasing tillage depth is occurring at the same rate, only the magnitude of soil strength is different. This data suggests that the effect of tillage in reducing soil strength levels is affected by initial levels of soil strength.

Soil texture analysis reveals dramatic differences between the two sides (Table 4). The west side has higher sand, lower silt, and a high percentage of coarse fragments throughout the profile. This loamy subsoil is quite different than the silty material of the east side. The subsoil material of the west side can be identified as calcareous till while the subsoil materials of the east side are from Peorian loess and Roxana silt. The high soil strength of the west side is more a result of transported compacted till with minimal disturbance than equipment traffic, which is equal on both sides. The soil materials originated from different premine soils or from different depths of excavation.

Table 3. 1988 - 1997 Yields

Soil Trt	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	88-97 Mean
	Yield, bu/ac (2/)										
	Corn										
CHS (1/)	38 e	61 d	70 b	8 c	122 c	128 cd	96 cd	63 abc	35 c	70 c	67 c
TG2	43 de	53 d	85 b	6 c	122 c	115 d	88 d	56 c	22 c	75 bc	65 c
RM1	56 cd	86 c	79 b	22 b	111 c	154 ab	108 bcd	62 abc	66 b	93 ab	82 b
TLG	68 c	83 c	76 b	22 b	120 c	143 bc	96 cd	57 bc	60 b	77 abc	79 bc
DM3				30 b	127 bc	152 ab	112 bc	62 abc	74 b	74 bc	90 b
DM1	87 b	127 b	113 a	67 a	150 ab	167 a	117 bc	77 ab	115 a	96 a	110 a
DM2		143 a	124 a	57 a	161 a	170 a	121 b	83 a	112 a	90 ab	117 a
Cisne	136 a	142 a	130 a	68 a	158 a	160 ab	154 a	(4/)			
	Soybeans										
CHS	14 b	13 c	(3/)	(3/)	17 de	29 c	(3/)	(3/)	(3/)	36 de	
TG2	13 b	14 c			16 e	32 bc				34 e	
RM1	14 b	14 c			21 cd	30 c				40 cd	
TLG	14 b	14 c			18 cde	30 c				42 bc	
DM3					22 c	38 abc				39 cd	
DM1	21 a	24 b			27 b	40 ab				45 ab	
DM2		30 a			33 a	41 a				46 a	
Cisne	19 a	24 b			34 a	31 c					

1/ Soil treatments are:CHS, conventional chisel plow, 9" tillage depth; TG2, DMI Tiger II , 14" depth; RM1, Harry Jones RM1 soil processor, 32" depth; TLG, Kaeble-Gmeinder TLG ripper, 32" depth; DM3, DMI prototype ripper, 36" depth; DM1, DMI deep plow (first design prototype), 48" depth; DM2, DMI Super Tiger, 48" depth.
2/ Yields followed by the same letter within a crop are not significantly different at the 0.05 level.
3/ Soybeans were not harvested in 1990, 1991 and 1996 and not planted in 1994 and 1995.
4/ Cisne not included in 1995 or later comparisons.

Table 4. Soil Texture by Depth

	WEST				EAST			
DEPTH Inches	**SAND %**	**SILT %**	**CLAY %**	**C F %**	**SAND %**	**SILT %**	**CLAY %**	**C F %**
0>6	8.1	70.9	21.0	1.0	11.8	69.4	18.9	0.1
6>12	9.8	68.5	21.8	1.3	11.5	68.7	19.9	0.3
12>18	20.5	52.8	26.7	2.5	11.5	64.1	24.3	0.3
18>24	27.9	45.0	27.0	4.2	9.6	61.0	29.4	0.9
24>30	30.4	47.2	22.6	6.1	9.9	58.6	31.5	0.3
30>36	30.4	40.8	28.7	4.5	9.9	59.3	30.9	0.2
36>42	30.0	42.1	27.8	4.1	9.7	59.7	30.7	0.2
42>48	29.8	40.6	29.7	4.3	10.4	58.6	31.0	0.2

Table 5 is a summary of differences between the two sides. **Till Depth** is the mean measured depth of tillage from soil cores. **12-48 SS** is the mean soil strength (PSI) of the 12 to 48 inch profile (below the depth of normal agricultural tillage. **12-48 BD** is similarly the subsoil mean measure by the core method. **88-97 Yield** is the mean corn yield in bushels per acre. **% Target** is the mean yield converted to a percentage of the target yield calculated by the Illinois Department of Agriculture for the mine permit area. This target is generated from the percent of the different natural soils affected and their productivity. **TS Depth** is the mean topsoil depth measured from soil cores.

Table 5. Tillage Treatment and Soil Effects on Productivity

SIDE	TRT	TILL DEPTH	12-48 SS	12-48 BD	88-97 YIELD	% Target	TS DEPTH
E	CHS	11.3	219	1.75	77.0	75.2	13.8
E	TG2	15.3	201	1.71	76.2	74.4	12.5
E	TLG	25.3	207	1.79	90.9	88.8	10.3
E	RM1	27.3	194	1.80	93.0	90.8	11.7
E	DM3	32.7	193	1.81	98.7	96.3	13.0
E	DM1	42.0	126	1.81	119.8	116.9	11.8
E	DM2	42.2	101	1.69	123.7	120.8	9.0
EAST MEAN		**28.0**	**177**	**1.77**	**97.0**	**94.7**	**11.7**
W	CHS	8.0	520	1.96	57.5	56.1	12.2
W	TG2	13.0	491	1.84	53.9	52.6	15.8
W	DM3	24.5	238	1.90	78.7	76.8	14.2
W	TLG	26.8	389	1.84	66.2	64.7	14.5
W	RM1	31.7	432	1.89	70.8	69.1	14.2
W	DM2	36.3	161	1.76	110.6	107.9	14.5
W	DM1	38.3	199	1.86	99.7	97.3	15.8
WEST MEAN		**25.5**	**347**	**1.86**	**76.8**	**74.9**	**14.5**

The table is sorted by tillage depth and shows that the same equipment could not till as deep on the west side due to the high strength materials encountered. This is a difference in the depth to a densic contact or the available rooting volume not only between treatments but also between sides. The soil strength after tillage is different within treatments between sides. While bulk density has not correlated with yield in any of the ten years of this study, it is higher on the west side. Yields increase with the depth of tillage on both sides. The yields achieved with the same tillage tool are lower on the west side. The productivity goal for high capability soils is to statistically meet 90% of the target. The intermediate depths of tillage appear to be adequate for this on the east side. The deepest tillage (DM1 and 2) is necessary to meet productivity on the west side. No relationship is apparent between topsoil depth and productivity in this experiment.

Since the two sides are different soils regardless of tillage, productivity modeling has combined tillage and soils providing 14 treatments. Figure 2 is a logarithmic correlation of mean 12 to 48 inch soil strength and 1988-1997 corn yield means. This is consistent with previous years results; yields decrease as soil strength increases (r=.93). Figure 3 is a linear correlation of tillage depth and 1988-1997 corn yield means. This is also consistent with previous findings; yields increase with increasing depth of tillage or available rooting volume of soil (r=.82). The combined effects of these two parameters are shown in the multivariate model in Figure 4. This is a highly significant model (r^2=.96), using natural log conversions, explaining 96% of the variability in yield with two soil parameters. Both soil parameters can be measured with the penetrometer. Soil strength measurements will be a major factor in the development of a soils based productivity model for this region. With the results of this experiment, the pursuit of this effort is certainly warranted.

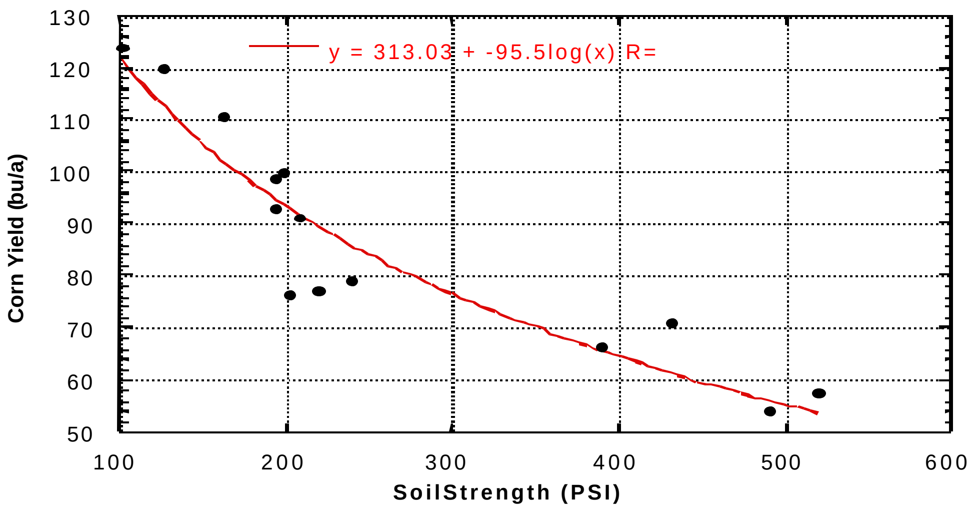

Figure 2. Soil Strength and Yield Correlation

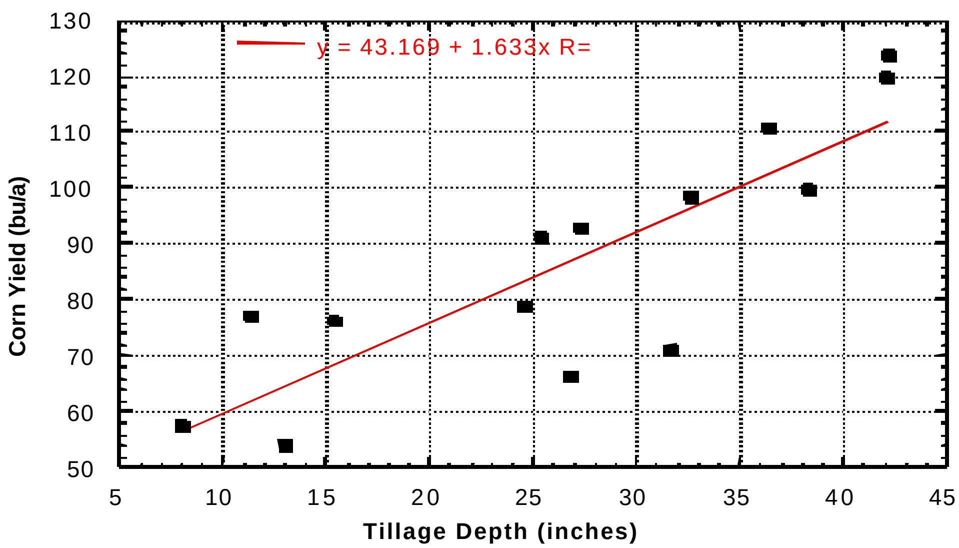

Figure 3. Tillage Depth and Yield Correlation

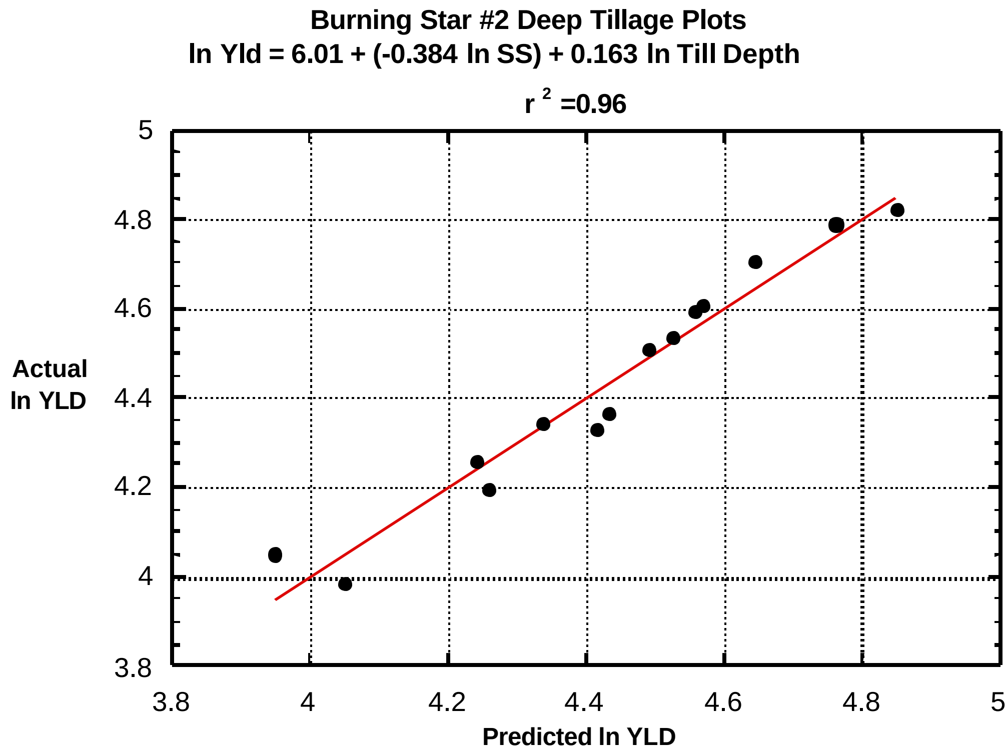

Figure 4. Soil Strength and Tillage Depth Correlation with Yield

Summary

Data from this study support the following general conclusions:

1. Tillage treatments significantly affected crop yields, soil strength levels, net water extracted by growing crops, and measured agronomic variables.

2. Corn yield increased with increasing tillage depth and decreasing soil strength within and across years. The only treatment response to tillage for soybeans occurred from the DMI deep plow (48 inch) treatments (DM1 and DM2).

3. Post-tillage penetrometer and yield data indicate that amelioration effects of tillage remain at least ten years after initial application of tillage treatments.

4. Depth of tillage needed to achieve productivity comparable to target yield levels will be affected by initial levels of soil strength.

5. Productivity can be reliably predicted with soil parameters measured by the deep profile penetrometer.

Acknowledgments

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Previous findings from this experiment have been reported in the following publications:

Dunker, R.E., C.L. Hooks, S.L. Vance, and R.G. Darmody. 1995. Deep Tillage Effects on Compacted Surface-Mined Land. Soil Science Society of America Journal. 59: 192-199.

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SOILS BASED PRODUCTIVITY EVALUATION

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Abstract

Since the passage of SMCRA, reclamation success on agricultural lands has been determined by long-term yield testing. This required a long bond release period lasting ten years or more. Recently, needs have been voiced from landowners, mine operators, and regulators for methods to expedite the bond release process. The financial burdens of annual cropping and field maintenance by mine operators and monitoring by regulators are of major concern. Landowners need to have the land returned to their production operations instead of being locked in the bond release process for a decade or more. A soils based formula could relieve these financial burdens and ensure the most efficient process to return the productive soil resource to the landowner. In addition, this method also will identify problem fields immediately after reclamation. Currently, some undergo 10 years of yield testing before a problem becomes evident. Then, after further remediation, another long period of testing is required. A soils based productivity index is currently being developed in Illinois. This includes the basic concepts and findings from earlier research. Two reliable approaches have been developed for southern Illinois. Additional information from the Mollisol region of the state will be included before final validation tests.

Background

In the first years following the passage of SMCRA, Illinois developed a regulatory program to insure the preservation of our valuable soil resource while continuing the development of our coal reserves. The Illinois program is superior to many in our neighboring states and it should be, since much of the reserves underlie some of the nations most productive farmlands. The Agricultural Lands Productivity Formula (ALPF) was developed as a part of this program to determine reclamation success. While it is superior to methods used in neighboring states, it is not without problems. ALPF does not consider within county weather variability or crop management practices. In some cases, it is difficult to determine whether success or failure to meet productivity is due to soil effects, a weather anomaly, or management practices. These limitations were accepted with the program, and tests with several crops over time can reduce these errors. The sampling method has been questioned, and a comparison of side by side corn yield measurements was conducted by the SIU/UI Cooperative Reclamation Research Station. The test correlated university measurements with those from state enumerators. Results yielded a high correlation (r=.93) indicating that the yield measurements are not different and statistically reliable.

Considerable time and effort is required from regulatory agencies and mine operators to implement and monitor the program. Recently, landowners, mine operators, and regulators have voiced the need for a method to expedite the bond release process. Landowners need to have the land returned to their production operations instead of being locked in the bond release process for a decade or more. A soils based formula to determine productivity capability could relieve these burdens and ensure the most efficient process to return the productive soil resource to the landowner. In addition, this method will allow the identification of problem fields soon after reclamation. Currently, fields undergo 10 years of yield testing before a problem becomes evident. Then, after remediation, another long period of testing is required.

The acres of land affected by surface mining in southern Illinois has declined in recent years; however, thousands of acres still will be in the bond release process for the next 10 to 15 years. More small off-site areas (substations, beltlines, etc.) are being reclaimed as mines continue to close in southern Illinois. The largest acreage of remaining strippable reserves are in the western part of the state. The development of these reserves is expected to continue for several years. Much of the remaining acreage will be affected by small "pod" mines that are different from the "classic" large mines of the southern part of the state. The pod mines may only cover 100 acres, more or less, as opposed to the vast areas covering several square miles. Individual fields may be much smaller and the mines are opened and reclaimed in a matter of months instead of years or decades. As the time required for resource extraction and reclamation is shortened, a method to validate productivity and return the land to the owner as soon as possible will be of great value. Currently, the time required for productivity validation with yield tests over time may be ten times that required for extraction and reclamation. A soils based method of productivity validation will provide the shortest period of time that the land will be out of the landowners normal production.

When it was developed, ALPF was the best measure possible for productivity over time. The reclamation research was also in its infancy, and the relationships of minesoils and crop productivity were not known. Today, after 18 years of reclamation research, the idea of a soils based productivity formula for bond release could be a reality in the near future. This will result in reduced time and effort from all involved while not compromising the accuracy of productivity testing. Most of the work is complete for southern Illinois, but additional reclaimed soils information is needed from western Illinois.

Methods

The basic approach to the soils based productivity concept is a comparison only of soil physical attributes. This determination does not consider controllable management factors such as fertility, pH, tillage practices, etc., since they are considered to be part of a sound, high level, crop management program. Soil attributes will be correlated with long-term yields from tests plots and field studies. Yields are converted to a percent of the expected target for the premine soils in the area of each soil tested. The initial approach is that potential productivity is a function of measurable soil properties and is summarized below:

Yield Potential = ASV + SUB + TS

ASV - Available Soil Volume relates to the physical rooting environment for the plant. Soil strength, depth to root limiting zones, and thickness of root limiting zones will determine this factor.
SUB - Subsoil Quality relates to the ability to hold water and provide it to the plant, and the favorability of the subsoil chemistry and drainage. Soil texture, reclamation method, and premine soils will affect this factor.
TS - Topsoil Quality relates to the volume of surface soil and its ability to hold and provide nutrients to the plant. Topsoil depth, texture, cation exchange capacity, and organic matter will determine this factor.

The database for this study includes yields in a period from 1979 to 1997 at various research plots and field tests. Periods of time for individual test sites varies from 3 to 10 years. The data represents 29 minesoils at five southern Illinois mines. Reclamation methods included are scraper haul, shovel/truck, cross pit wheel, and wheel/beltline, with and without various deep tillage methods. It is unique in that it contains a wide range of productivity: success and failure from long-term test plots. Soil attributes measured include % organic matter, topsoil depth, tillage depth, soil strength, bulk density, texture, and coarse fragments.

Southern Illinois Results

The database is near complete and the initial analysis has yielded encouraging results. Soil texture has not been completed on seven soils. Texture results from the 22 soils show major differences in subsoils. Figure 1 shows a loamy subsoil originating from calcareous till. Texture is somewhat variable with depth resulting from scraper placement. Figure 2 shows a silty subsoil originating from Peorian loess and Roxana silt. Texture is more uniform with depth representing shovel/truck reclamation. These are the dominant parent materials in this region and occur in varying degrees in the minesoils depending on the natural soils being reconstructed and the method of excavation and placement. Tests indicate no significant texture influence over the wide range of minesoil productivity.

Initial results clearly confirm that subsoil soil strength and depth of tillage (or depth to a densic contact) are the dominant independent variables over the wide range of productivity. Figure 3 is the correlation of the natural log of mean soil strength in psi (12 to 48 inch depth) and % target success. The dependent variable (% target) is the ratio of long-term yield means from university tests and the ALPF calculated target for the permit area of each minesoil in the test.

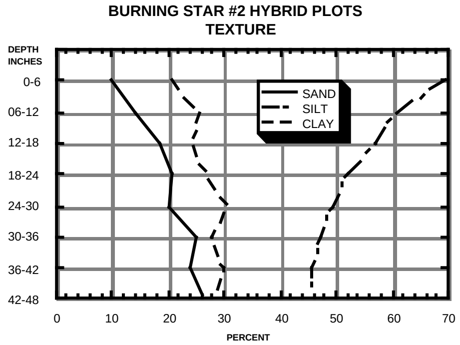

Figure 1.

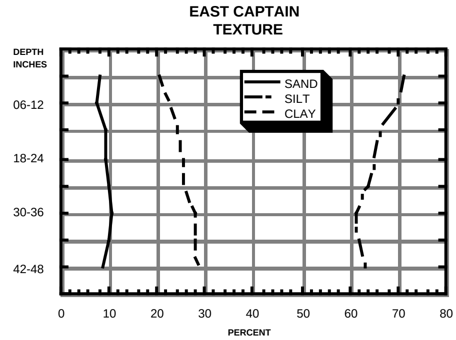

Figure 2.

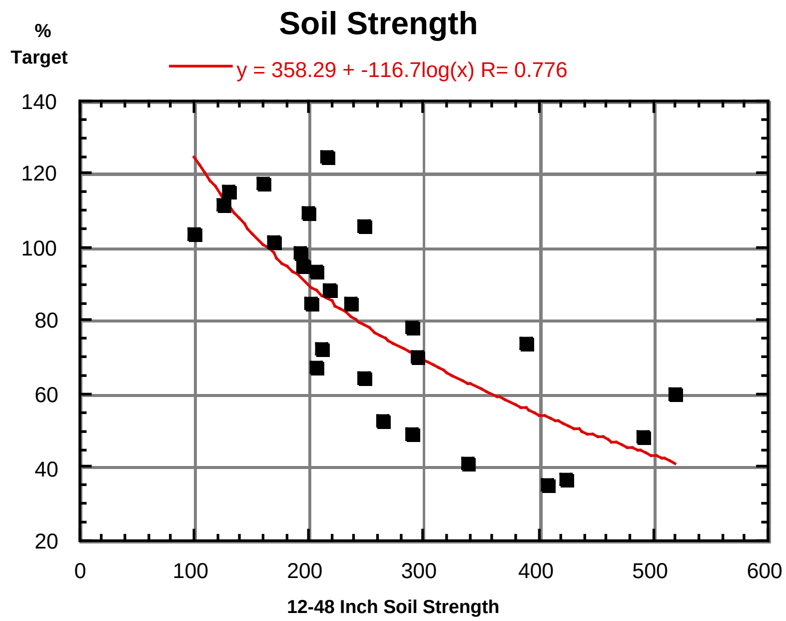

Figure 3.

This illustrates the same relationship discovered in earlier small plot research: yield decreases as soil strength increases. Soil strengths above 300 psi are limiting to root growth. In this area of the relationship, soil strength is the dominant factor determining yield. As soil strength decreases below that level, the soil becomes more favorable to root growth to the point where maximum rooting volume is available and soil strength is less important. In this transition zone, other factors begin to play a significant role in productivity.

Depth of tillage also plays a role in the minesoil evaluation. This represents the depth to a densic contact or a root limiting zone. It relates to the available soil depth or soil volume favorable to support plant growth. Mean subsoil soil strength below 300 psi may indicate a uniform but marginal subsoil environment. It could also indicate a very favorable upper profile over a high strength lower profile, which could have superior productivity. While both values can be measured with the penetrometer, subsoil soil strength alone may not be adequate for the productivity formula across a wide range of minesoils.

Stepwise analysis provides the best fit for the data in southern Illinois. A significant multivariate model is represented in Figure 4.

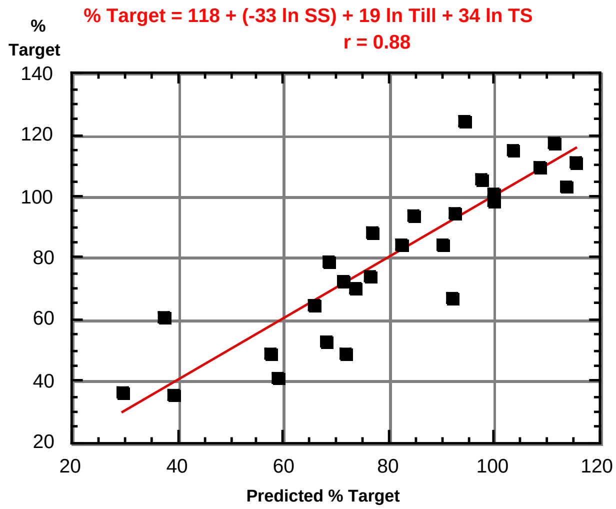

Figure 4.

In this model, % target is predicted from the combined effects of soil strength in psi, tillage depth or depth to a densic contact in inches, and topsoil depth in inches. It is a significant correlation that explains 78% of the variability in % target in this southern Illinois data set. Another approach to further improve the accuracy has been considered in Figure 5.

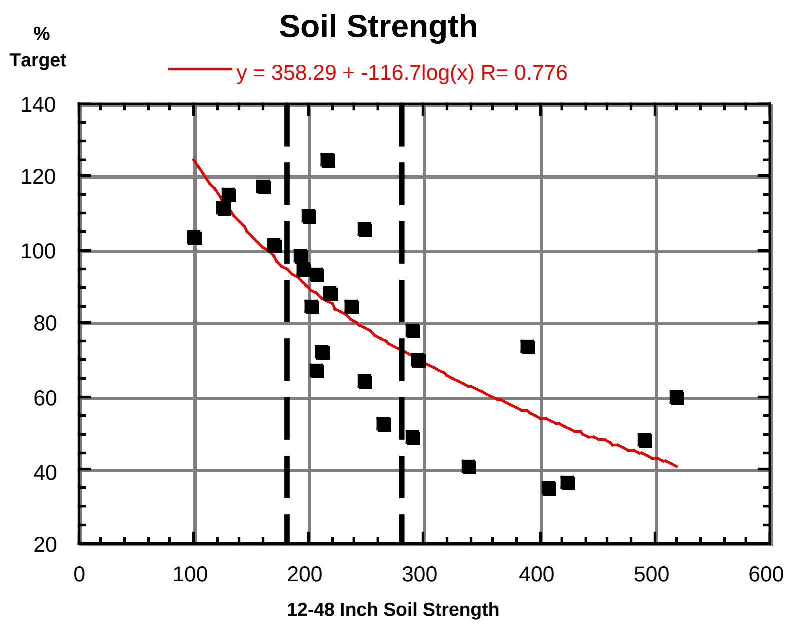

Figure 5.

In this approach, lower and upper thresholds are set at 180 and 280 psi. The lower limit indicating a minimum of 100% success and the upper limit indicating less than 80% of target (augmentation needed to increase productivity). Many Illinois minesoils are in the "transition zone" in the middle. Soil texture is needed on all but nine of the soils tested in that range. A significant correlation (r=0.96) from the nine soils with texture data suggests that yield is a function of soil strength, tillage depth, % clay, and bulk density. Completion of the data set will improve the accuracy of the formula.

Summary

Initial results from this study support the following conclusions:

1. A valid soils based productivity formula for southern Illinois minesoils is near completion.

2. The two-stage approach utilizing upper and lower thresholds will be most efficient.

3. The database should be expanded to include the Mollisol region of western Illinois.

4. The final formula will have to be validated and equal the reliability of the ALPF results.

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This study represents the continuation of prime farmland reclamation research by the Southern Illinois University/ University of Illinois Cooperative Reclamation Research Station through the Coal Research Center, Southern Illinois University, Carbondale. It is a continuation of research, published and unpublished, from both universities.

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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 modelwhich 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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[2]Robert G. Darmody was born in Washington, D.C. IN 1949, and grew up in the Washington suburbs. He received from the University of Maryland a B.S. in Natural Resources with a minor in Botany (1972) and a M.S. (1975) and Ph.D. (1980) in Soils with a minor in Geology. From 1975 to 1977 he taught introductory soil science as an instructor in the Agronomy Department, University of Maryland. In 1981 he was hired by the University of Illinois Department of Agronomy as an Assistant Professor of Pedology to conduct research and teach soil science. Research interests include reclamation of surface mined soils and the agriculture and environmental impacts of mine subsidence and coal combustion. He is married and lives in Champaign, Illinois with three children, one dog, and one mortgage.

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.

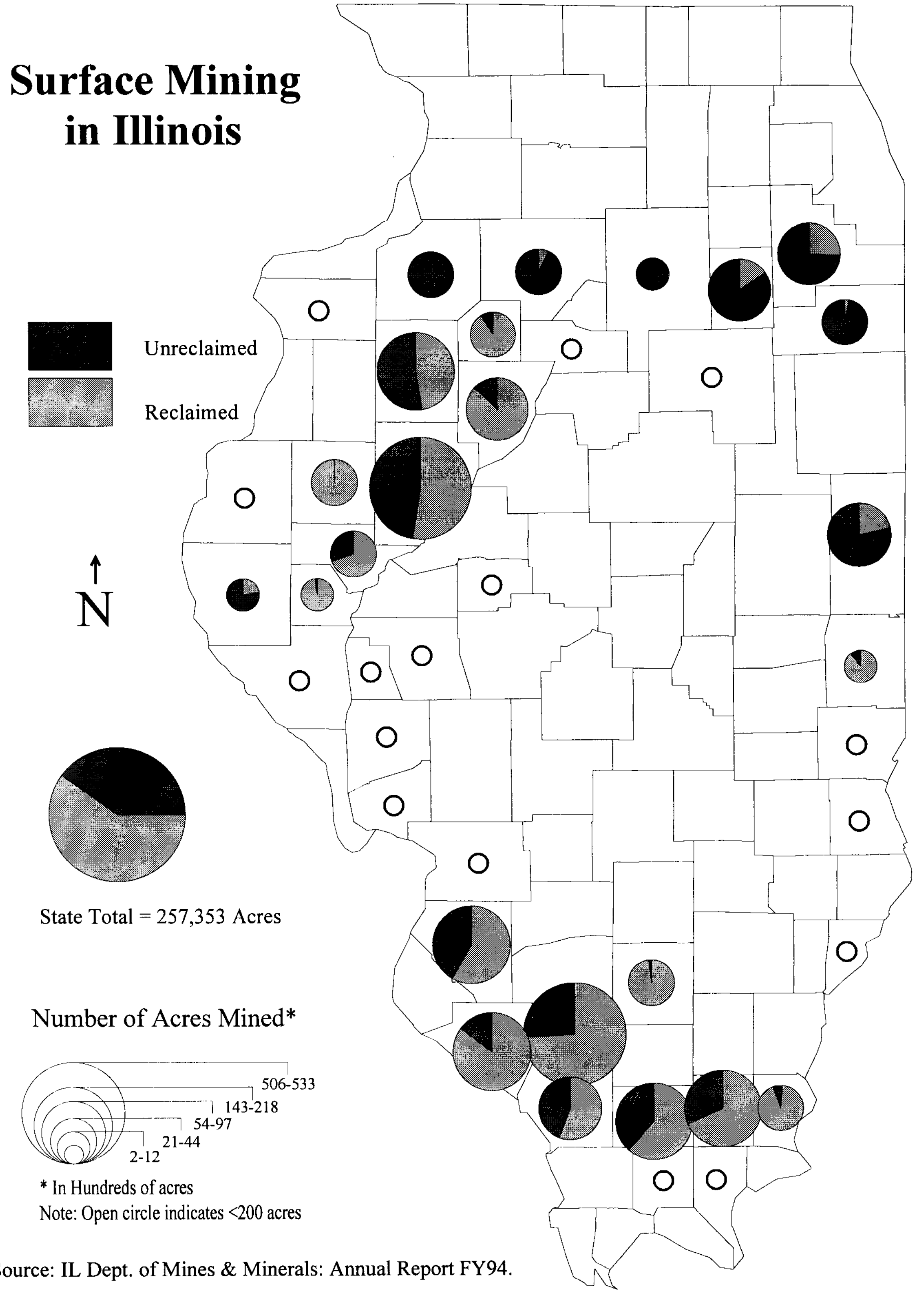
Map Unit Number	Map Unit Name	Established	Texture	Reaction	Classification
MD, ML, SM	Strip Mine	Pre 1978	*Undifferentiated strip mined and other made land*		
801	Orthents	1978	silty	--	Udorthent
802	Orthents	1978	loamy	--	Typic Udorthent
803	Orthents	1978	--	non-acid	Udorthent
804	Orthents, acid	1978	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



Source: IL Dept. of Mines & Minerals: Annual Report FY94.

Figure 1. Distribution of surface mining in Illinois.

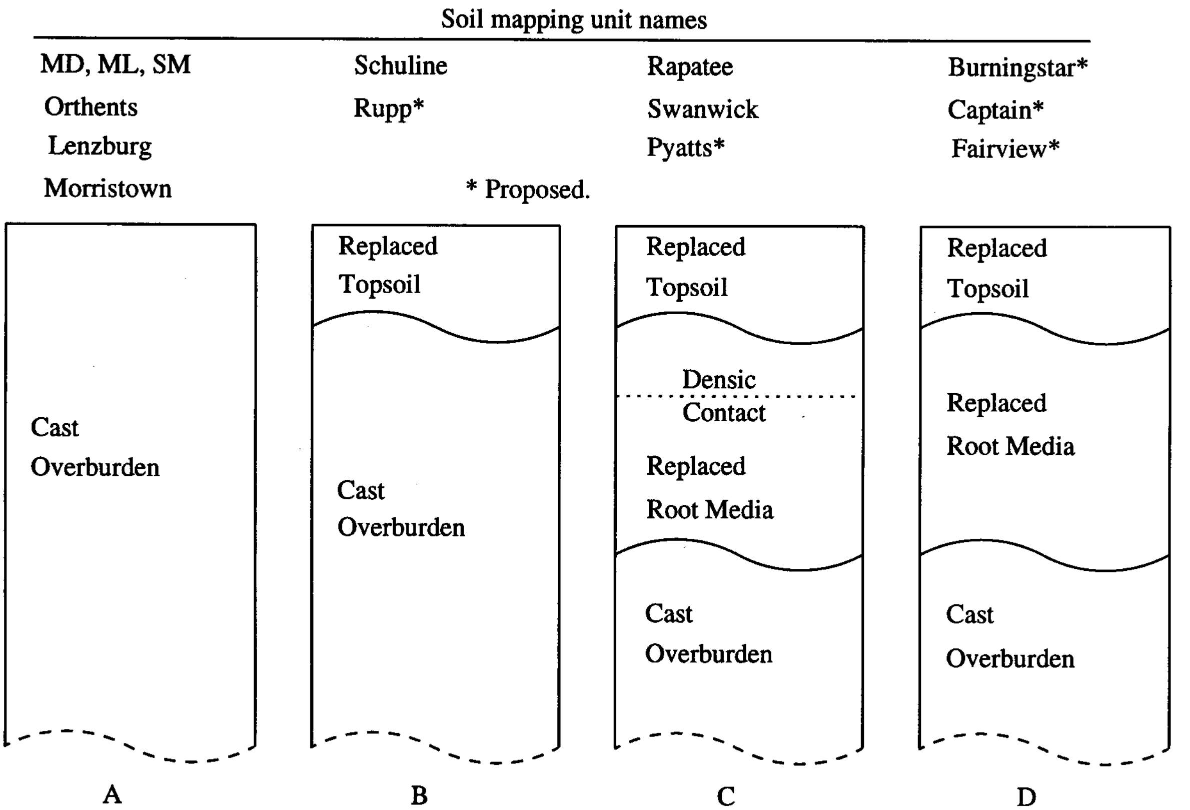


Figure 2. Idealized post-mine material placement profiles showing soil mapping unit names.

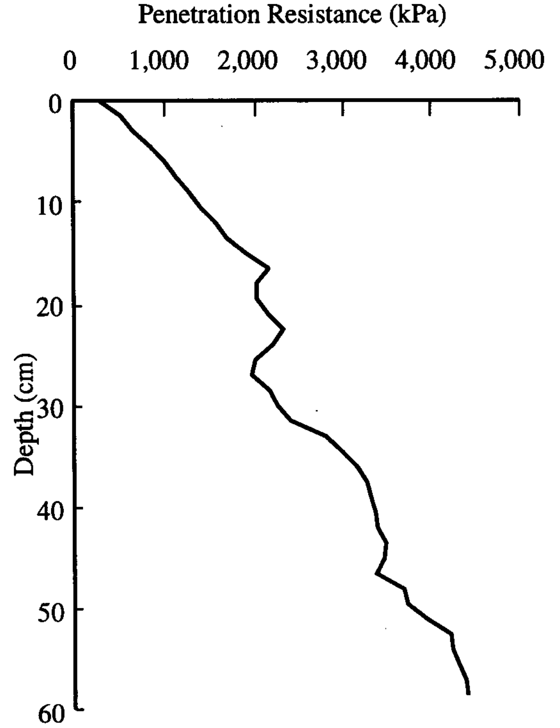


Figure 3. Penetration resistance in a soil mapped as Rapatee, 30 cm topsoil replaced over rocky cast overburden. This soil meets the guidelines for the proposed Rupp series.

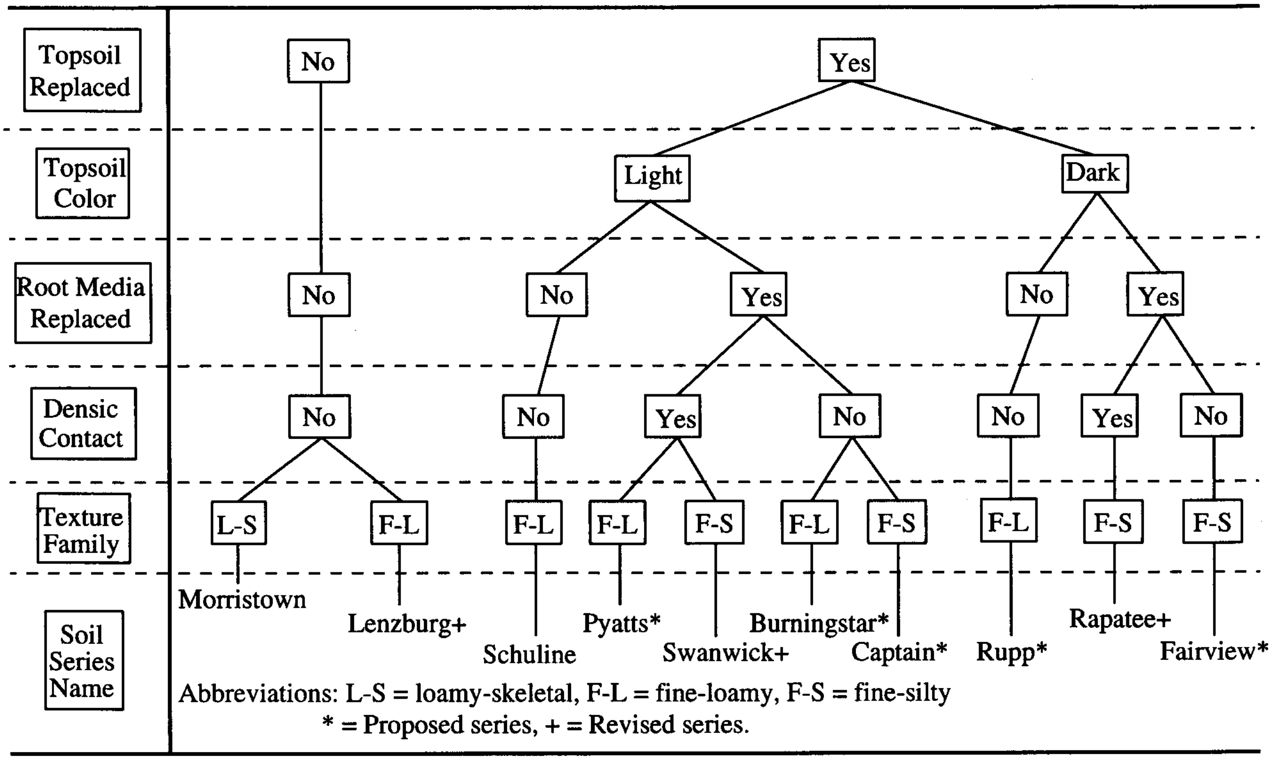


Figure 4. Key for Illinois minesoils including proposed and revised series.

GLOBAL POSITIONING SYSTEMS (GPS) AND SITE SPECIFIC MANAGEMENT

Richard 1. Barnhisel[1]
University of Kentucky,
Lexington, KY

There are several items of equipment necessary in order to use GPS for managing surface-mined soils. The most important is a DGPS (Differential) receiver that ranges in price from $2,500 to $5,000 depending on the brand and its capability, For example, the Starlink Invicta has a suggested retail price of $4,200, capable of receiving 10 satellites and two U.S. Coast Guard (USCG) signals. DGPS receivers are those which obtain free signals from the U.S. Coast Guard radio beacons that correct the built-in efforts of the GPS satellites. Most DGPS receivers obtain signals from at least eight satellites and at least one USCG correction signal. Others may receive up to 12 satellites and two USCG beacons. Only the strongest four satellites and one USCG signal are used to compute the position of the DGPS antenna in the field.

Depending on the cost of the instrument, DGPS positions are within plus or minus I to 2 meters, as a worse case. In general, the more expensive the instrument, the more precise the position. Some of the receivers can provide sub-meter accuracies. A survey grade instrument, which may cost several tens of thousands of dollars, can deliver positions within I or 2 centimeters in the X-Y direction. In general, elevation or the Z direction is 3x poorer than those of the X-Y direction.

A second piece of equipment needed is some method of recording the position in the field so that maps can be produced. This may range from a palm-top computer that costs around $500 to a lap-top that ranges from $1,500 and up, depending on what accessories it may have and how rugged it may be. Ordinary lap-tops will serve this purpose, but remember they are not designed to bounce around in the field especially under dusty conditions. If such a computer is used, it is highly recommended to down-load all data each day to a more stable computer as a "crash" is likely to occur sometime during its use.

Software is the third component. The cost ranges from $500 to as high as $8,500, Cheaper software packages can do only simple mapping and generate output to a printer. The more expensive software packages have Geographic Information Systems (GIS) components that allow the user to link information to points or features of a map. In the case of surface-mining, this may rangefrom simply linking the permit data to an area or a polygon. This data can be as large as desired as long as it is within the space limitations of the computer. One can link seeding and fertilizer rates applied, yields taken as a part of productivity measurements, and even data from individual soil or plant sampling locations within the permitted area. Location of areas where reseeding is needed, where gullies are found. diversion structures, sediment basins, etc., are other components that may be included in the GIS database. Essentially, the database can include any kind of GIS data that can be linked to the map or GPS position from the very first time the boundaries are defined, through the mining phase, to when the bond is released and beyond if record keeping is needed.

Sources of Field Variations

Most of my personal use of GPS on surface-mined lands is related to recording yields associated with prime farmland. Yields are subject to many components, some of which are the results of physical and chemical properties of the soil. Yield maps from a combine can show zones within a field that have good to poor yields. These areas can be linked to physical properties through GPS and GIS databases.

Prior to planting a permitted area, one should sample the soils or spoils within the area. Grid sampling is one method to detect regions within the permit area that may need special treatment to bring conditions to a level where yield goals can be met. The first step in preparing to grid sample is to determine the increment or field boundary within the permit. This is simply driving the perimeter with an ATV vehicle equipped with GPS, or it may be established by scanning the permit map and linking latitude and longitude positions to this map. An example of a boundary map is given in Figure 1. Superimposed on such a map, as is the case in Figure 1, are grid sampling points. In this case, I started with sample #26 in the upper left hand corner and ended with #87 in the lower right hand comer. This illustration of a grid map is perhaps much more intensively sampled than is usually, necessary, and it has a spacing of 150 x 200 feet. The spacing used in this study, allowed for a slightly more intense sampling interval in one direction due to change in slope. It also allowed for the determination of how frequently should one sample reclaimed land. More commonly grid sampling is done on 330 x 330 or 445 x 445 feet or 2.5 or 4.5 acres per sample.

Physical and chemical properties could be determined for the soil samples at each location. In this case, I determined only soil fertility values, but since GPS positions were recorded, I can always return to these positions,, within plus or minus one yard, and collect other data such as compaction or bulk density, soil strength. or soil depth. It is planned to collect physical data only where the yield map for corn indicates possible problems may be limiting yield. These yield data will be collected in the future.

Soil Fertility Variations

Another grid soil sampling study will be presented in the next few figures as an example of soil nutrient variations. This study is not from a mdace-mined field, but is adjacent to where a surface-mine occurs. It was my hope to have the data from the previous area completed and included in this paper, but soil sampling and data analysis are not complete.

This field shown in Figure 2 is bordered on both of the long edges by open ditches. On the right side ', the soil from this ditch was placed within the field. Although this had minimal effect on pH, it did influence other nutrients. The bottom of this field has a road running along its edge.

Figure 2 illustrates the variation of pH within this 20 a field. This field is of one soil type, yet the pH varied from <5.4 to >7.5. Although such maps are more vivid in color, the contour lines surrounding the dark shading illustrate pH boundaries where the pH is low. Through the center section is a zone of higher pH, more or less parallel to the field's longest axis. The pH in this area is greater than 6.6, with two small points where the pH was greater than 7.5.

The Mehlich III Ca data are plotted as Figure 3. There is a similar pattern in this Ca data as that for pH, as one would expect. In general, regions low in pH arc also low in Ca, and vice versa. The degree of fit between two figures, as a general rule, can be manipulated by changing the scale or range in values. However, I did not attempt to manipulate these ranges to produce a better fit, but generally tried to keep the number of shades at the same level, or to represent differences for recommendation of nutrients.

For the Ca data, there tended to be higher levels along the ditch on the left side of this figure. The soil that was spoiled along this portion of the field is higher in clay and had been spread onto this soil for the first 50 feet.

Figure 4 illustrates the level of Mg in this field. Essentially, the Mg is uniformly low and below 300 lbs/a, except along the open ditch, especially up to about the first 1,400 feet. Along the ditch, Mg levels were about 5x greater than the rest of the field. In all cases, however, Mg levels were adequate.

Figure 5 gives the Mehlich III P data. This pattern does not match any of those presented earlier. There arc "islands" of high levels throughout this field that are 4x greater than the low areas. Near the top of this figure are a couple low areas that are <20 lbs/a, which occur within 200 ft from a level between 70 and 80lbs/a.

It appears that P levels are high along the road at the bottom of this figure. It is likely (my speculation) that extra fertilizer (both P and K) has beenapplied here in order to empty the spreader truck prior to its departing the field.

Figure 6 presents the Mehlich III K data. Again, this nutrient has a different pattern, with the exception of being high along the road. The majority of the K was in the medium range between 140 and 220 lbs/a.

Conclusions

It may appear that perhaps grid sampling presents more data than one can manage. In the examples given here,, all elements except for Mg are candidates to be managed separately by variable additions of these nutrients. Since these patterns vary widely and present large differences in nutrient levels', variable fertilizer application would challenge most computer driven spreader trucks. In fact, the sampling frequency in this field was more intense than given in the first figure, being at 75 x 75 ft. We used this pattern since many available spreader trucks could spread nutrients at such a spacing. On an average, and if only applying P and K. adjustments in either of these elements would need to be made four or five times across this field of 2,000 ft in length. Since there are about eight passes of the truck, 40 adjustments would be needed for each element, or a total of 80. This is not beyond the capability of commercially availabletrucks. It is not known if applying nutrients according to these maps would be economical, but if this were a surface-mined field, this may be important to a coal operator to insure a timelv bond release, at least the first couple of years for corn production. Hopefully with time, the fields will become more uniform and variable rates would no longer be needed or advantageous.

Preliminarydata from a grid-sampled, surface-mined field indicates a wider degree of variability than seen for this non-mined field. This is not surprising since, as you will recall, the field illustrated in figures 2 to 6 were all from the same soil series.

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[1]Richard Barnhisel, Professor of Agronomy and Geology. Department of Agronomy. University of Kentucky. PhD. Virginia Tech. 64. 25 years reclamation experience.

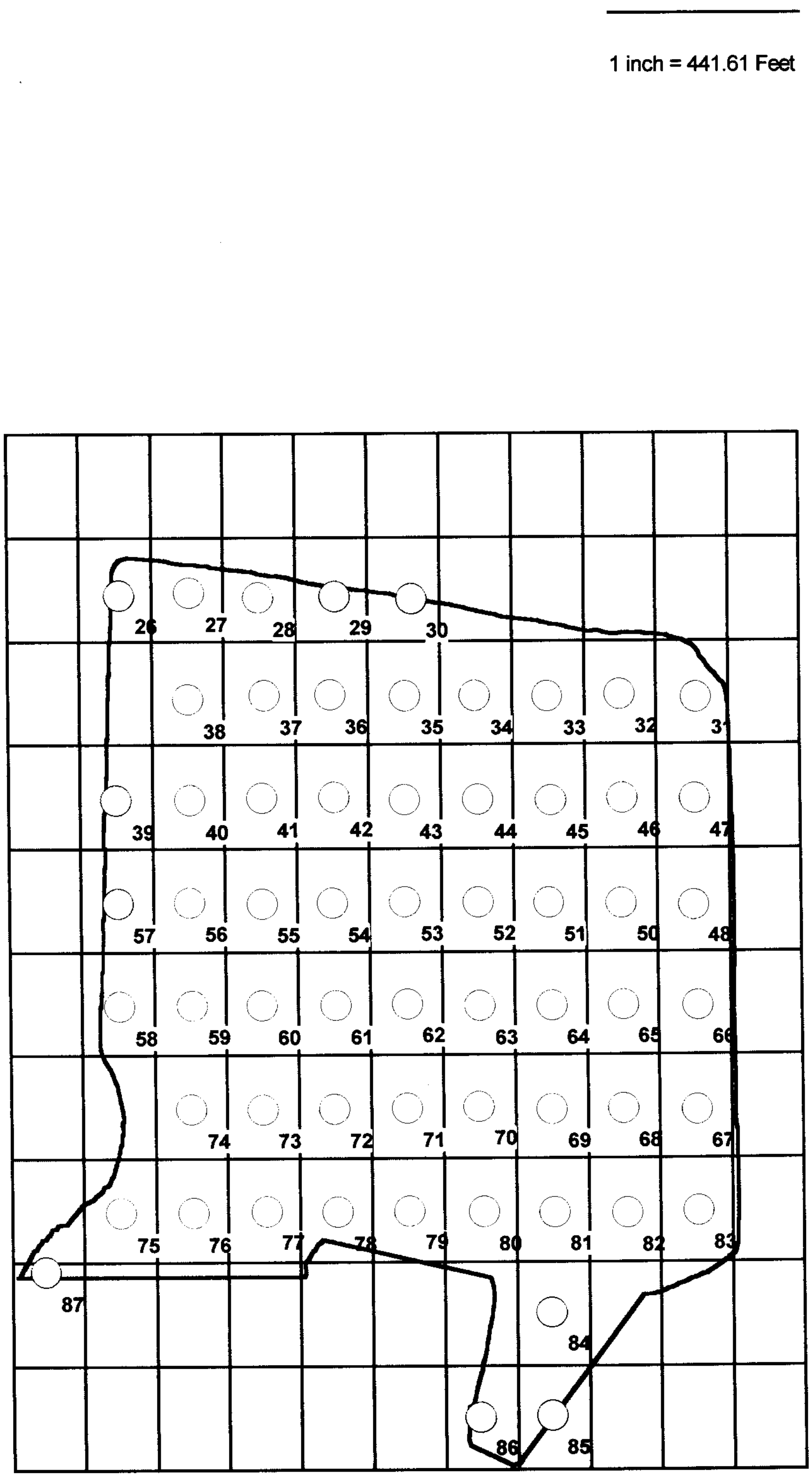
1 inch = 441.61 Feet
26 27 28 29 30
38 37 36 35 34 33 32 31
39 40 41 42 43 44 45 46 47
57 56 55 54 53 52 51 50 48
58 59 60 61 62 63 64 65 66
74 73 72 71 70 69 68 67
75 76 77 78 79 80 81 82 83
87
84
86 85

Figure 1.

LUCK FARMS
Water - pH

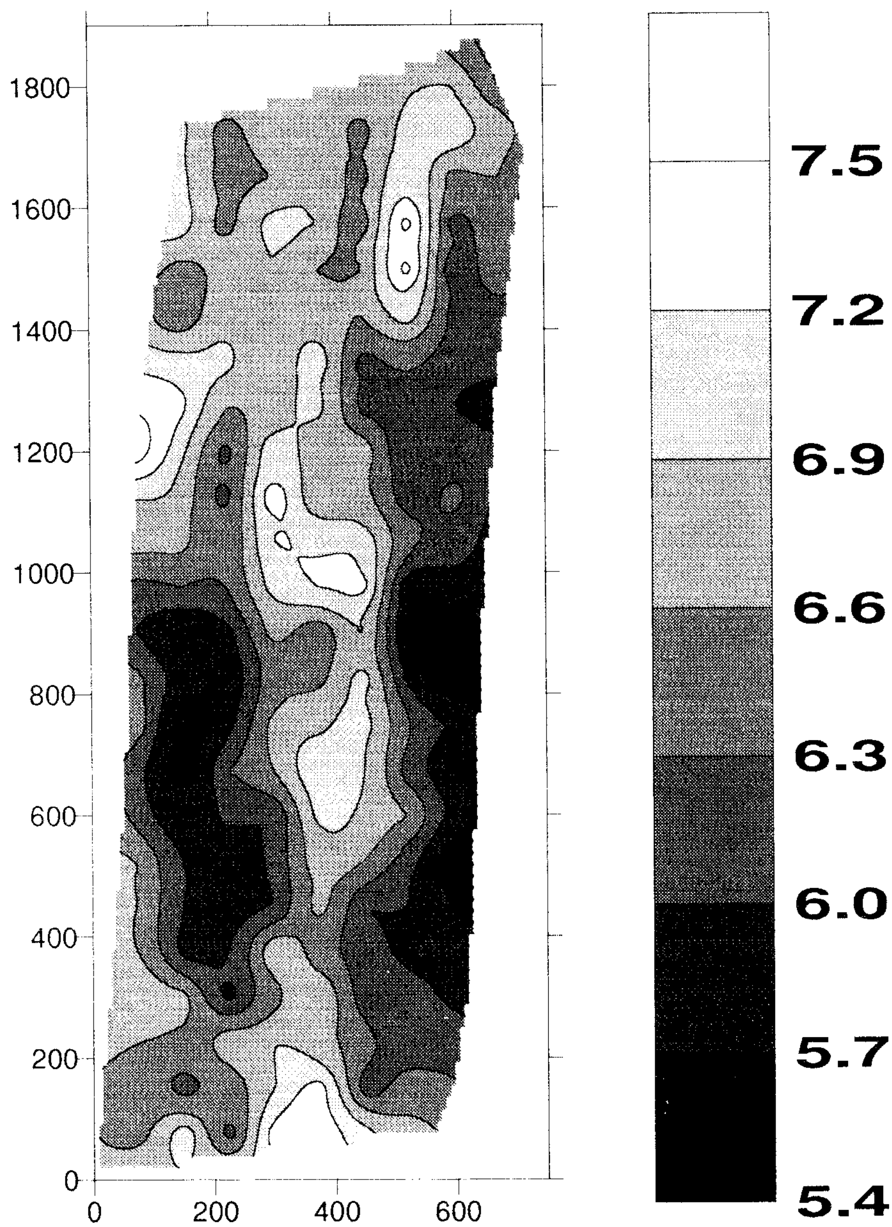

Figure 2.

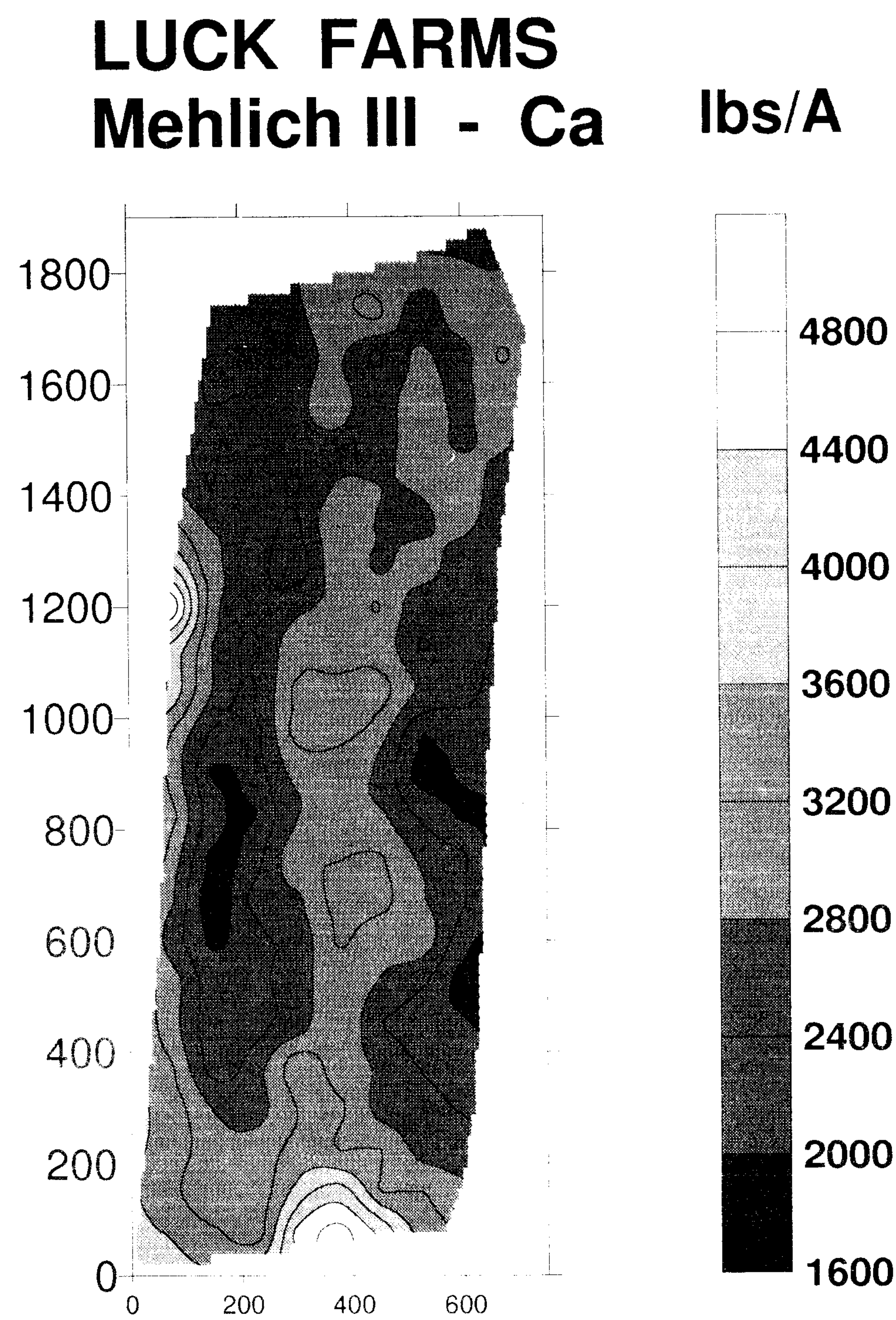
LUCK FARMS
Mehlich III - Ca lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
4800
4400
4000
3600
3200
2800
2400
2000
1600

Figure 3.

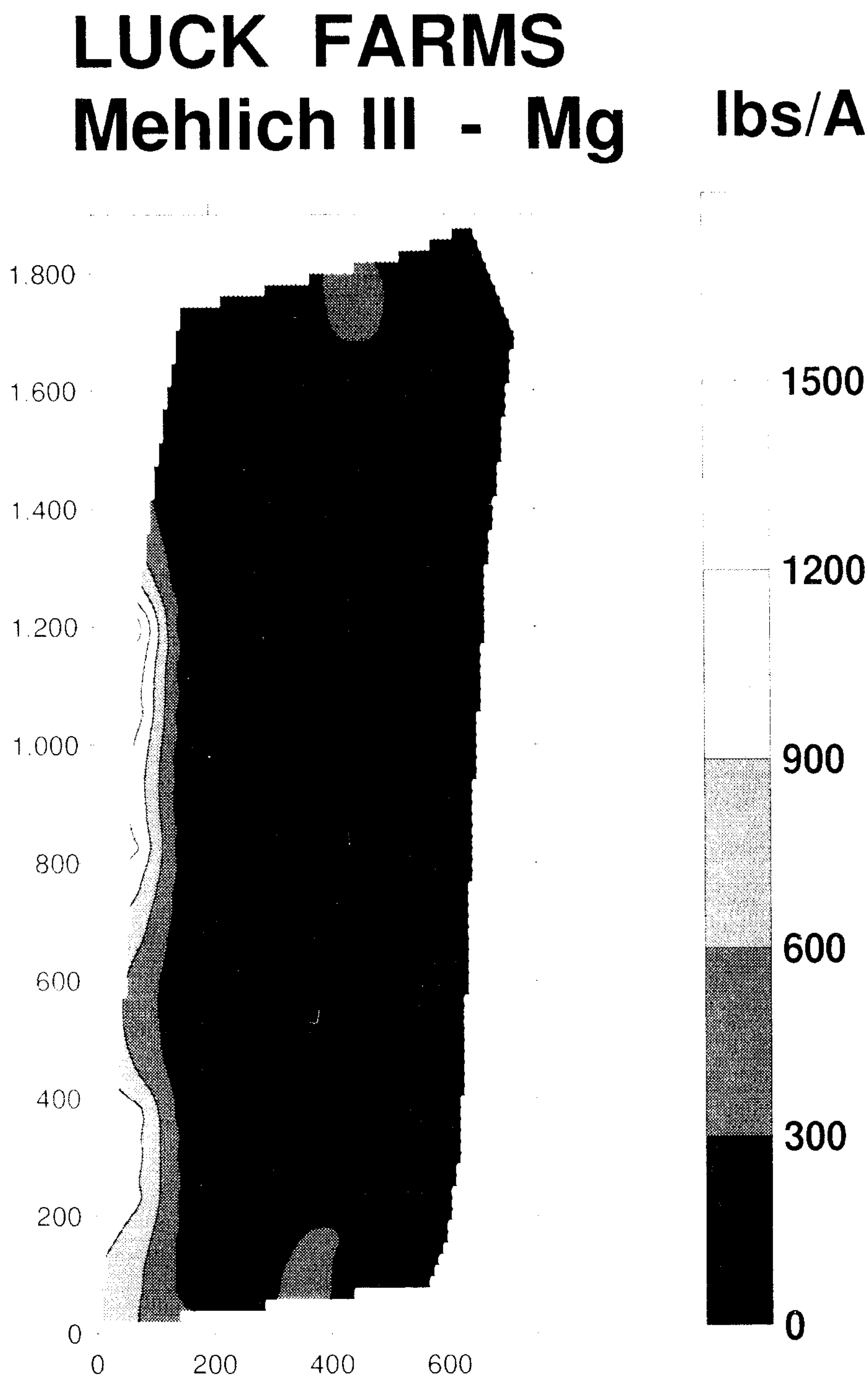
LUCK FARMS
Mehlich III - Mg
lbs/A
1.800
1.600
1.400
1.200
1.000
800
600
400
200
0
0
200
400
600
1500
1200
900
600
300
0

Figure 4.

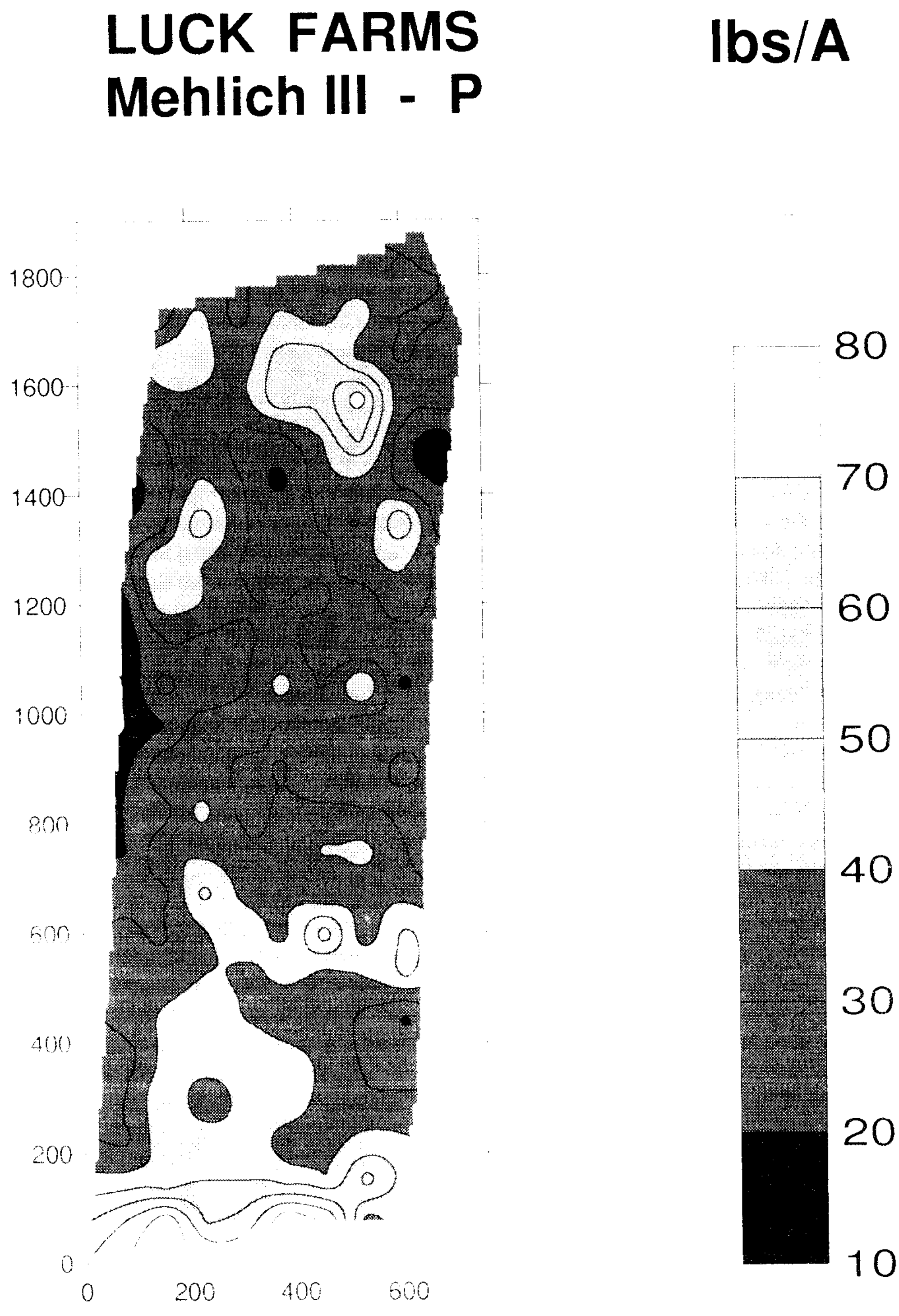
LUCK FARMS
Mehlich III - P
lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
80
70
60
50
40
30
20
10

Figure 5.

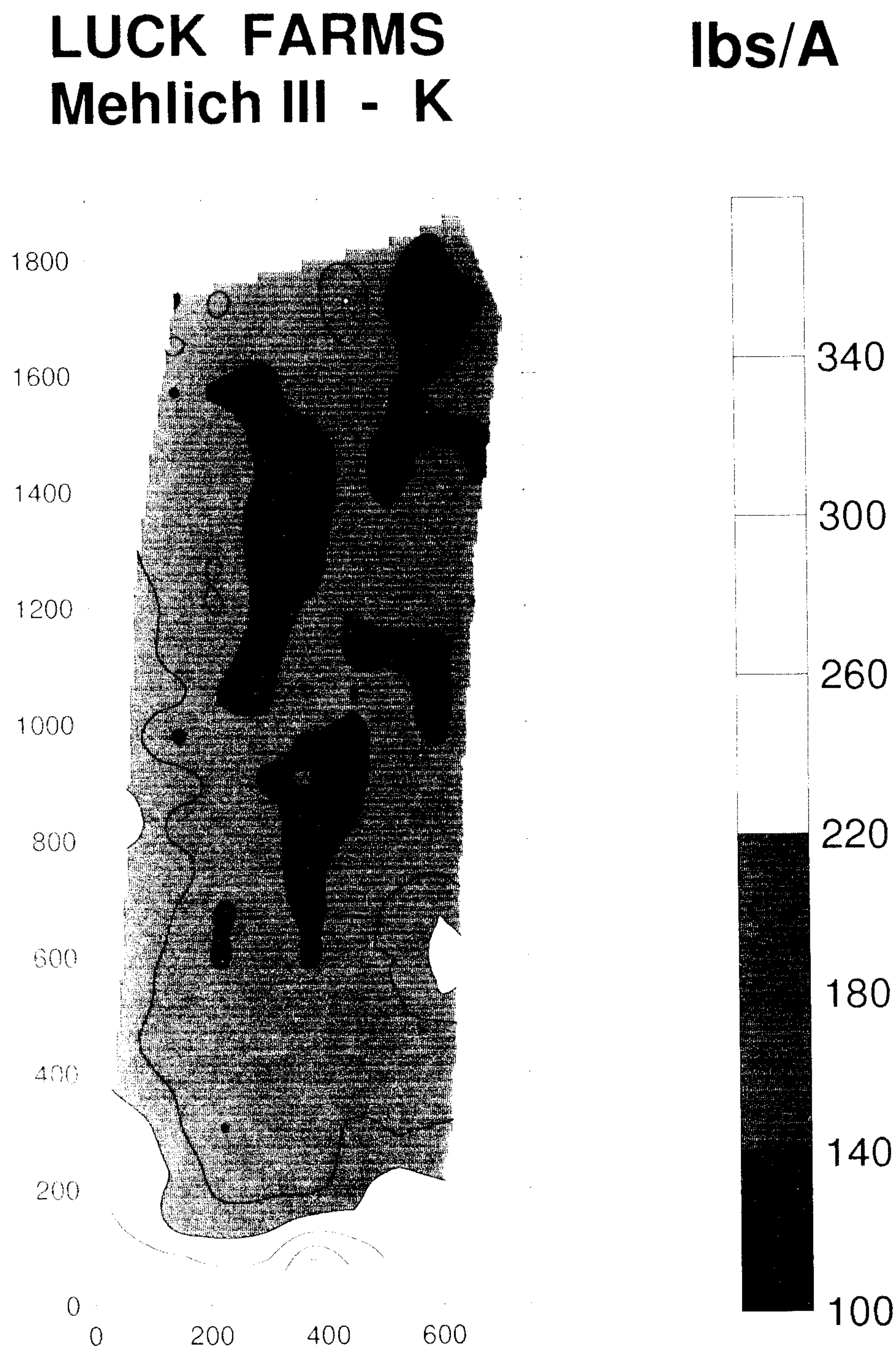
LUCK FARMS
Mehlich III - K
lbs/A
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
340
300
260
220
180
140
100

Figure 6.

LAND USE AND VALUE AFTER RECLAMATION

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St. Louis. Missouri

Abstract

This presentation discusses the process of analyzing the size and condition of producing land parcels concerning management and income relationships, tract location., and soil and water conservation structures. It reviews production schemes for crops such as corn, soybeans. wheat, alfalfa hay, and warm season grasses, as well as use for recreation. Management of tenants and leases is discussed concerning evaluation of crop share leases, cash renting, custom farming, and tenant selection. Issues related to planning for and management of taxes, long-term improvements, and other land costs are presented.

Introduction

I have been with ARCH Coal for five years. My responsibilities include managing and leasing all of ARCH's properties that are no longer under bond, as well as lands that are undisturbed by mining. I am going to talk about management of property in terms of (1) building asset values, (2) current property values of reclaimed lands in southern Illinois where we have tested the market, and (3) some future trends, such as some nonconventional uses of these properties, both those that are emerging and those that may become more important in the future.

Property Management

Concerning property management, management of both the reclaimed and undisturbed areas are key to unlocking the maximum values of these properties. We had been looking atthe property as a leftover from mining rather than as an asset. Internally we had to change our mind set and start looking at this property as an asset. We had to start looking at it on an individual tract-by-tract basis, both in terms of sales potential and as a management responsibility. Instead of acting like one of the largest landowners in southern Illinois, we had been acting like a coal mine, until recently.

ARCH has reduced the number of operators that we have working on these properties from 55 to 23 individuals over the last five years. Tenant selection is very important in this process. One of the first things we did was to significantly raise the tenant rent for cash renting and custom farming. Although not popular initially, the benefits were more than we had anticipated. We ended up working with a much higher quality of tenants that were more successful land managers. We eliminated rental of small tracts of land and ended up with fewer but larger tracts of 2,000 to 5,000 acres. This gave us more bargaining power in the market. This was done both for agricultural tracts as well as for the hunting rights. In order to manage this successfully, we had to ensure that our tenants who were raising crops, those raising cattle, and our hunters were all working together.

Land Values

We also had to look closely at those enterprises that were actually making us the most money. We looked at corn production and saw that this was our most risky enterprise. We found that wheat and hay production were the least risky and many times the most profitable crops. We have been very aggressive at matching our cattle producers with the right hay ground. This combination added value to both operations. We also greatly increased our control over the properties in order to reduce our problems from trespassing.

We knew that some day we would want to sell these properties, and we knew approximately what the value of the properties were. We looked at the market for land in this area. We projected that the land values would increase with time because people were moving out of the St. Louis, Missouriarea and moving into the country. We were getting a lot of calls from people who wanted to hunt on our property. Pressure for land in this area was going up rather than down.

We determined that in our area, the market for hunting is what is going to drive the price of these properties up. In response to this hunting pressure, we established hunting clubs on the properties to develop the hunting resource and stopped all of the trespassers and other individuals that wanted to hunt on these areas. This has allowed our populations of deer, turkey, and other game animals to increase. We actually plant crops in the area just to encourage water fowl to utilize the area so they will be present when we show the properties to potential land buyers.

We also had to change the mind set of the locals in the community. One thing about land value is that 70% of all land sales in the Midwest will be to local buyers within two to three miles from the property. We had to change the property potential in the minds of the patrons of the local coffee shop. Prior to this, the locals would only value previously mined land at $200 to at most $400/acre.

In order to do this, we had to set some standards for land values and stick to them. We determined that the hunters were going to drive the market. We were about 90 miles from St. Louis, Missouri and about 50 miles from Carbondale. Illinois. We knew that there would be people coming from these urban areas that would drive the demand for our properties. Although 70% of our sales have been to local people, it has been the pressure from this urban hunter market that has allowed for the increase in land values.

We have worked with our local real estate brokers in order to change their mind sets about the value of these lands. It is very important that the real estate broker actually feels that land is worth the asking price for the land. If he truly feels the land is only worth $400/acre, he will have little success trying to get $800/acre. If the buyer says the price is too high, then the broker will agree with the buyer because that is what he believes.

One thing that has helped us to raise the per acre value of the property is to divide it up into moremarketable tracts prior to sale. We take an area that has 1,000 acres and has water on it, and subdivide it into two 500 acre tracts. You need to make logical divisions that increase the value of the land. You need to make sure that you have access to the property so that people do not have to build roads to get to their property.

We plan to market the ground at least one year in advance. Although most buyers can not tell what 60 bushel soybean land looks like, they can tell whether or not the road ditches have been mowed. If the row ditches are mown, then they think you are doing a good job taking care of the land. Another thing we do is to ensure that the tenant farmer who rents the property does not go the local coffee shop and bad mouth the property. We make it very clear to the tenant farmer that this will not happen. If he doesn't like some particular feature of the property, such as he thinks the water way should be in some other place or there are some rocks he does not like, that is just between us and him. You can not afford to have him not speak well of the property as he will get asked frequently.

We have sold about $11 million worth of land over the last 13 months. The market has come up significantly in the last two years and will probably level out soon. In 1995, we sold some, what I would call nuisance acres, pre-law ground with spoil ridges still standing that had a pretty good coverage of pine trees. We had a terrible trash dumping problem on this property. After trying hard for six months, we finally sold it for $325/acre and were happy to get it at that point. We learned a lot in this process. Even though we cleanedit up just prior to the sale, we and everyone else knew that trash dumping was a problem. After changing our management practices in 1997, we sold 550 acres of mostly reclaimed land that had about 30 acres of water, 62 acres of cropland, and the remainder in scrub woodland with a lot of rocks for $530/acre. In our best sale this year, we sold 1,035 acres with 150 acres of crop land, with the remainder in water, timber, and pasture that made a very good hunting area for $800/acre. It had a county road on three sides and we really marketed it well. We have had several other sales in the $750/acre range.

We figure that reclaimed crop land is worth about 75% of un land currently. This is the best price assuming that you manage it and market it properly. Areas that have been planted with trees that are six to eight years old are worth within $50/acre of undisturbed forest properties. Reclaimed pasture is worth about $700 - $800/acre. This depends upon the number and condition of the fencing and the number of separately fenced areas. The pre-law lands with standing spoil ridges are worth under $500/acre if they have water and water fowl will use them.

Maximum values are enhanced by subdividing the land. You increase the number of potential buyers by tenfold if the sale concerns a$300,000 tract of land rather than a $1,000,000 tract of land. By subdividing the land you transform a 5,000 acre parcel worth $500/acre into several tracts worth $700 to $750/acre.

Future Trends

Concerning future trends, the number of farmers in America are decreasing at 3.5% per year. Every time a farmer goes out of business, he usually has two to three people that use his land for hunting that are now looking for a new place to hunt. Also hunters are never satisfied with what they have and are always looking for new places to hunt Although I think that the hunting value of the land may not increases I do not think it will come down.

Another emerging market, if the property is large, is for a hog or poultry feeding operation. These operations are trying very had to find land that is remote from human populations. These people are looking for an isolated 40 acre tract of land with road access. I think the market for such property is in the $8,000 to $10,000/acre range. If you can arrange to obtain the hog manure and put it on surrounding crop land, it will increase the crop land value by $400 to $600/acre.

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ILLINOIS RECLAIMED SOIL PRODUCTIVITY: RESTORATION TECHNIQUES

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Consolidation Coal Co. (Consol) has nearly 8,000 acres of high capability and prime farmland reclamation responsibilities in Illinois. It has been involved imresearch in the area of restored soil productivity since 1976 with the University of Illinois and Southern Illinois University at Carbondale. Consol maintains an intensive internal program to demonstrate and test deep tillage equipment.

The research and in-house demonstrations identified soil physical strength (compaction) as the main limiting factor to restoring a soil's productive capacity. There are two primary ways to address this issue: prevention and amelioration. The former was not an option for Consol because many acres were already reclaimed and the company has a major scraper fleet. Along with other operators in Illinois, Consol started an aggressive search for equipment and techniques that could loosen compacted soils.

In 1987 Consol was the first to use the DMI-Super Tiger deep soil plow, originally developed and manufactured DMI, Inc. of Goodfield, Illinois. This plow is composed of a single parabolic, static shank with a 44-inch wide sweep weighing 1,200 pounds. It is capable of plowing 48 inches deep while leaving the topsoil in place. A Catapiller D9L tractor with 46.0 horsepower is used to pull the plow. In 1990 the decision was made to commit to this equipment as the best technology currently available. In 1994 Consol received a patent waiver from DMI to build its own plow. The Consol-built plow has been in use since the er of 1995. To date, Consol has plowed over 3,900 acres with a DMI plow.

In summary, Consol's program for deep tillage after topsoil replacement is as follows:

(1) Wheat is planted for the first two years. This allows for an intensive land leveling program following each harvest, During this time, the majority of surface water management structures (terraces and grass waterways) are constructed.

(2) Alfalfa is established and maintained for a minimum of two to three years. Just prior to the plowing, the remainder of the build-up fertility is applied, based on variable rate technology sampling and application. Alfalfa roots can penetrate the dense clays and dry out the subsoils. This is important because the action of the plow is significantly enhanced when the subsoil is dry. The lifting motion of the sweep combined with the ground speed of the tractor does an excellent job of shattering the large massive blocks of high density clay but only if the soil materials are dry.

(3) The plowing season is limited to the driest part of the southern Illinois summers Start-up is normally planned for the first two weeks in July, allowing time for the alfalfa to pump out the subsoil moisture gained during the last wet season. The plowing continues as late in the fall as possible. Consol plants to plow around 600 acres per year that normally includes one mobilization between mine sites. The best productivity for this combination of equipment has been around three quarters of an acre per hour. The contractor can usually ran the plow for 20 to 24 hours per day.

(4) After plowing, these fields are rough because the plow leaves a corrugated pattern in the soil surface. The soil peak in the plow path averages 21 inches above the original soil surface. The surface of the fields are re-leveled as quickly as possible through off-set discing and multiple passes with a field cultivator. If the field receives a three inch rain or less immediately following deep tillage, a long delay can result before an entry into the field is again possible.

The program, as described above, has been applied for over ten years, and the cropping results have been very good. On soils that have been plowed with the DMI, there have been 130 fields, with cumulative total of 4,000 acres, tested by the Illinois Agricultural Lands Productivity Formula. The results of this testing are as follows:

(1) com-96 fields tested and passed 83.3% of the time;

(2) soybeans-20 fields tested and passed 85% of the time; and

(3) wheat-14 fields tested and passed 78.6% of the time.

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