ROWCROP RESPONSE TO TOPSOIL REPLACEMENT ON HIGH TRAFFIC VS LOW TRAFFIC SOIL RECONSTRUCTION SYSTEMS[1]

R. E. Dunker and R. G. Darmody[2]

Abstract. Poor soil physical condition is identified as the most limiting factor to successful row crop production on mined land in Illinois. Compacted mine soils lack a continuous macropore network to provide for water movement, aeration and root system extension. Critical to reclamation success are i) selection of the best available soil materials used in soil reconstruction and ii) reclamation methods which will minimize compaction during soil reconstruction. In Illinois, topsoil replacement has generally enhanced seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials. Yield response to topsoil replacement has ranged from strongly positive to strongly negative. Excellent corn and soybean yields have been achieved when reclamation methods result in low strength soils. Total crop failures have commonly occurred when high traffic soil replacement methods result in mine soils with high soil strength.

Additional Key Words: topsoil, minesoil, prime farmland reclamation, compaction

---

[1] Paper was presented at the 2005 National Meeting of the American Society of Mining and Reclamation, Breckenridge CO, June, 19-23 2005. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Robert E. Dunker is an Agronomist, Department of Crop Sciences, University of Illinois, Urbana, IL 61801 email:r-dunker@uiuc. Robert G. Darmody is a Professor of Pedology, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL 61801 email: rdarmody@uiuc.edu
Proceedings America Society of Mining and Reclamation, 2005 pp 302-327
DOI: 10.21000/JASMR05010302
https://doi.org/10.21000/JASMR05010302

Introduction

This paper will report and summarize research done by the University of Illinois concerning rowcrop response to various reclamation practices. Discussion of results will focus on yield responses, observations, and summary of the Illinois research. There will be little attempt to distinguish between prime and non-prime farmland, even though prime farmland is addressed separately in federal legislation. The principles of reclamation for row crops, and to a large degree, the potential for success are quite similar for prime and non-prime farmland. Most prime farmland must by law be reclaimed to row crop capability, but not all row crop reclamation is on prime farmland.

Selection of Soil Materials

Segregation and replacement of horizons from the premine soils is a practice that is required by Public Law 95-87 (1977). Early reclamation research focused on the evaluation and characterization of selected soil materials to be used for soil horizon replacement or substitution, if the substituted soil material could be shown to be as productive as the natural soil horizon it replaced. Construction of minesoils with good quality soil materials and desirable physical properties is essential to attain productivity levels necessary for bond release.

Greenhouse evaluation revealed that replacement or alteration of the claypan subsoils of southern Illinois would increase crop growth by enhancing the chemical and physical properties of mined land (Dancer and Jansen, 1981; McSweeney et. al., 1981). Topsoil materials generally produced somewhat greater plant growth than did mixtures of B and C horizons, but the B and C horizon mixtures were commonly equal to or better than the B horizon materials alone. The natural subsoils of this region are quite strongly weathered and acid, or are natric and alkaline (Snarski et al., 1981). Alternative material was generally much higher in bases than the acid soils and lower in sodium than the natric soils. Liming and fertilizing of the soil horizon material produced good yield response and reduced the need for material substitution. McSweeney et al. (1981) also got favorable greenhouse response to blending of substratum materials with B horizon materials from the high quality Sable soils (Typic Haplaquolls) in western Illinois. This response to blending was less pronounced than that observed with materials from southern Illinois.

Most of the Illinois research has centered around field experiments to evaluate row crop response to soil replacement and various reclamation practices. Premine soils ranged from the highly productive deep loess soils developed under prairie vegetation (Mollisols) at the western Illinois sites to the lighter colored, more strongly developed Alfisols at the southern Illinois sites. Corn (*Zea mays L.*) and soybeans (*Glycine max (L.*) Merr) were grown on these newly constructed soils to evaluate productivity. Most of the early field studies addressed the issue of topsoil and subsoil horizon replacement.

Topsoil replacement has generally been beneficial for seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials (Jansen and Dancer, 1981). Yield response to topsoil replacement has ranged from strongly positive to strongly negative. At the Norris mine in western Illinois, scraper placement of 18 in of dark prairie topsoil resulted in a significant positive corn yield response in three of four years when irrigated and two of four when not irrigated (Table 1). Soybeans responded favorably to topsoil in one of the two years studied (Dunker and Jansen, 1987a). Significant negative yield responses to topsoil occurred in years of weather stress. Year to year variation in corn yield was considerably greater on the unirrigated topsoil than the unirrigated wheel spoil. Compaction caused by the use of scrapers to replace topsoil is assumed to be the reason for low topsoil yields in years of weather stress. The zone directly below the topsoil has a bulk density of 1.7 to 1.9 g/cm^3 and very low hydraulic conductivity..

Table 1. Corn yields in response to irrigation and topsoiling at Norris Mine in western Illinois.

Treatment	1979 bu/ac	1980 bu/ac	1981 bu/ac	1983 bu/ac	Mean bu/ac
Irrigated Topsoil/Wheel Spoil	191 a	166 a	175 a	193 a	181 a
Unirrigated Topsoil/Wheel Spoil	155 b	70 d	165 a	20 c	102 c
Irrigated Wheel Spoil	142 b	144 b	105 b	169 a	140 b
Unirrigated Wheel Spoil	100 c	89 c	109 b	70 b	92 d
Undisturbed Sable soil	156 b	124 b	173 a	70 b	131 b

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

At the Norris topsoil wedge experiment, A horizon material was replaced over wheel spoil by scrapers in thickness ranging from 0 to 24 in. There was a significant positive yield response to increasing topsoil thickness for corn, but not for soybeans . Year by year results showed positive relationships to topsoil thickness in years of favorable weather, but negative responses in years of moisture and temperature stress (Jansen et al., 1985).

At Sunspot mine, in western Illinois, topsoil and B horizon materials replaced over dragline spoil was evaluated over an eight-year period. Soil treatments consisted of 15 in of topsoil replaced over replaced B horizon; 15 in of topsoil replaced directly over dragline spoil; 36 in of B horizon replaced directly over dragline spoil; and dragline spoil only. Bulldozers pushed the soil materials onto the plot areas and it is important to note that scrapers were never allowed directly on the plots at any time during construction (Figure 1).

An undisturbed tract of Clarksdale soil (Udollic Ochraqualf) was used as an unmined comparison. Topsoil replacement resulted in significantly higher corn yields in four out of eight years when replaced over B horizon materials and six of eight years when topsoil was replaced directly over dragline spoil (Dunker and Jansen, 1987b). Corn grown on the topsoil replaced treatments had a higher percent stand at harvest, had fewer barren stalks, and a higher ratio of shelled grain per total ear weight than corn on the non-topsoil treatments. Soybean yields were significantly higher on the topsoil replaced treatments in six of seven years whether or not B horizon materials were replaced. The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale in five of seven years while the B horizon treatment without topsoil produced corn yields comparable to the undisturbed in only one year. The dragline spoil was unable to produce corn yields equal to the Clarksdale in any of the years studied whether topsoil was replaced or not (Table 2). Fehrenbacher et al., (1982) found that corn roots penetrated significantly deeper in the B horizon materials than the dragline spoil and that bulk densities were significantly higher in the graded dragline spoil than the replaced B horizon at a depth of 22 in and deeper. Bulk densities between the B horizon material and the undisturbed Clarksdale were similar. It is not possible to determine whether the favorable response to the B horizon treatment was due to the B horizon material, or to the lower soil strength which resulted from the careful handling.

Figure 1. Placing B horizon material at Sunspot mine

Table 2. 1981-86 average corn and soybean yields in response to topsoil and subsoil replacement at Sunspot Mine in western Illinois.

Treatment	**Soybeans bu/ac**	**Corn bu/ac**
Topsoil/B Horizon	36 b	130 a
Topsoil/Dragline Spoil	31 c	110 b
B Horizon only	27 d	86 c
Dragline Spoil only	17 e	65 d
Undisturbed Clarksdale soil	40 a	135 a

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Soil strength data taken with a continuous recording cone penetromter showed low soil strength values for Topsoil/B Horizon and B Horizon only compared to those plots constructed with dragline spoil (Fig. 2). Average soil strength (9-44" Average Penetrometer Resistance) was significantly correlated with corn yields averaged over the seven-year study (Fig. 3).

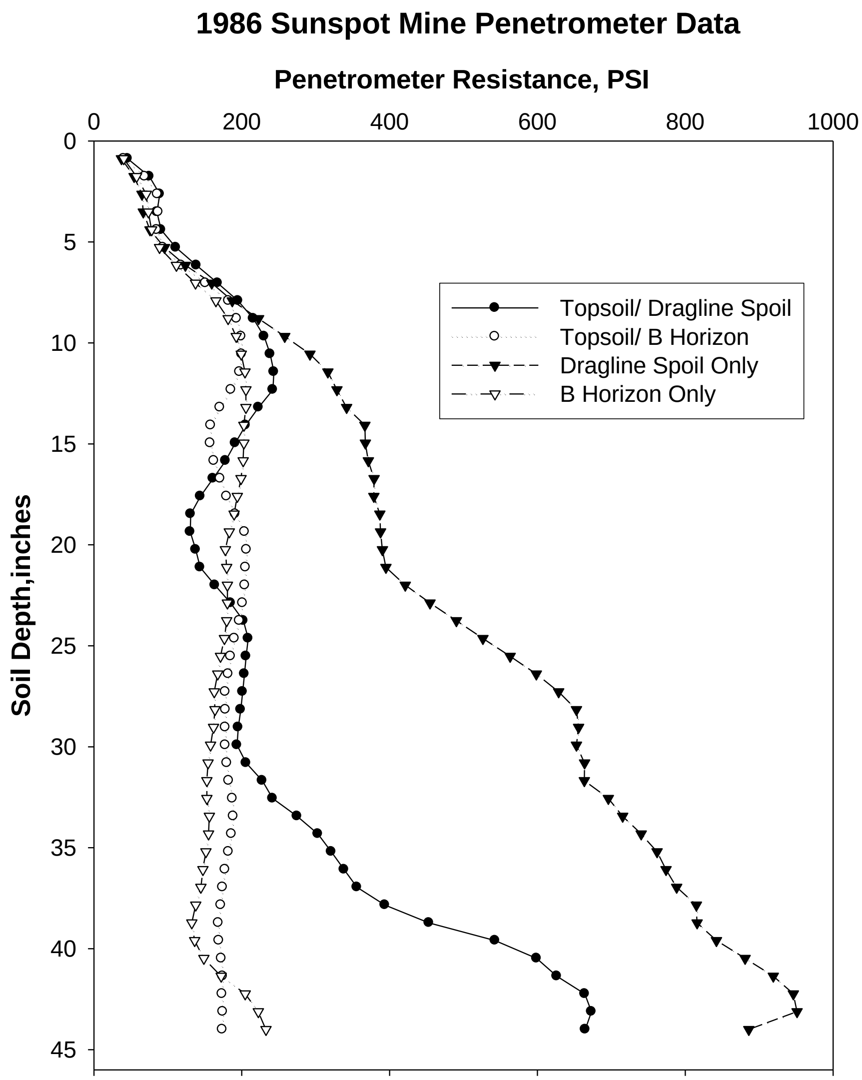

Figure 2. Soil strength profiles of Sunspot treatments

Positive crop yield response to soil horizon replacement in southern Illinois has been less dramatic than has been observed at the western Illinois sites (Table 3). This is understandable considering that A horizons are more highly weathered and average 8-9 inches in depth compared to 15-18 inches in the highly productive western Illinois soils. At River King, in southern Illinois, 9 inches of topsoil replaced by scrapers over wheel spoil significantly increased corn yields in only one of eight years and soybeans in three of six . The River King site has good quality spoil and rather mediocre topsoil. A nearby plot of topsoil and root media replaced entirely by scrapers was included as a comparison to the wheel spoil treatments. Crop performance on all three mine soils can be characterized as poor. Extensive grading and traffic zones between the topsoil and wheel spoil negatively affected the ability of rowcrops to develop root systems to adequately take up nutrients and water.

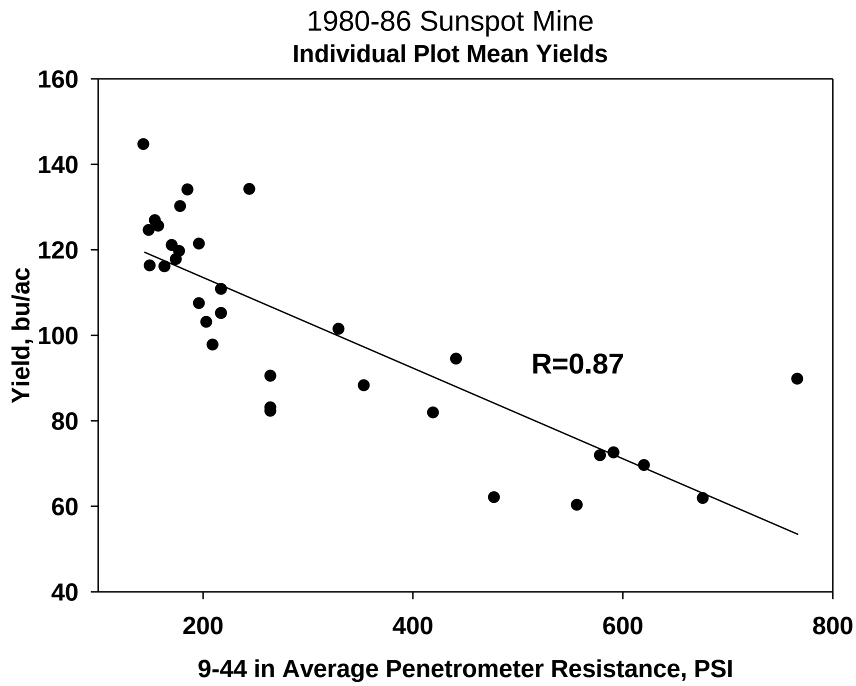

Figure 3. Relationship of soil strength and corn yields on Sunspot plots

Table 3. 1978-85 average corn and soybean yields in response to topsoil and subsoil replacement at River King Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Scraper Placed Topsoil/Wheel Spoil	18 a	54 a
Wheel Spoil only	13 b	52 a
Scraper Placed Topsoil & Root Media	13 b	33 b

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Soil horizon replacement and thickness of soil materials from southern Illinois was studied at the Captain mine in Perry County, Illinois. The Captain wedge experiment evaluated corn and soybean yield response to thickness of scraper (Fig. 4) placed rooting medium (0 to 48 in thick) over graded cast overburden, with and without 9 inches of replaced topsoil.

Yields of both corn and soybeans increased with increasing thickness of hauled material to about the 24-30 in depth (Fig. 5). Meyer (1983) found very few roots below the 24 in depth and found that roots in the subsoil were largely confined to desiccation cracks. The physical condition of the scraper placed rooting medium is best characterized as compact and massive with very high bulk density and poor water infiltration. Soil strength profiles taken at the 48" soil depth end of the Captain wedge indicated high soil strength values throughout the entire profile (Fig. 6) These scraper built soils lack the macropore network needed to conduct water and to provide avenues for root growth. Soybean yields on the scraper placed root medium were significantly lower than a nearby undisturbed tract in all seven years of the study, whether topsoil was replaced or not. Corn yields were comparable to the undisturbed site in three of the years which can be characterized as low stress years (Table 4).

Figure 4. Scraper haul system replacing soil materials with high axle load on rubber tires results in high strength soils

Table 4. 1979-86 average corn and soybean yields in response to scraper placed topsoil and root media replacement at Captain Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Scraper Topsoil/Scraper Placed Root Media	13 b	33 b
Scraper Placed Root Media only	12 b	38 b
Undisturbed Cisne/Stoy soil	27 a	70 a

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Poor soil physical condition has proven to be the most severe and difficult factor limiting reclamation of many prime farmland soils. Indorante et al. (1981), in a comparison of mined and unmined land in southern Illinois reported that reconstructed mine soils studied had higher bulk densities and they lacked any notable soil structure. Natural improvement in compacted mine soils is a slow process. Thomas and Jansen (1985) studied soil development in eight mine spoils ranging in age from 5 to 64 years by evaluating physical, chemical and micromorphological properties. All eight minesoils showed some evidence of soil development, but depth of structure development ranged from only 1.5 in at the 5 yr old site and 14 in at a 55 yr old site. No evidence of clay translocation attributable to soil development was found. Color and texture pattern changes were determined to be a result of the mixing of materials rather than developmental processes.

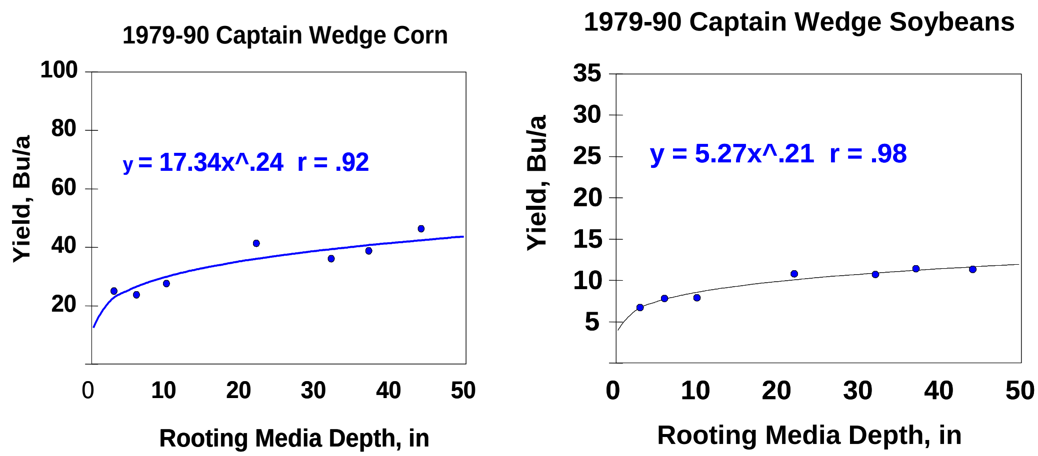

Figure 5. Relationship of scraper placed rooting media wedge and 1979-90 average crop yields

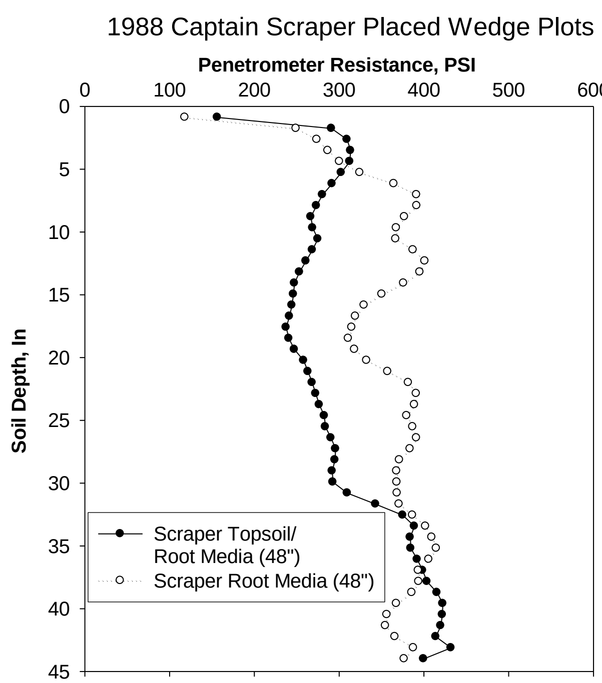

Figure 6. Soil strength profiles of Captain wedge plot treatments

Illinois has an abundance of high quality soil materials for use in soil construction. Row crop success on mine land has been as dependent upon the method by which soil horizons have been replaced as the quality of soil materials selected. Excellent corn and soybean yields have been achieved on low strength soils in high stress as well as low stress years. Soil horizon segregation and replacement in Illinois has generally shown a moderate positive yield response. In most cases , however, the soil physical condition that is established during soil construction is clearly a more significant concern than whether or not materials from the natural soil horizons are replaced (Jansen and Dancer, 1981).

McSweeney and Jansen (1984) studied the soil structure patterns and rooting behavior of corn in constructed soils. On a site that received extensive subsoil grading, the subsoil was severely compacted and massive. Root penetration into these subsoils was primarily horizontal instead of vertical. Cross sections of the roots were noticeably flattened and compressed. The researchers described a "fritted" soil structure they defined as an artificial soil structure consisting of rounded loose aggregates formed by rolling along the soil conveyor, resulting in soil of low strength and high in macropores. Although subject to compaction at the upper surface, the extensive void spaces between aggregates allow for excellent root penetration. Four-year average corn and soybean yields on these plots with well developed fritted structure were equal to or better than yields obtained on nearby natural soils (McSweeney et al., 1987). By contrast, corn and soybean yields from a nearby set of plots with root media replaced entirely by scrapers were unable to produce comparable yields to the undisturbed soil in any of these four years. The rooting materials for both experiments were similar with major differences associated with method of soil replacement

The Captain Mix Plots created using the wheel-conveyor-spreader (Fig. 7) were designed to follow a series of greenhouse experiments which began in 1977. Greenhouse evaluation revealed that alteration of the claypan soils in southern Illinois increased crop growth by enhancing the chemical and physical properties of the reclaimed land. The Captain Mix Plots consist of several treatments that are composed of differents depth mixes of the original soil profile replaced by the conveyor-spreader.

Figure 7. Captain wheel-conveyor- spreader system resulting in low strength soils

Excellent corn and soybean yields have resulted on these low strength soils in high stress as well as low stress years. Penetrometer data from the Mix Plots reflect the excellent physical condition resulting from placing rooting materials with the wheel-conveyor system (Table 5 and Fig. 8). Rowcrop yields comparable to those obtained on nearby undisturbed soils were achieved in all eleven years of this study (Dunker et al., 1992). Topsoil replaced with the soil spreader infrequently produced any significant yield response (Table 6).

Table 5. Mean penetrometer resistance values for soil treatments constructed with wheel-conveyor-spreader on the Captain Mix Plots.

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	36-44" Depth PSI
Topsoil/3' Mix	179 abc	97 d	77 b	98 b
Topsoil/10' Mix	183 ab	136 bc	91 b	96 b
Topsoil/15' Mix	210 a	161 ab	125 a	111 ab
Topsoil/20' Mix	219 a	176 a	117 a	108 ab
10' Mix	135 c	103 b	100 ab	170 a
20' Mix	121 c	110 cd	101 ab	112 ab

Values followed by the same letter within a column are not significantly different at the P≤0.05 level.

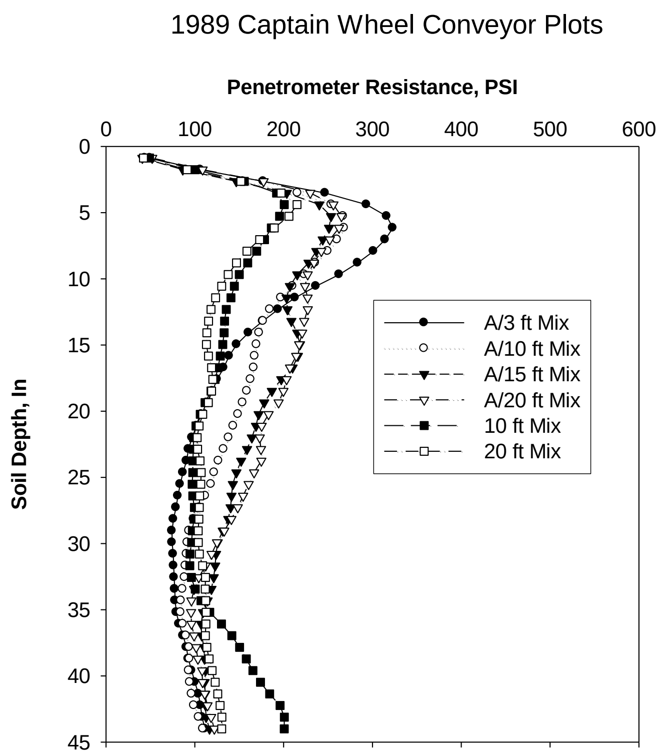

Figure 8. Soil strength profiles of Captain wheel-conveyor mix plots

Although the mining wheel-conveyor-spreader system proved successful in constructing productive soils after surface mining, it does not offer a generally applicable solution to the problem of restoring land to agricultural productivity after mining. The method is an inflexible system and cannot be used at most mines. Evident options are to develop a method by which excessively compacted soils can be ameliorated to a significant depth or to develop other material handling options which will produce soils with good physical characteristics. Natural soil improvement processes are slow, especially at greater depths, as is evident from the 10-year corn and soybean yields observed on the wedge and mix plots (Fig. 9). Year to year variation is associated more with weather stress and management factors than from any measurable natural soil improvement.

Table 6. 1981-91 average corn and soybean yields in response to soil treatments constructed with wheel-conveyor-spreader at Captain Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Topsoil/3’ Mix	29 a	113 a
Topsoil/10’ Mix	27 ab	109 a
Topsoil/15’ Mix	27 ab	111 a
Topsoil/20’ Mix	27 ab	98 b
10’ Mix	24 b	100 b
20’ Mix	25 ab	102 b
Undisturbed Cisne/Stoy soil	27 ab	112 a

Values followed by the same letter within a column are not significantly different at the P≤0.05 level.

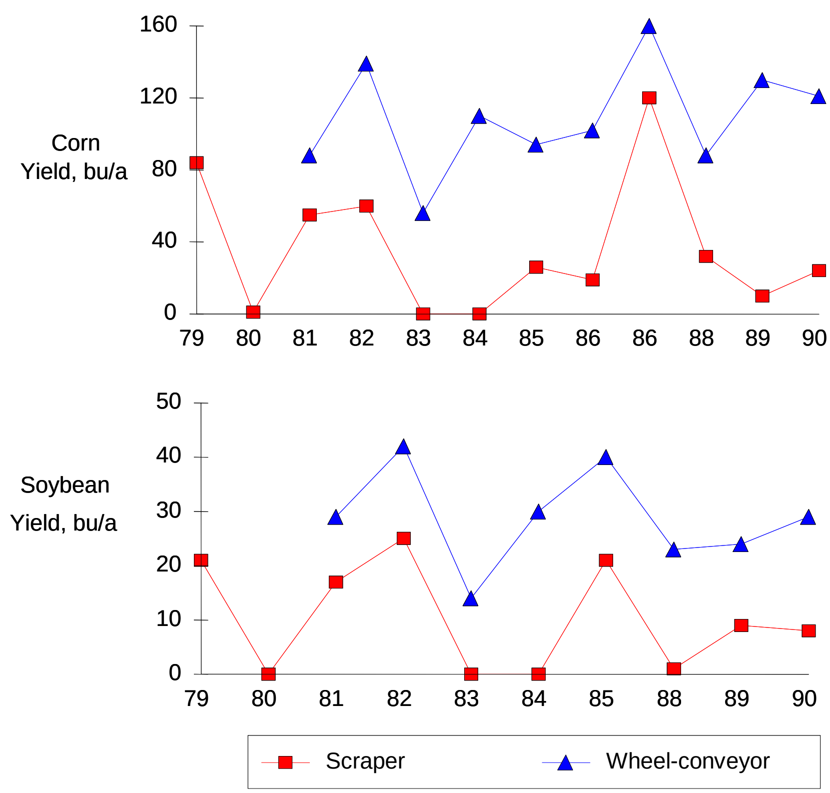

Figure 9. Comparison of corn and soybean yields on root media placed by wheel- conveyor system (TS/3’ Mix) and nearby scraper placed root media

As an alternative to the wheel-conveyor system, corn and soybean response to mine soil construction with rear-dump trucks and scraper pans were studied from 1985-91 at Denmark Mine in southern Illinois (Hooks et al., 1992). Two truck-hauled treatments, one which limited truck traffic to the spoil base only(TNT), and one which allowed truck traffic on the rooting media as it was placed (TWT), were evaluated (Fig. 10).

Figure 10. Rear dump trucks replacing root media with traffic on media (TWT)

A third treatment consisted of scraper hauled rooting media (SCR). The rooting media was comprised primarily of the B horizon of the natural unmined soil and all treatments had 8" of topsoil replaced on the rooting media using dozers to prevent wheel traffic compaction. Significant differences in soil strength, a measure of soil compaction, and rowcrop yields were observed among treatments over the five-year period. The lowest soil strength and highest rowcrop yields occurred on the treatment without truck traffic. Soil strength and yield response were similar for the truck with surface traffic and the scraper treatment (Table 7 and Table 8). Soil strength profiles are shown in Fig. 11. Aerial photo of corn and soybean plots show effects of each treatment on vegetative growth (Fig. 12).

Table 7. Mean penetrometer resistance values for soil treatments on the Denmark Plots.

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	36-44" Depth PSI
Truck Placed Root Media w/o Traffic	182 b	189 b	161 b	172 b
Truck Placed Root Media with Traffic	223 ab	227 ab	213 ab	217 ab
Scraper Placed Root Media	272 a	275 a	258 a	258 a

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Table 8. 1985-91 average corn and soybean yields in response to rear-dump truck placed and scraper placed root media at Denmark Mine in southern Illinois.

Treatment	Soybeans bu/ac	Corn bu/ac
Truck Placed Root Media w/o Traffic	20 b	99 a
Truck Placed Root Media with Traffic	16 c	71 b
Scraper Placed Root Media	16 c	63 b
Undisturbed Cisne/Stoy soil	26 a	103 a

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

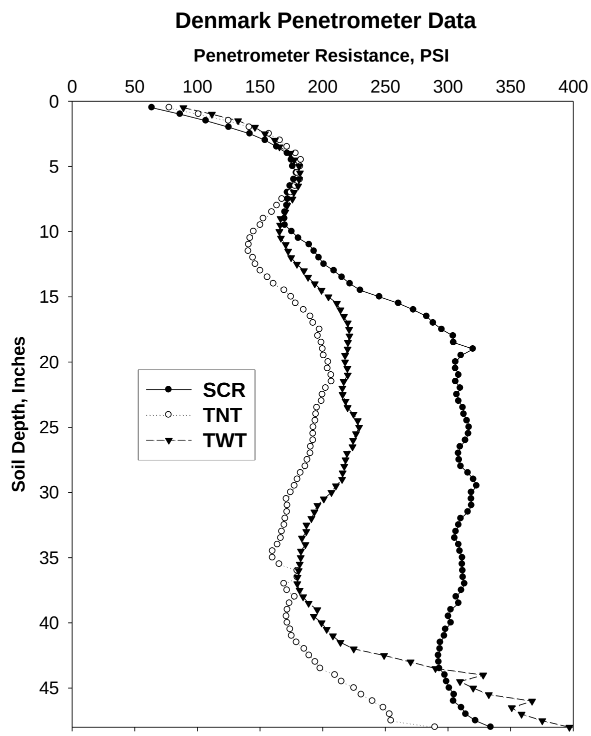

Figure 11. Soil strength profiles of Denmark treatments

Severe compaction and compacted interfaces between soil layers have proven to be major problems which limit productivity of most reclaimed soils. A truck handling system which handles both topsoil and subsoil in one operation was evaluated at Cedar Creek Mine in western Illinois from 1992-94. During plot construction, each rear-dump truck was loaded with the equivalent of 36 in of subsoil and 12 in of topsoil on top of the load (Fig. 13). Subsoil and topsoil were dumped by the trucks in one operation eliminating the need for topsoil replacement by scapers. Some mixing of the topsoil and subsoil occurred but the majority of topsoil remained at the soil surface. Thin lenses of topsoil extended into the subsoil material. These lenses could actually encourage root exploration into the subsoil below.

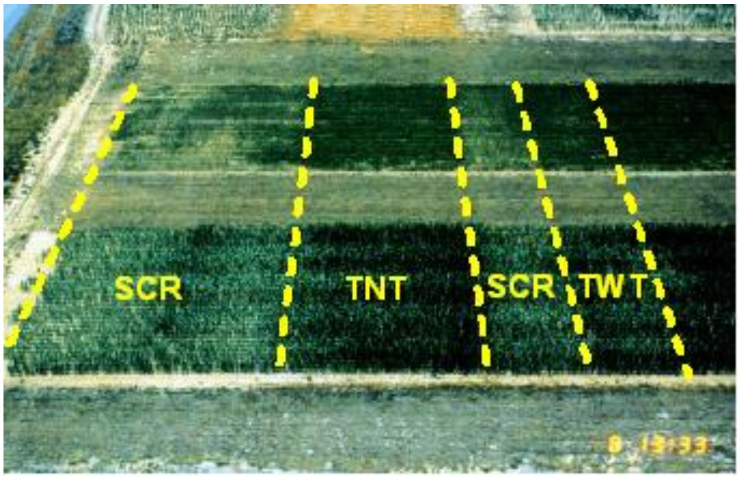

Figure 12. Aerial photo of Denmark plots showing vegetative growth differences of corn and soybean among treatments.

Figure 13. Rear-dump truck loaded and placing the equivalent of 36 in of subsoil and 12 in of topsoil on top of the load in one operation

Two other treatments, one being rear-dump truck placed subsoil with scraper placed topsoil and the other rear-dump truck placed subsoil without topsoil were included in the evaluation. Penetrometer resistance data collected in 1994 (Fig. 14) indicated that wheel traffic from the use of scrapers to replace topsoil had a negative impact on the underlying placed subsoil. Soil strength values increased due to scraper traffic by 82% over that of the rear-dump system. 1992-94 mean yields indicate the system using rear-dump trucks to simultaneously replace both rooting media and topsoil is superior to using scrapers to replace topsoil over hauled rooting media. Results also show a significant response to topsoil replacement using this system (Table 9). On a nearby tract a mixture of the topsoil and root media combined was included in the comparisons.

Cedar Creek, May 1994

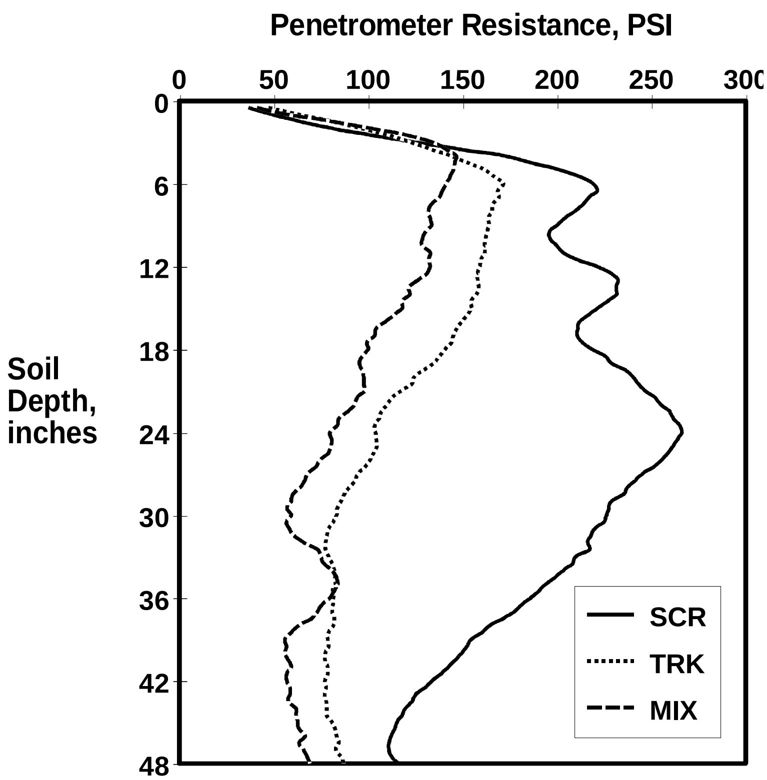

Figure 14. Soil strength profiles of Cedar Creek truck plot treatments

Table 9. 1992-94 average corn yields in response to rear-dump truck placed root media and topsoil and scraper placed topsoil at Cedar Creek Mine in western Illinois.

Treatment	Corn bu/ac
Truck Placed Root Media with Topsoil	159 a
Scraper Placed Topsoil over Truck Placed Root Media	131 b
Truck Placed Root Media w/o Topsoil	130 b

Values followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Thompson et al. (1987) used root length and root length densities to evaluate bulk densities and soil strength values as indicators of root system performance. Because root restriction is generally the factor most important in limiting crop performance in mine soils, determining the suitability of soils for root system development could be a useful method of evaluating reclaimed soils. Soil strength was evaluated with the use of a constant rate recording cone penetrometer developed by Hooks and Jansen (1986). Results indicate that both penetrometer resistance and bulk density are useful methods to predict root system performance in soils. They are especially useful in predicting root extension into deeper depths of the root zone. Penetrometer resistance and bulk density were highly correlated in the lower root zone, but poorly correlated nearer the soil surface.

Penetrometer data have proven useful for evaluating the soil strength effects of several reconstruction methods, of high traffic lanes on reclaimed areas and of tillage methods for alleviating compaction (Vance et al., 1992). Soil strength values decreased with decreasing traffic. Scraper soil material handling methods produced the highest soil strengths, soils from truck-haul systems were intermediate, and soils built by a wheel-conveyor-spreader system had the lowest soil strength. Penetrometer measurements have resulted in wide ranging values between reclamation treatments and corresponding wide ranging values in crop yield. Correlation of penetrometer resistance with crop yield has been good. Average soil strength over the 9-44 inch profile depth was highly correlated with five-year mean yields across reclamation treatments (Table 10).

Table 10. Linear correlations between logarithmic transformation of six-year mean yields and penetrometer resistance values from four reclamation treatments in Illinois (Vance et al., 1992).

Soil Depth Segment	Crop: Corn	Crop: Soybeans
	Correlation Coefficient (r^2)	
9-18 in	-0.97*	-0.91†
18-27 in	-0.96*	-0.99**
27-36 in	-0.96*	-0.99**
36-44 in	-0.96*	-0.99**
Avg 9-44	-0.98*	-0.99**

†, *, **, Statistically significant at the 0.10, 0.05, and 0.01 levels of probability respectively.

Soil strength measurement with the deep profile penetrometer is a viable method for assessing long term yield potential of mined land when chemical and plant nutritional variables are not yield limiting factors. While yield variation among years is associated more closely to weather variables than soil factors, soil strength appears to be closely correlated to mean yields averaged over multiple years (Fig. 15).

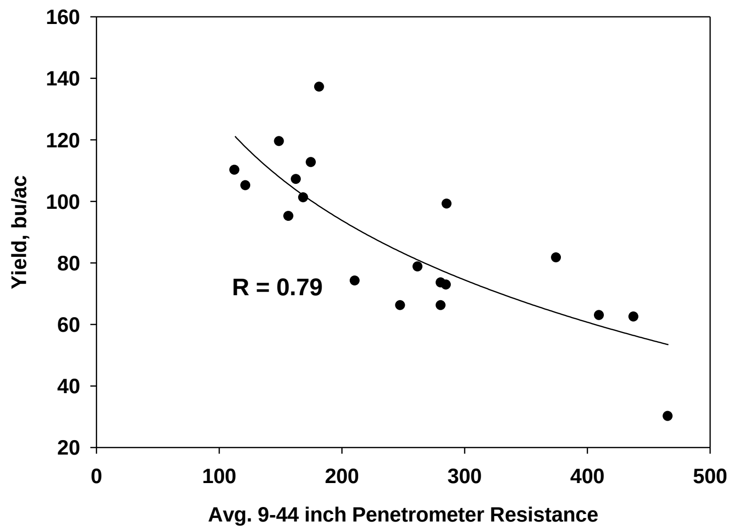

Figure 15. Relationship of 9-44" average soil strength and corn yield of mine soils Data set consist of data from topsoil replaced treatments of five mine sites with a minimum of five years of yield data..

The penetrometer can also be an important management tool for the mine operator to assess levels of soil compaction so it can be determined if deep tillage will be needed as well as to evaluate the effectiveness of such deep tillage operations (Dunker et al., 1994). An example of differences in soil strength as a result of moving topsoil with a cross-pit wheel to create topsoil stockpiles on the graded rooting media is illustrated in Fig. 16. This mine had previously used a scraper haul system to transport and replace topsoil, but unacceptable compaction resulted. This new approach eliminated the wheel traffic from scrapers by allowing use of low-ground-pressure dozers to push topsoil from the stockpiles created by the cross-pit wheel. The operator concerned about the effects of the size of the topsoil stockpliles on the graded rooting media used the cone penetrometer with a gridded sampling pattern to assess soil strength with depth to evaluate the effect of this reclamation method. Penetrometer data provided the operator information to determine where compaction problems occurred and to make decisions on the number and size of topsoil stockpiles to be placed in the reclaimed area.

From an engineering or physical approach, soil strength is a parameter that could be predicted based on density, texture and moisture conditions of the soil. In the reclamation studies reported by Illinois researchers, soil strength is considered as a relative composite value. Moisture content is a major factor controlling penetromter values when soils are drier than field capacity. Data collected in the spring, when soils are uniformly moist, and when minor differences in soil moisture occur between adjacent treatments are more likely to be correlated with yield. Such measurements under the same cropping system are considered to be a reflection of the soil x environment interaction and a valid part of the composite-value soil strength. Penetrometer data are also reproducible over time, as reported by Dunker et al. (1994). Fig. 17 shows the effects of two different deep-tillage treatments, TLG (32 in) and DM1 (48 in), over a five-year sampling period. These curves demonstrate both the repeatability of penetromter data and the ability to assess effective depth of tillage operations.

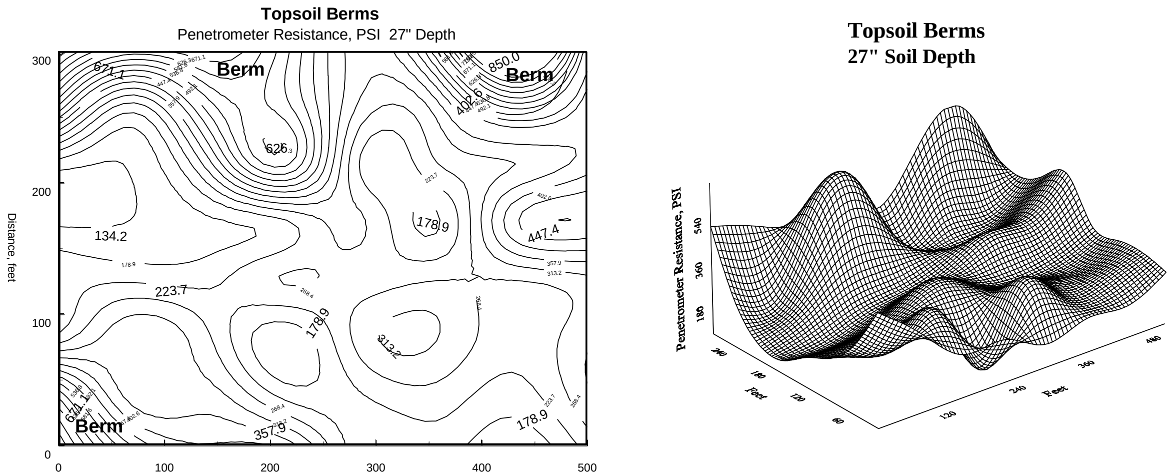

Figure 16. Gridded contour plots (two dimensional and three dimensional contour) showing effects of topsoil berms on soil strength (PSI) at 18 to 27 inch soil depth

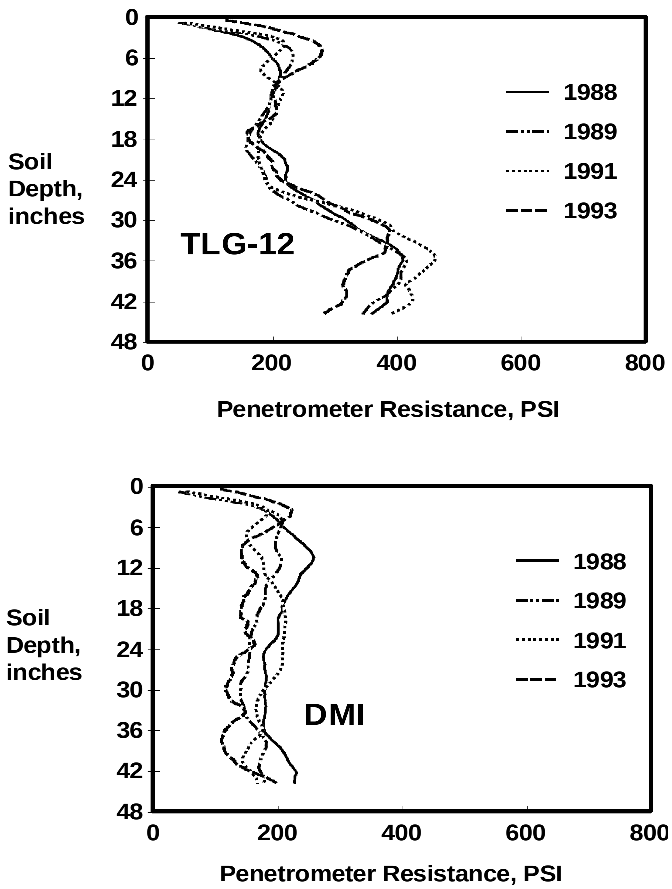

Figure 17. Results of penetrometer data taken over a 5-year period evaluating tillage effects. The TLG-12 is a tillage tool that works to a 32 in depth, DMI deep plow works to a depth of 48 in.

Ameiliorating Compaction with Tillage

The effect of using a deep soil loosener (Kaeble-Gmeinder TLG-12) on corn grown on wheel spoil was evaluated over a two-year (1985-86) period at Norris Mine in western Illinois (Dunker et al., 1989). The TLG-12 has an effective tillage depth of approximately 32 in and was successful in significantly lowering penetrometer resistance in both the 9-18 in and 18-27 in depth segments when compared to the unripped wheel spoil treatments. Corn yields increased significantly with the TLG-12 treatment in both years, although the magnitude of response was greater in 1985, a year of greater climatic stress. Significant differences for pollination dates, percent barren stalks, shelling percentage, and soil moisture potential levels at certain depths were observed between the ripped and non-ripped treatments. Two-year average corn yields for both topsoil/wheel spoil and wheel spoil without topsoil were comparable to corn yields from a nearby undisturbed Sable (fine-silty, mixed, mesic Typic Haplaquolls) soil while two-year non-ripped mine soil yields were not (Figure 18).

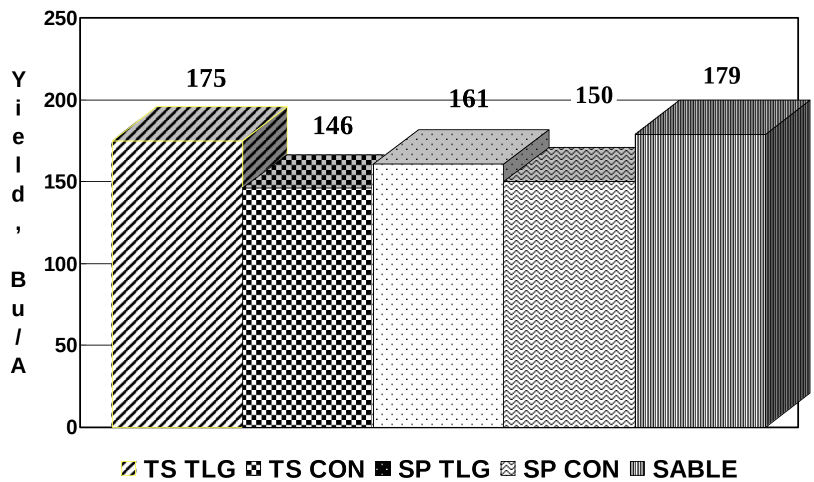

Figure 18. Two-year corn yield means for TLG (32 in Tillage) and conventional (9 in tillage) for topsoil and non-topsoiled wheel spoil plots at Norris Mine.

The effects of seven tillage treatments (Fig. 19) ranging in depth from 9 to 48 in) were evaluated on a reclaimed mine soil over a 6-year period in southern Illinois (Dunker et al., 1995). The mine soil consisted of 8 in of topsoil replaced over 42 in of scraper-placed rooting media. The pre-tillage physical condition of this mine soil was compact and massive. A nearby tract of Cisne silt loam (fine, montmorillonitic, mesic Mollic Albaqualfs) was used as an unmined comparison. Crop yields for both corn and soybeans significantly increased with tillage depth. Average soil strength decreased and net water extraction by the growing crop increased with increasing depth of tillage. The 42 in deep tillage treatments with the DMI deep plow significantly reduced soil strength (9-44 in avg.) from 2.8 to 0.93 Mpa. Significant correlation (alpha=0.01) occurred between 9-44 in mean soil strength and 6-year mean corn (-0.92) and 4-year mean soybean (-0.92) yields.

Figure 19. Burning Star deep tillage treatments

Fig. 20 shows regression equations of penetrometer levels and mean yields for tillage treatments. Deep tillage successfully restored productivity. However, the depth of tillage required to meet productivity levels was influenced by initial level of soil strength. Tillage significantly affected crop yield and measured agronomic variables, such as barren plants, shelling percentage, average ear weight, and average test weight in grain. Corn and soybean yields increased with increasing tillage depth within and across the six-year period (Fig. 21). Crop yields comparable to the undisturbed Cisne soil were achieved on the deepest tilled treatments (48 in depth) in 5 of the 6 years that corn was tested and 4 of the 4 years that soybeans were tested. Post-tillage penetrometer data indicate that amelioration effects of tillage persisted, and significant positive yield effects of deep tillage were observed after 7 years, the conclusion of the study (Fig. 22). However, because deep-tilled soils may be subject to mechanical recompaction, management plans must include compaction-avoidance techniques.

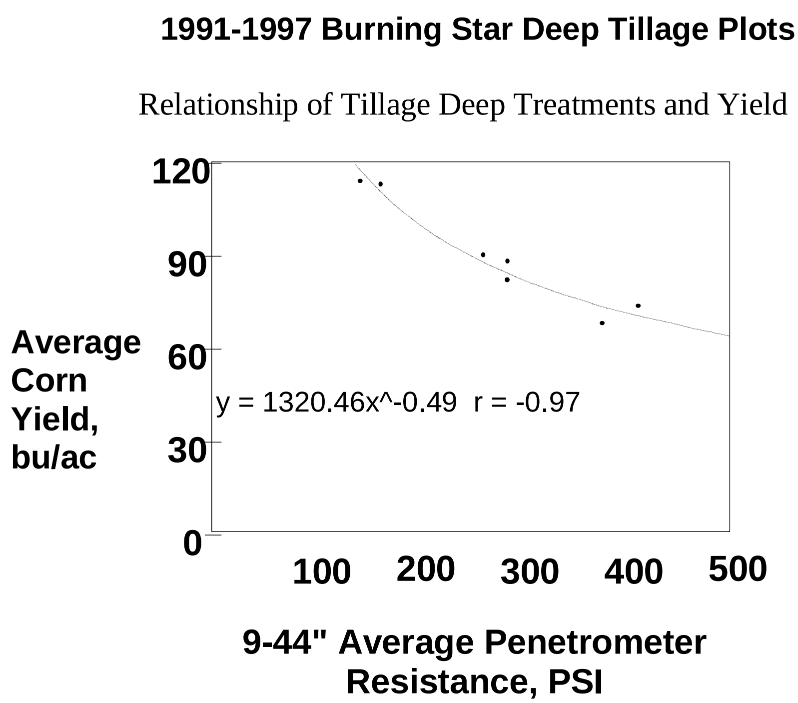

Figure 20. Relationship of 1991-97 mean corn yields and soil strength at Burning Star 2 deep tillage plots

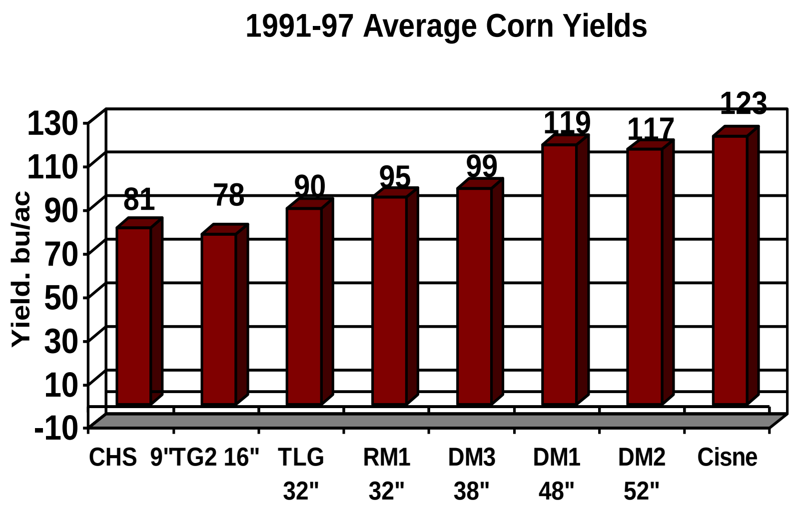

Figure 21. 1991-1997 average corn yields on Burning Star 2 deep tillage plots

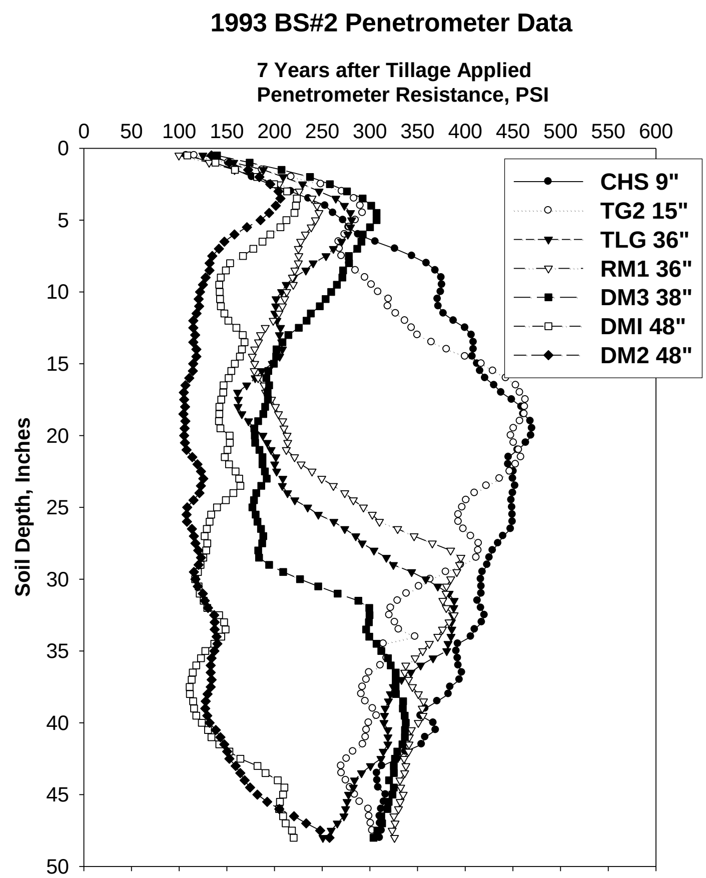

Figure 22. Soil strength profiles of Burning Star 2 tillage treatments seven years after application

Summary- Constructing Productive Post-Mine Cropland Soils

In summary, results from the Illinois work shows that achieving mine land productivity is attainable if reclamation plans are designed to minimize compaction, use good quality soil materials and use high management levels (herbicides, fertility, adapted crop varieties) in rowcrop production. Illinois has an abundance of high quality materials to use for soil construction and row crop success on mined land has been dependent upon the method by which soil horizons have been replaced and the quality of the materials selected. Excellent corn and soybean yields have been achieved on low strength soils in high stress as well as low stress years. However crop failures have occurred when reclamation methods result in mine soils with high soil strength. Truck handling of rooting media with limited surface traffic has resulted in a more productive and less compacted soil compared to a high traffic scraper haul system for replacing root media.

Building productive and useful postmine cropland requires planning, innovation, and commitment to succeed. Jansen and Hooks (1988) discuss the following concepts for successful cropland soil reclamation.

Design.

Construction of productive post-mine soils should be done by developing and following a definite design. The design could be patterned after the premine soils on the site to be mined, and in many instances that is appropriate. A better practice, however, is to develop an ideal design patterned after the best natural soils for the crops to be grown. It will not be possible to duplicate any natural soil (McCormack, 1974). Though the ideal soil cannot be matched, it will serve as a useful guide for selecting materials, for placing them in the new soil, and for evaluating the finished product.

Selecting Suitable Materials.

The A and B horizons of the premine soil will often be the best available material with which to construct a new soil. There will be, however, locations where material from some horizons in the premine soil is less favorable for construction of a new soil than is material from a deeper strata in the geologic column. The various layers in the geologic column at each site should be evaluated to determine which are best for soil construction. Some sites have a surplus of excellent quality soil building materials available, whereas the quantity of good material will be inadequate at other sites.

The top 5 ft of the new soils should be constructed of medium textured materials (silt loams, loams, or light silty-clay loams). Coarse fragments (gravel and rock) should be absent or make up only a small portion of the total soil volume. Medium textured soils that are low in coarse fragments generally have the highest capacity to store available water for plants. High water storage capacity is most crucial in climates where dry periods during the growing season are common. Clays are active in storage and release of plant nutrients and hence important, but soils that are too high in clay commonly have poor tilth, low hydraulic conductivity, and poor aeration.

The soil pH should be near neutral or slightly acid for most crops (midwest). Base saturation should be high, and monovalent ions such as sodium should be low enough in relation to calcium or magnesium on the exchange complex so that clays will flocculate. The soil should be rich in weatherable minerals. Elements essential to plant and animal life should be present in adequate quantities. Materials that are toxic to plant or animal life, or that release toxic materials upon weathering, should be absent.

Soil organic matter stabilizes soil structure, improves tilth, and is active in storing and releasing plant nutrients. It is particularly important in the plow layer because that is where the seedbed must be prepared and where many of the plant nutrients will be stored. Soils that are low in organic matter are more prone to sealing, and crusting than similar soils high in organic matter. The infiltration rate is lower on low organic matter soils causing high runoff and high erodibility.

Microbial life in the soil plays an important role in plant growth. Generally an abundance of desirable microbes can be obtained only from the premine soils. Deeper geologic strata are not a good source. A desirable microbial population can be established quite rapidly, however, if the chemical and physical environment is favorable.

Soil structure is important for soil tilth, aeration, water movement, and water storage. Only the material from the premine soil will have desirable soil structure. Soil structure should be considered when selecting materials for the new soil only if the material can be moved without destroying that structure. Soil structure will very slowly develop in the new soil, even if absent immediately after soil construction.

Moving Materials and Constructing the Soil.

The means used to move overburden must be capable of segregating the selected materials and placing them at the appropriate level in a new soil while preserving soil structure or establishing a favorable density or soil strength. The only alternative to intensive grading is to have control over material placement by equipment used to move overburden, so that only minimal grading will be needed. Another option is to use deep tillage after final grading to alleviate compaction and create a favorable structure. Deep tillage has been shown to be effective in returning productivity of compacted mine soils.

There is no simple formula for reconstructing soils that can be applied to all lands to be mined. Soils are complex entities and soil needs vary with climate, land use, and management systems. Each site will have a unique set of materials available with which to construct a soil. Characteristics that are usually desirable in cropland soils can be described, but the final detailed planning will need to be done separately for each site. Technology has been developed to insure that cropland, both prime and non-prime, can be successfully reclaimed.

Literature Cited

Dancer W. S. and I. J. Jansen. 1981. Greenhouse evaluation of solum and substratum materials in the southern Illinois coal field. I. Forage crops. Journal of Environmental Quality. 10:396-400.http://dx.doi.org/10.2134/jeq1981.00472425001000030031x.

Dunker, R. E. and I. J. Jansen. 1987a. Corn and soybean response to topsoil replacement and irrigation on surface-mined land in western Illinois. J. Soil and Water Cons. 42:277-281.

Dunker, R. E. and I. J. Jansen. 1987b. Corn and soybean response to topsoil and rooting medium replacement after surface miming. Proceedings, National Symposium on Mining, Hydrology, Sedimentology and Reclamation. Springfield, Illinois. December 6-11, 1987. Pp 83-89.

Dunker, R. E., I. J. Jansen, and W. L. Pedersen. 1988. Corn hybrid responses to reconstructed mine soils in western Illinois. Agron. J. 80:403-410. http://dx.doi.org/10.2134/agronj1988.00021962008000030005x.

Dunker, R. E., C. L. Hooks, S. L. Vance and R. G. Darmody. 1992. Rowcrop resonse to high traffic vs low traffic soil reconstruction systems. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 11-18.

Dunker, R.E., S.L. Vance, C.L. Hooks, and R.G. Darmody. 1994. Use of cone penetrometer data to evaluate prime farmland rooting media. Proc. International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acid Drainage. April 24-29, 1994, Pittsburgh, PA. pp. 38-46.
https://doi.org/10.21000/JASMR94030038
Dunker, R.E., C.L. Hooks, S.L. Vance, and R.G. Darmody. 1995. Deep tillage effects on compacted surface-mined land. Soil Sci. Soc. Am. J. 59:192-199. http://dx.doi.org/10.2136/sssaj1995.03615995005900010029x9.

Fehrenbacher, D. J., I. J. Jansen and J. B. Fehrenbacher. 1982. Corn root development in constructed soils on surface mined land in western Illinois. Soil Sci. Soc. Am. J. 46:353-359. http://dx.doi.org/10.2136/sssaj1982.03615995004600020028x.

Hooks, C. L. and I. J. Jansen. 1986. Recording penetrometer developed in reclamation research. Soil Sci. Soc. Am. J. 50:10-12. http://dx.doi.org/10.2136/sssaj1986.03615995005000010002x.

Hooks, C. L., R. E. Dunker, S. L. Vance, and R. G. Darmody. 1992. Rowcrop response to truck and scraper hauled root media systems in reconstruction of surface mine soils. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 19-24.

Indorante, S. J., I. J. Jansen, and C. W. Boast. 1981. Surface mining and reclamation: Initial changes in soil character. J. Soil and Water Conserv. 36:347-351.

Jansen, I. J., and W. S. Dancer. 1981. Row crop response to soil horizon replacement after surface mining. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, Lexington, Kentucky. Dec 7-11, 1981.

Jansen, I. J., R. E. Dunker, C. W. Boast, and C. L. Hooks. 1985. Rowcrop yield response to soil horizon replacement. Symposium on Reclamation of Lands Disturbed by Surface Mining: A

Cornerstone for Communication and Understanding. Science Reviews Limited. Middlesex, England. Pp. 410-430.

McSweeney, K., I. J. Jansen and W. S. Dancer. 1981. Subsurface horizon blending: An alternative strategy to B horizon replacement for the construction of post-minesoils. Soil Sci. Soc. Am. J. 45:795-799. http://dx.doi.org/10.2136/sssaj1981.03615995004500040024x.

McSweeney, K. and I. J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. Soil Sci. Soc. Am. J. 48:607-612. http://dx.doi.org/10.2136/sssaj1984.03615995004800030028x.

McSweeney, K., I. J. Jansen, C. W. Boast, and R. E. Dunker. 1987. Row crop productivity of eight constructed minesoils. Reclamation and Revegetation Research. 6:137-144.

Meyer, J. J. 1983. Corn root behavior in soils constructed after surface mining for coal in southern Illinois. Unpubl. M.S. Thesis, Univ. of Ill., Urbana, Illinois.

Public Law 95-87. 1977. Surface Mining Control and Reclamation Act. U. S. Code Vol. 30, Sec 1265.

Snarski, R. R., J. B. Fehrenbacher, and I. J. Jansen. 1981. Physical and chemical characteristics of pre-mine soils and post-mine soil mixtures in Illinois. Soil Sci. Soc. Am. J. 45:806-812 http://dx.doi.org/10.2136/sssaj1981.03615995004500040027x

Thomas, D. and I. J. Jansen. 1985. Soil development in mine spoils. J. Soil and Water Conserv. 40:439-442.

Thompson, P. J., I. J. Jansen, and C. L. Hooks. 1987. Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. Am. J. 51:1288-1293. http://dx.doi.org/10.2136/sssaj1987.03615995005100050035x.

Vance, S. L., R. E. Dunker, C. L. Hooks, and R. G. Darmody. 1992. Relationship of soil strength and rowcrop yields on reconstructed surface mine soils. Proceedings, 1992 National Symposium on Prime Farmland Reclamation, University of Illinois, Urbana, IL, August 10-14, 1992. Pp 35-42.