CORN RESPONSE TO DEEP TILLAGE ON SURFACE-MINED PRIME FARMLAND[1]

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Abstract. The effect of using a deep ripper (Kaeble-Gmeinder TLG-12) to corn grown on reconstructed mine soils was evaluated at Consolidation Coal Company's Norris Mine in west central Illinois during the 1985-86 time period. Two mine soils, one being 45 cm of topsoil replaced over graded wheel spoil and the other being wheel spoil only, were evaluated with and without the TLG-12 treatment. A nearby tract of Sable soil (Typic Haplaquoll) was used as an unmined comparison. The use of the TLG-12 which has an effective depth of approximately 75 cm was successful in significantly lowering penetrometer resistance in the 23-45 cm and 45-69 cm sample segments as compared to the unripped treatments in both mine soils. Corn yield response to the TLG-12 was significant in both 1985 and 1986, although the magnitude of response was greater in 1985, a year of higher climatic stress. Significant differences for pollination dates, % barren stalks, shelling %, and soil moisture tension levels at certain depths were observed between the ripped and unripped treatments. Corn yields averaged over the two year period for both the topsoil and wheel spoil treatment with TLG-12 were comparable to yields produced on the unmined Sable soil, while the two year non-ripped mine soils were not. No yield response to topsoil replacement occurred for either tillage treatment in either 1985 or 1986. Corn yields were significantly correlated with soil strength levels at the 23-69 segment depths.

Introduction

Soil compaction has been identified as one of the chief limiting factors in achieving post mine productivity for mine soils in Illinois. The degree and depth of compaction in mine soils varies with the reclamation practice used in reconstruction (Vance et al. 1987). McSweeney and Jansen (1984) found that mine soils constructed with a bucket wheel excavator-conveyor-spreader system resulted in a desirable fritted structure which is fairly loose and contains a network of voids favorable for water movement and root growth. Excellent corn and soybean yields have been achieved on these low strength soils in high stress as well as low stress years (McSweeney et al. 1987). Mine soils constructed with rubber tired scrapers and requiring extensive grading yielded poorly in low to moderate stress years, even though the rooting medium materials of the two methods were similar. Root penetration into the scraper placed materials was extensively horizontal instead of the normal vertical direction.

Soil strength and bulk density of graded wheel spoil from a cross pit bucket wheel excavator has been found to be at a level between those of the conveyor-spreader system and a scraper haul system (Thompson et al. 1987; Vance et al. 1987). Cross pit wheels were used extensively in the Illinois coal belt, and while they handle rooting materials more gently than a scraper system, the common practice has been to use scrapers to replace topsoil over the graded wheel spoil. Compaction

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created during topsoil replacement by scrapers has resulted in lower yields and increased sensitivity of row crops to weather stress (Dunker et al. 1982). The objective of this study was to evaluate corn response on wheel spoil mine soils with and without deep tillage and the effects of replacing topsoil with scrapers.

Study Area and Methods

The experiment was conducted at the Consolidation Coal Company's Norris Mine located in Fulton County in west-central Illinois. The plot area was constructed in the fall of 1978 under favorable moisture conditions and maintained in forage-legumes until 1983 when corn was planted in a preliminary study. The predominate pre-mine soils of this area are in the Sable-Ipava soil association (Aquolls and Udolls), which are highly productive, dark colored soils developed in deep loess under prairie vegetation. They are characterized by having thick A horizons relatively high in organic matter, a desirable medium textured B horizon, and an underlying C horizon favorable for plant growth (Fehrenbacher et al. 1977). In the surface mining operation, the topsoil (A horizon) was segregated from the remaining profile by scrapers for later replacement after final grading. A bucket wheel excavator removed the remaining unconsolidated material and transported it across the pit. The graded resultant material is referred to as wheel spoil.

Two constructed soils, one with 45 cm of topsoil replaced by scrapers over wheel spoil and one soil consisting of graded wheel spoil only were studied. Both soils are Typic Udorthents. The wheel spoil at the Norris site consists of a mixture of leached loess, calacareous loess, calcareous glacial till, and some soft shale fragments. An undisturbed tract of Sable silty clay loam located 0.4 km away was used as an unmined comparison. Table 1 shows soil test results for surface samples (20 cm depth) from these plots taken in November 1984 for the topsoil, wheel spoil and Sable soil.

In August, 1984, under dry soil moisture conditions the Kaeble-Gmeinder TLG-12 was used as a deep tillage treatment. The TLG-12, which was developed in West Germany, utilizes a shank and moving foot to cut and lift to a depth of 76 cm. Three shanks are spaced at 81 cm and

Table 1. Soil test results for surface samples (20 cm depth) from Norris plots, November 1984.

Soil Trt	pH	P1	Olsen	K
		-----------kg/ha	-----------	
Wheel Spoil	7.6	30	41	205
Topsoil	5.5	46	46	378
Sable Soil	5.7	120	98	403

operated by auxillary hydraulics. The TLG-12 was mounted on a 750 John Deere tractor and has a productivity of 1 to 1.2 acres/ hour depending on soil conditions.

Corn (*Zea mays* L.) was planted on May 20 in 1985 and May 13 in 1986 at a rate of 64,220 seeds ha^{-1} with rows spaced 76 cm apart. The hybrid used was Mo17 x B73. Management practices were similar to what would be followed by a typical central Illinois farming operation. Fertilizer was applied in a dry form (268 kg N ha^{-1}; 134 kg P ha^{-1}; 134 kg K ha^{-1}) and incorporated before planting. The herbicides atrazine and metolachlor at 2.3 L ha^{-1} and 2.6 L ha^{-1}, respectively, were preplant incorporated and resulted in excellent weed control. To control rootworm (*Diabrotica* spp) the insecticides carbofuran in 1985 and chloropyrifos in 1986 were applied through the seedbox applicator.

Dates on which 50% of the plants of a plot had silked and shed pollen were recorded and converted to days from planting for each plot. Rainfall at the research plots were recorded daily to the nearest 0.25 mm. Tensiometers were installed in each soil treatment to record soil moisture tension levels at the 30, 60, 90, and 120 cm depths twice each week. At harvest, plants per plot, ear number, and ear weight were recorded. This allowed for estimates of barren stalks, ear size, and shelling percentage on a dry weight basis on each soil treatment.

Grain yield samples were hand harvested after black-layer formation indicated physiological maturity. Grain yield estimates were based on the amount of shelled grain after adjusting for variation in moisture content of grain to 155 g kg^{-1}.

Penetrometer measurements were taken with a constant rate recording penetrometer capable of recording soil resistance to penetration to a depth of 112 cm (Hooks and Jansen 1985) to evaluate the loosening effects of the deep tillage and to characterize the non-ripped mine soils. The data was collected in April of 1986 while soils were uniformly moist to minimize the effects of variable soil moisture on penetration resistance.

Because the soil treatment blocks were located on both the mine soil area and a nearby undisturbed tract the following procedure for statistical analysis was followed for agronomic comparisons: (i) Homogeneity of variances was tested for the soil treatment area. (ii) Variances were found to be homogeneous, allowing for an analysis of variance procedure to be used to test for treatment effects. (iii) The variance for the 1985 and 1986 experiments were homogeneous, allowing for a combined years analysis to be used in interpreting responses.

Results and Discussion

Yield and Agronomic Response

Corn yields were consistently higher on the TLG-12 treated plots (Table 2). The TLG-12 effect was significant (0.05 level) over the two year study where topsoil had been replaced. On the wheel spoil, two year corn yields were 684 kg ha^{-1} higher on the TLG-12 treated areas than on the untreated areas, but the effect was not significant at the 0.05 level. Corn yields from mine soils ripped with the TLG-12 were not significantly different from yields on the Sable soil over the two year period, while non-ripped mine soil yields were significantly lower than than the undisturbed site. When averaged over the two year period, no significant response to topsoil replacement occurred for either the TLG-12 ripped or non-ripped treatments.

Weather variables were distinctly different in 1985 than 1986 (Table 3). Temperatures in May, 1985 were warmer than normal promoting rapid early season growth, while cooler than normal temperatures occurred during June, July and August. Rainfall was below normal in June and most of July. Moderate rainfall (24 mm) occurred during the pollination period of 25 July to 4 August. Weather during the growing season of 1986 was characterized by above normal temperatures in May, June, and July as well as well above normal rainfall during the vegetative and reproductive stages in June and July. 1985 could be characterized as a moderate stress year, while 1986 could be characterized as one of relatively little temperature and moisture stress.

Table 2. Mean Corn yields for mined land and Sable soil treatments at Norris mine.

Soil Trt	1985	1986	Mean
		kg/ha	
TS TLG[1]	10346	11733	10968
TS CON	7370	11394	9160
SP TLG	8280	12368	10101
SP CON	8010	11175	9417
SABLE	11068	11545	11238
LSD(0.05)	2423	1098	1406

1/ Soil treatments are as follows: TS TLG, topsoil replaced and TLG deep ripped; TS CON, topsoil replaced and conventional chisel plowed; SP TLG, wheel spoil and TLG deep ripped; SP CON, wheel spoil and conventional chisel plowed; SABLE, undisturbed Sable soil.

Table 3. Precipitation and temperatures for 1985 and 1986 growing seasons at Norris Mine.

Month	Mean Temp.	Depart. of Norm	Total Precip.	Depart. of Norm
	C		cm	
		1985		
MAY	17.9	+1.5	7.9	-1.8
JUN	20.4	-1.3	3.9	-6.0
JUL	23.1	-0.8	6.3	-3.8
AUG	21.2	-1.6	14.6	+4.4
SEP	19.2	+0.9	8.7	-0.5
		1986		
MAY	17.8	+1.5	9.2	-0.5
JUN	22.8	+1.0	16.6	+6.7
JUL	25.4	+1.5	17.2	+7.1
AUG	20.9	-1.9	4.8	-5.4
SEP	21.1	+2.5	15.0	+5.8

Soil moisture tension levels were considerably higher at the 60 and 90 cm depths in 1985 as compared to 1986 (Figure 1). Soil moisture tension levels were beyond the range of tensiometers at the 30 and 60 cm depths by pollination in 1985. Significantly higher soil moisture tension levels at the 90 cm depth the week before pollination (July 24) on the non-ripped topsoil treatment compared to the non-ripped wheel spoil. These differences may have been due to increased demand for water by vegetative growth differences, low hydraulic conductivity, or a combination of both. Lah (1980) measured saturated hydraulic conductivity on soil cores from adjacent plots to be 28.3 cm d^{-1} for the topsoil material and 12.8 cm d^{-1} for the wheel spoil. Very low conductivity values of 7.6 cm d^{-1} were measured from the wheel spoil interface with the topsoil. Plant heights for the topsoil were significantly higher for the topsoil (210 cm) as compared to the wheel spoil (197 cm) indicating a greater demand for water for the topsoil treatment. The TLG-12 treatment had significantly higher soil moisture tension at the 90 cm depth compared to the non-ripped wheel spoil which may indicate deeper rooting.

Measurement of other agronomic variables resulted in significant differences in % barren stalks and pollination date between soil treatments (Table 4). Topsoil replaced plots had a significantly higher rate of barren plants in 1985, a year of higher weather stress, as compared to the wheel spoil only treatment. In earlier studies, Dunker and Jansen (1987) have reported significant negative response to topsoil replaced by scrapers in years of moisture and temperature stress. In 1986, mine soils with the TLG-12 had a higher ratio of ears to plant number. Those plots with deep tillage produced multiple ears while the non-ripped plots had a 3-4 % rate of barren stalks. Plant population at harvest was not significantly different for the topsoil and Sable soil, but both had significantly higher populations than the wheel spoil, indicating a lower seed germination rate for this treatment.

Two year average days after planting to 50 % pollen shed were significantly different for all soil treatments. Both topsoil replacement and tillage affected anthesis date. Topsoil replaced

Table 4. Percentage of barren plants and number of days to 50% pollen shed.

Soil Trt	1985	1986	Mean
		------% barren plants------	
TS TLG	18.5	-1.9	9.4
TS CON	23.8	3.1	14.6
SP TLG	4.1	-11.8	-2.9
SP CON	0.2	4.2	2.0
SABLE	10.5	1.1	6.3
LSD(0.05)	11.7	15.4	9.0
		------pollination, days------	
TS TLG	71.6	74.7	73.1
TS CON	72.8	78.0	75.4
SP TLG	72.8	80.5	76.6
SP CON	74.4	83.2	78.8
SABLE	70.8	75.0	72.0
LSD(0.05)	1.1	1.6	0.9

plots pollinated earlier than those plots without topsoil. Deep tillage also significantly reduced the number of days to pollen shed. These differences are believed to be due to reduced plant stress factors during the vegetative growth period. Seed emergence on the wheel spoil treatment was also generally 1 d later than on the topsoil or Sable. Early season vegetative growth was visibly greater on the topsoil and Sable. Within mine soils, those plots with the TLG-12 treatment also exhibited more vigorous vegetative growth.

Soil Strength

Results from the use of the cone penetrometer show that the TLG-12 was successful in significantly lowering soil strength to a depth of 69 cm (Table 5). Full profile graphics to the 112 cm depth are presented in Figure 2. The penetrometer resistance curve for the non-ripped (No TLG) topsoil/ wheel spoil treatment shows the deleterious effects of replacing topsoil with scrapers. The highest soil strength occurs in the zone directly below the topsoil. The TLG-12 was very effective in alleviating compaction in this zone. Correlation

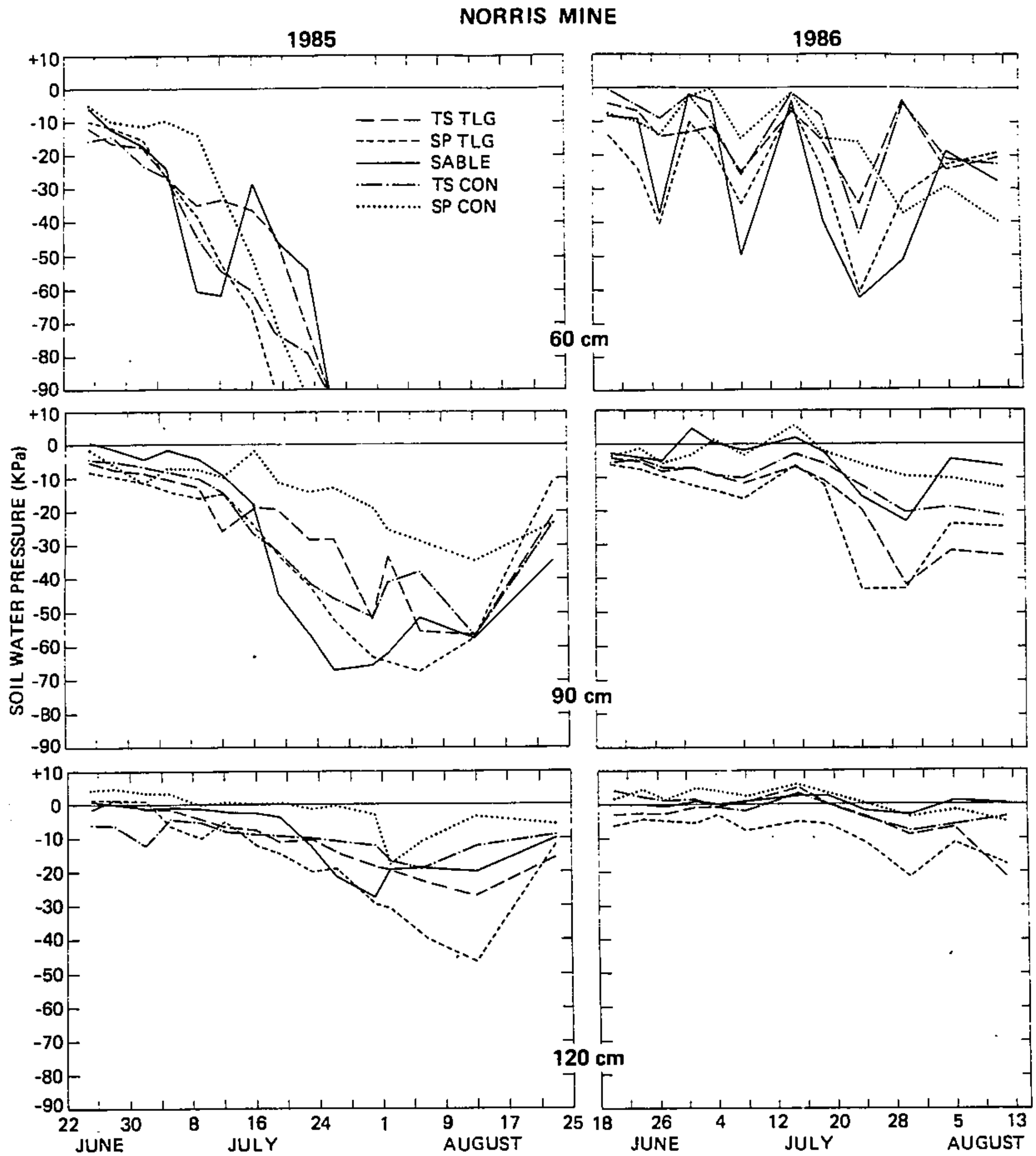

Figure 1. Soil moisture tension curves for 1985 and 1986 growing seasons at Norris Mine.

between mean corn yields for mine soil treatments and mean penetrometer resistance show that soil strength was significantly correlated with yield in the 23-45 cm segment depth at the 0.05 level and in the 45-69 cm segment depth at the 0.10 level of significance (Table 6). Corn yields were significantly correlated with the average soil strength across the 23-69 cm depth.

Table 5. Penetrometer resistance for mined land treatments at Norris Mine, April, 1986.

Soil Trt	23-45	45-69	69-91	91-112
	Segment Depth, cm			
	-------resistance, KPa --------			
TS TLG	799	715	3003	2552
TS CON	1920	3182	2926	2339
SP TLG	1050	1120	1925	2123
SP CON	1871	1966	2363	2461
LSD(0.05)	449	674	1023	1000

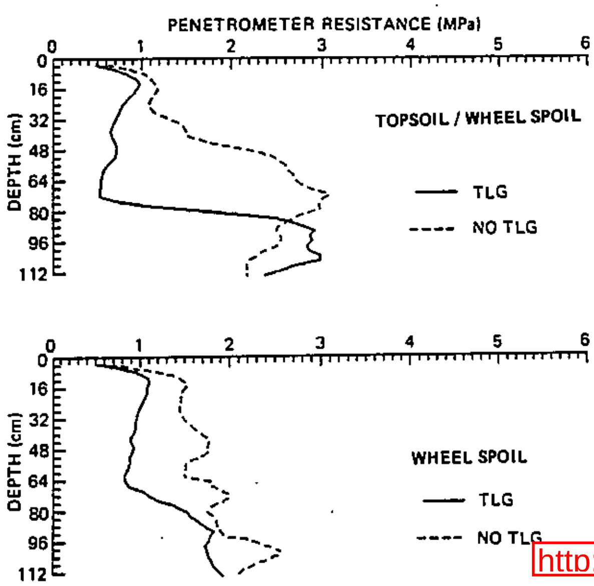

Figure 2. Penetrometer resistance curves for mined land treatments at Norris Mine, April, 1986.

Table 6. Correlations between mean treatment corn yields and mean penetrometer resistance for mine soils.

Segment (depth)	R (N=4)
2 (23-45 cm)	-0.9571 *
3 (45-69 cm)	-0.9036 +
4 (69-91 cm)	0.1424
5 (91-112 cm)	0.2770
Ave 2-3 (23-69 cm)	-0.9537 *

*, Statistically significant at the 0.05 level.
+, Statistically significant at the 0.10 level.

Conclusions

The data analyzed in this study support the following general conclusions: (i) Deep tillage to 76 cm significantly increased corn yields, with and without topsoil replaced; (ii) Soil strength as measured by a recording cone penetrometer was reduced to about the 80 cm depth by the deep tillage treatment; (iii) The deep tillage treatment consistantly advanced the corn pollination date relative to that on untreated plots; (iv) Corn yields on TLG-12 treated mine soils were similar to those on undisturbed Sable soils, whereas yields on untreated mine soils were significantly lower.

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