Reclamation of Surface-Mined Land

Tenth Annual Report, 1987

Agricultural Experiment Station
Department of Agronomy
University of Illinois at Urbana-Champaign

RECLAMATION OF SURFACE MINED LAND

TENTH ANNUAL REPORT TO SPONSORS

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This report supplements previous reports and presents progress through 1986. Some of the included data and interpretations are incomplete or tentative. This is a progress report only and should not be cited in any form.

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ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

RECLAMATION OF SURFACE MINED LAND

I. Introduction:

The major emphasis of this project centers around field experiments that involves growing rowcrops on postmine soils. Research sites vary in the methods of reclamation and how the mine soils were reconstructed. At most sites there are two or more different kinds of postmine soils being rowcropped, some of these soils meet the requirements of both federal and state reclamation laws, others vary from current regulations in order to learn the effect of a wide range of reclamation practices on soil productivity.

II. List of Research Sites, and Objectives at Each:

A. Norris Mine, Consolidation Coal Company, Norris, Illinois.

The Norris Mine, now closed, was a wheel-shovel operation. The post mine soils in the Norris plots consist of graded wheel spoil, with and without A horizon material from the premine soils replaced at the surface. The premine soils were Sable, Ipava, and Tama soils, excellent quality prairie soils developed in Peorian loess. The loess is about 10 feet thick and is underlain by Illinoian glacial till, which as a Sangamon paleosol developed in its top few feet. The wheel spoil consists of a blend of the loess, the Illinoian glacial till., and some of the soft shales. It is commonly silt loam to loam in texture and is slightly acid to calcareous in reaction. The first crop year at Norris was 1979.

Objective at the Norris site include the following:

1) Determine the rowcrop yield potential of reclaimed land, immediate and the trend over time.

2) Measure the rowcrop growth and yield response to A horizon replacement.

   a) Determine whether there is a favorable response and how great that response is.

   b) Determine the relationship between crop performance and the thickness of A horizon material replaced.

   c) Determine the trend over time in response to A horizon replacement.

3) Evaluate the crop growth and yield response to irrigation on post mine soils.

4) Determine the crop growth and yield response to deep tillage designed to alleviate the effects of compaction during soil construction.

5) Determine the relationship between rowcrop yields on reclaimed land and those on nearby undisturbed land.

B. Sunspot, Amax Coal Company, Vermont, Illinois.

The Sunspot Mine is a dragline operation, with the dragline operating from a bench on the consolidated materials. The experimental design at this site compares four different post mine soils constructed as follows: 1) graded cast overburden, rototilled to a 13 inch depth, 2) same as the above, but with 15 inches of A horizon material from the premine soils superimposed, 3) three feet of B horizon material replaced over graded cast overburden, and 4) same as above but with 15 inches of A horizon material superimposed. The fourth soil meets prime farmland standards. A tract of undisturbed land nearby is managed the same as the above disturbed soils to provide a yield comparison. The undisturbed land has Clarksdale and Ipava soils, excellent quality transition and prairie soils developed in Peorian loess. The first crop year at Sunspot was 1979.

Objectives at the Sunspot site include:

1) Determine the rowcrop yield potential of reclaimed land, immediate and trend over time.

2) Determine the effect of B horizon replacement on rowcrop performance.

3) Determine the effect of A horizon replacement, with and without replaced B horizon material, on rowcrop performance.

4) Determine the relationship between crop yields on reclaimed land and those on nearby undisturbed land.

5) Determine the effect of an initial period under forages on subsequent rowcrop yields.

6) Determine the crop growth and yield response to deep tillage designed to alleviate the effects of compaction during soil construction.

C. River King Mine, Peabody Coal Company, Marissa, Illinois.

The disturbed soils at this site consist of graded wheel spoil with and without replaced A horizon material from the premine soils. Those plots having replaced A horizon material should meet prime farmland standards with substitution of wheel spoil for B horizon material. The wheel spoil at this site is a high quality material for soil construction, whereas the B horizons in the natural soils of the area are excessively developed, being too acid, too clayey, or too high in sodium to be first choice for use in post mine soil construction. The first crop year was 1978 at this site.

Objectives at the River King site:

1) Determination of the yield potential of reclaimed land, immediate and trend over time.

2) Evaluate any rowcrop performance response to A horizon replacement.

3) Determine the effect of an initial period under forages on rowcrop performance.

4) Compare yield response on A/hauled root media to that on wheel spoil and A/wheel spoil.

D. Captain Mine, Arch of Illinois, Inc., Percy, Illinois.

We have two sets of plots at Captain Mine, differing in design and objective. The first set was first cropped in 1979. It consists of shovel spoil (quite rocky) covered by a layer of hauled root media (mostly B horizon material) varying in thickness from 0 to 4 feet. Superimposed are randomly located strips that have had A horizon material replaced. The second plots were designed to follow up a series of greenhouse experiments which began in 1977. The purpose is to evaluate several different available materials for use in soil construction. It consists of a randomized complete block design having the following treatments: 1) A and B horizon material from the premine soils replaced in their original sequence, 2) A horizon material segregated and replaced over a blend of the next 10 feet of material from the premine soils and underlying substratum, 3) A replaced over a blend of the next 15 feet of material, 4) A replaced over a blend of the next 20 feet of material, 5) a blend of the top 10 feet of premine soil and substratum materials without separating or replacing any A horizon material, and 6) a blend of the top 20 feet with no A horizon separation or replacement. The natural soils in the Captain Mine area are excessively developed and relatively unproductive. Greenhouse experiments as well as physical and chemical analysis have shown alternative materials to be superior to material from the premine B horizon for use in soil construction. These experiments will test the alternative material under field conditions.

Objectives at the Captain site include:

1) Identify the best material for use in construction of the post mine subsoil.

2) Measure any rowcrop growth and yield response to A horizon segregation and replacement

3) Determine the relationship between rowcrop yields and thickness of selected root media material over graded shovel spoil.

4) Determine the rowcrop yield potential of reclaimed land, immediate and trend over time.

5) Evaluate the relationship between rowcrop yields on reclaimed land and those on nearby undisturbed land.

E. Eads Mine, Belle Rive, Illinois.

The Eads Mine is now closed. Our research plots there were completed in the summer of 1977 and 1978 was the first crop year. There are numerous acid spots in the plots at this site which introduce variability without contributing much toward the objectives of the study. The primary stripping machine was a dragline which operated from the surface. The practice was to build a pad to support the dragline by placing 3 feet of shale on top after removing the A horizon material. A small dragline was used for most of the reclamation grading. Finish grading was done with dozers and the A horizon was replaced with scrapers. The reclamation dragline operator attempted to sort materials from the spoils of the primary stripper, burying the toxic materials and covering with the best materials.

Objectives at the Eads site:

1) Determine the rowcrop yield potential of graded dragline spoil, with and without replaced A horizon.

2) Measure any yield response to A horizon replacement.

3) Evaluate the relationship between rowcrop yields on newly reclaimed land and those on nearby undisturbed land.

The objectives at this site had originally included determination of the crop performance trend over time and of the effect of an initial period under forages. These latter objectives were dropped because of the decision to terminate this site in 1981.

F. Denmark Mine, Arch of Illinois, Inc., Willisville, Illinois.

The Denmark Mine (formerly Leahy Mine) is a shovel operation which is unique in that the shovel used has a variable pitch bucket which allows for somewhat better sorting than normally occurs in a conventional shovel operation. The construction of the Denmark plot was completed in July 1984 by Amax Coal Company. It consists of a completely randomized design with 5 replications of the following treatments: 1) topsoil replaced over scraper hauled root media, 2) topsoil over truck hauled root media dumped with truck driving on the base material only, and 3) topsoil over truck hauled material in which truck traffic was on the root media itself.

Objectives at the Denmark site are as follows:

1) Determine the rowcrop yield potential of reclaimed land, immediate and the trend over time.

2) Evaluate the effect of methods of root media replacement on rowcrop performance.

3) Determine the relationship between crop yields on reclaimed land and those on nearby undisturbed land.

CAPTAIN MINE

The accidental diversion of surface water near the Mix plots resulted in erosion damage to the first five plots on the north end which was repaired in late March. In order to correct compaction that has occurred on these plots from past spring discings the soybean plots were not planted this year on either the Mix or Wedge plots. In late May these areas were planted to Sudax and deep chisel plowed in early August. Fertilizer (40-80-80) was applied to the plots before discing and then seeded with a cover crop of oats. These plots will be planted to no-till corn in 1987.

Fertilizer was spread April 15. Primary tillage was done with a field cultivator. Herbicides were applied and incorporated on April 26. Corn was planted on all plots and the control area on April 27. A light shower (.17 in) occurred the next day followed by cooler temperatures. Emergence on the topsoil plots occurred about 2 days earlier than the non-topsoil plots. Rodents (Voles) caused damage to 10-20 % of the emerging stand by digging out the planted seeds. Corn was interplanted May 19 at and around the harvest sites where damage was severe. This later planted corn, in most places, did not produce a yield due to further rodent damage and competition for moisture with the earlier planted deeper rooted corn. Preventative measures to control rodents will be implemented to control rodents in future plantings.

Nitrogen deficiency symptoms were apparent during the cool, wet weather in late May on all corn plots although the symptoms were less severe on the topsoil treatments as compared to the non-topsoil plots. By early June these symptoms had disappeared. Early season growth showed corn to be taller on the topsoil replaced treatments but the height differences between the topsoil and non-topsoil treatments were not evident by pollination time. Corn on the TLG portion of the Wedge plots remained taller than the untreated portion throughout the season. Corn plants on the thin edge of the wedge were only 2' foot tall and showing leaf curl by June 13. These moisture stress symptoms progressed over the entire non-ripped portion of the wedge. The TLG portion of the wedge did not begin to show visible stress until a few days before pollen shed on July 2. No rainfall occurred from June 13 to June 30. On July 1 0.9" of rain was received. Corn on the Mix plots during this period remained green showing no leaf burn or curl.

It was observed that corn plants growing on the middle of the wedge (No TLG) were taller than those plants on either side of the non-ripped portion. Although under stress these middle rows pollinated better and set larger ears than the rows on the thinner or thicker non-ripped portion of the wedge. This modest rise and fall in yield across the wedge has been noted in prior years.

Pollination was complete by mid-July with corn on all areas of the wedge showing leaf burn. Dead leaves varied from the bottom third of the plant on the TLG to the entire plant on the spoil bench while corn on the Mix plots were green with no visible height differences between treatments. Hand sampling was done in early September and it was observed that the late interplanted corn produced some poorly pollinated and smaller ears. Plots were chisel-plowed in October.

Yield results from the Mix plots showed corn yields for all mine soil treatments to be significantly higher than yields obtained on the undisturbed Stoy in 1986. The 10' Mix treatment corn yields were significantly lower than any of the other mined land treatments. These lower yields may have been influenced to some degree by the fact that rodent damage was noted to be most severe in the non-topsoiled plots and resulted in a higher proportion of later interplanted corn at the harvest sites. Some plots in this treatment have been damaged and repaired in the past years with grading of some of these plots before planting this spring.

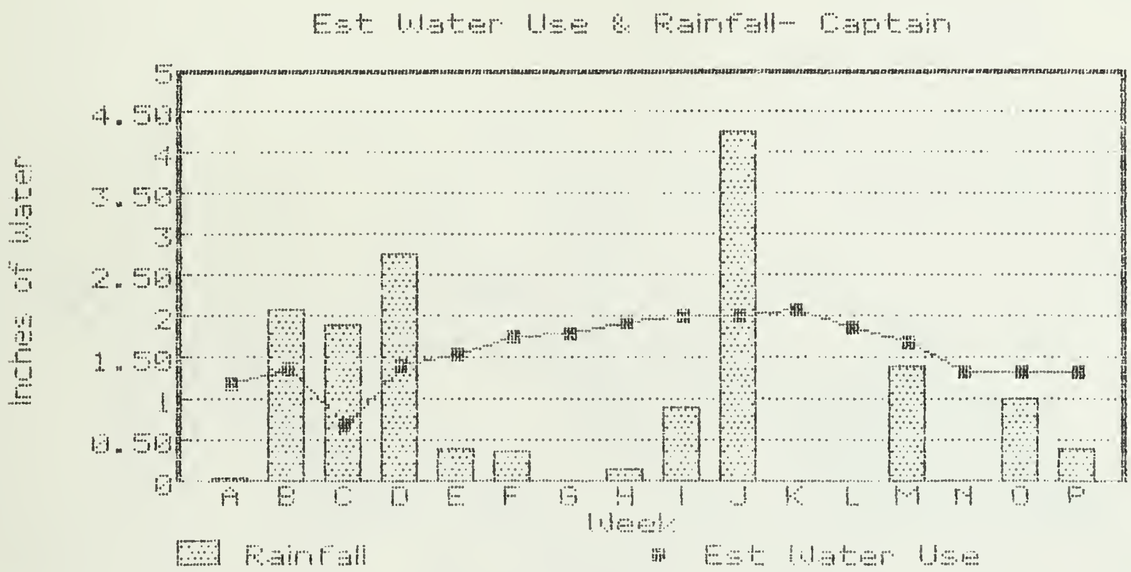
Corn yields from the Wedge plots show a significant positive yield response to the TLG treatment compared to the non-ripped area. Yields from the thinner side of the wedge (<20") was zero. Yields for the topsoil/root media and the root media were not different across the wedge.

DUQUOIN

Week	Ave Max	Ave Min	Mean	Rainfall (in)
May 4-10	83.7	60.0	71.9	0.00
May 11-17	80.9	61.7	71.3	3.08
May 18-24	69.7	52.3	61.0	0.26
May 25-31	79.3	61.1	70.2	0.80
June 1-7	82.0	65.3	73.6	0.66
June 8-14	85.7	67.0	76.4	0.12
June 15-21	88.6	63.6	76.1	0.00
June 22-28	91.4	67.0	79.2	0.00
June 29-July 5	90.3	68.0	79.2	0.97
July 6-12	93.7	68.3	81.0	5.63
July 13-19	94.9	72.0	83.5	0.72
July 20-26	91.3	69.3	80.3	0.06
July 27-Aug 2	89.9	67.3	78.6	0.09
Aug 3-9	85.4	62.0	73.7	1.23
Aug 10-16	84.3	62.3	73.3	2.48
Aug 17-23	87.0	65.0	76.0	0.03
Aug 24-30	81.4	56.0	68.7	0.43
Aug 31-Sept 6	84.1	59.7	71.9	0.23
Sept 7-13	77.7	53.4	65.6	0.99
Sept 14-20	81.3	60.6	70.9	2.90
Sept 21-27	87.9	68.1	78.0	0.50

	Ave Max	Ave Min	Mean	Depart from normal	Days over 90	Pptn.	Depart from normal
May	77.5	57.7	67.6	1.6	0	4.19	0.42
June	87.5	66.0	76.8	2.3	10	0.78	-2.59
July	92.2	69.2	80.7	2.5	21	7.47	3.72
Aug	84.4	61.4	72.9	-3.3	3	4.17	0.90
Sept	83.3	61.3	72.3	2.7	2	4.63	1.79

ESTIMATED WEEKLY WATER USE AND RAINFALL AT CAPTAIN MINE



Week	Date	Est Weekly Water Use	Rainfall
A	May 4-10	1.19	0.07
B	May 11-17	1.37	2.09
C	May 18-24	0.70	1.90
D	May 25-31	1.40	2.75
E	Jun 1-7	1.54	0.42
F	Jun 8-14	1.77	0.37
G	Jun 15-21	1.79	0.00
H	Jun 22-28	1.96	0.15
I	Jun 29- Jul 5	2.01	0.90
J	Jul 6-12	2.03	4.25
K	Jul 13-19	2.10	0.00
L	Jul 20-26	1.89	0.00
M	Jul 27- Aug 2	1.70	1.40
N	Aug 3-9	1.33	0.00
O	Aug 10-16	1.33	1.00
P	Aug 17-23	1.33	0.40

PLOT MANAGEMENT RECORD 1986

CAPTAIN ROOTING MEDIA WEDGE

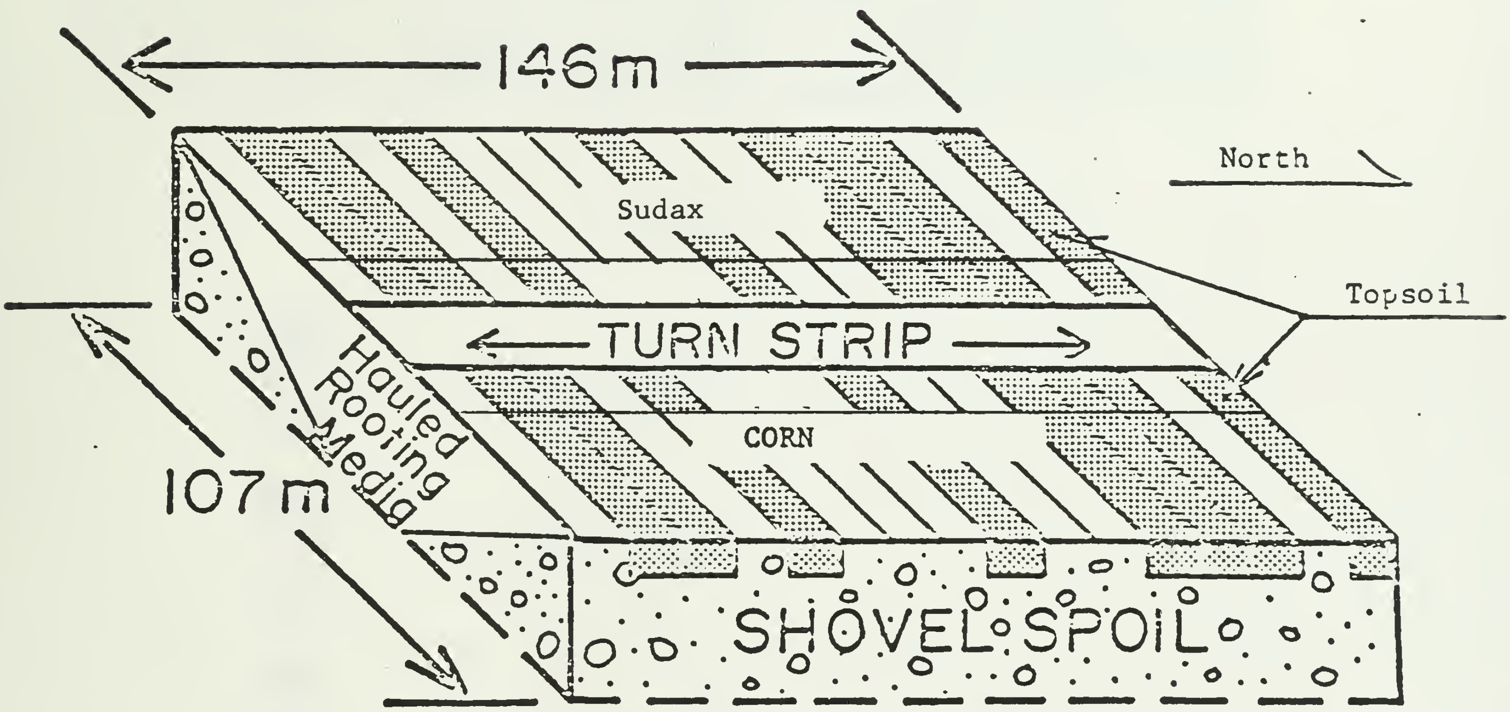
CORN Mo17 x B73

Planting date - 27 April

Planting rate - 23,200 seeds / acre

Fertilizer	- 200 lbs N / acre
	0 lbs P / acre
	0 lbs K / acre
Herbicide	- 2 pt Dual / 2 pt Atrazine
Insecticide	- Furadan

Captain Wedge - 1986



PLOT MANAGEMENT RECORD 1986

CAPTAIN MIX PLOTS

CORN Mo17 x B73
LH119 x LH51

Planting date - 27 April

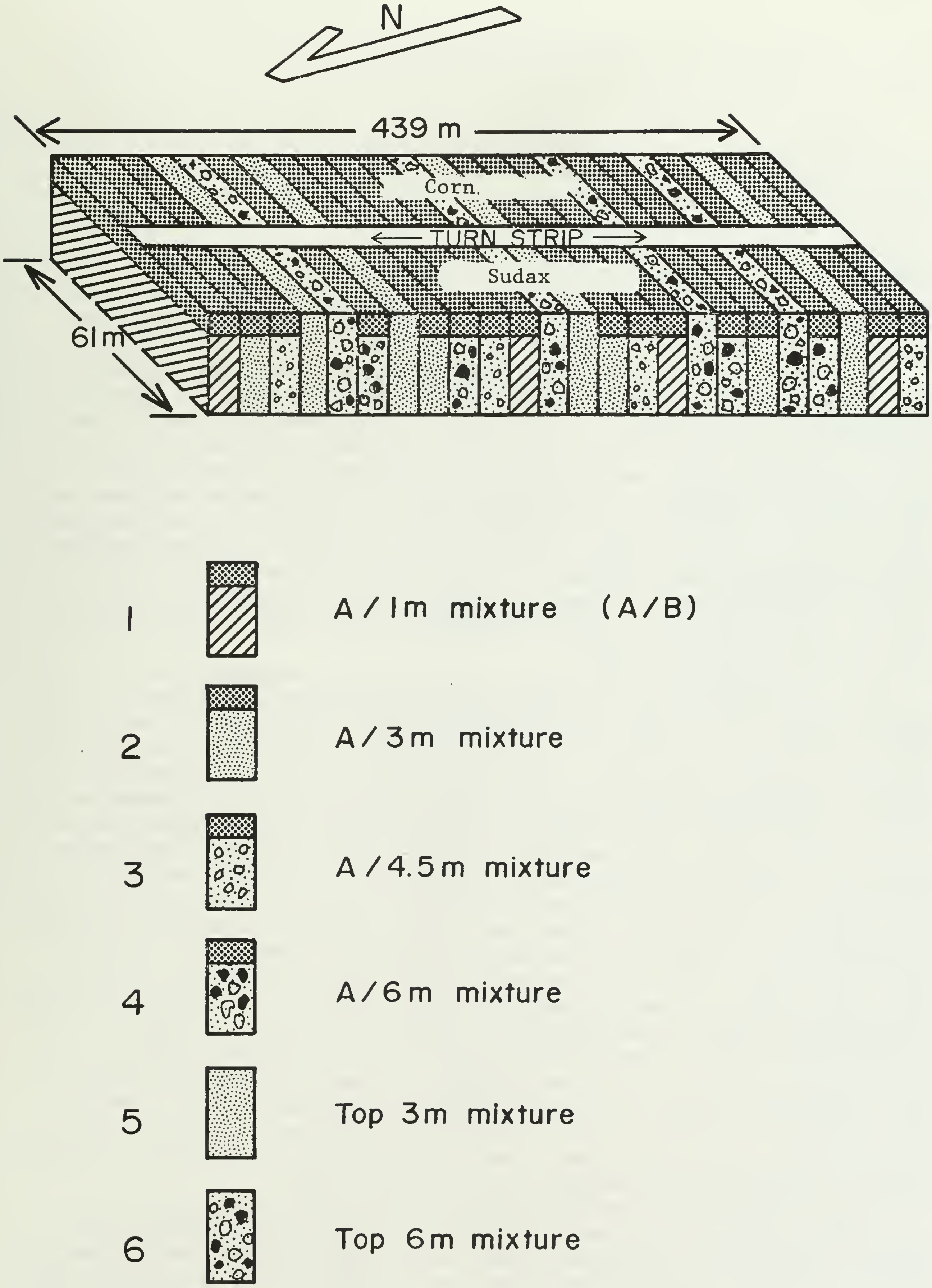
Planting rate - 23,200 seeds / acre

Fertilizer - 200 lbs N / acre
70 lbs P / acre
60 lbs K / acre

Herbicide - 2 pt Dual / 2 pt Atrazine

Insecticide - Furadan

Captain Mix Plots- 1986



CAPTAIN TLG PLOTS

The surface and subsurface drainage work completed on these plots last year helped provide favorable surface conditions for planting. This spring only minimal tile maintenance/ repair was required. Phosphorous and potassium was fall applied and disced. Nitrogen was spring applied as urea on the corn and sorghum plots. All new crop plots were chisel plowed this spring with a field cultivator used to finish the seedbed. All herbicides were custom applied and incorporated with a harrow.

The wheat plots were damaged in some areas by grazing from local geese. This damage was mainly limited to the northern plots (Areas 2 & 3). The FS 402 wheat variety had more prior season growth and some die-back was present in March. Nitrogen was aerial applied (45 #/a) on March 24. Weeds did not become a problem except where geese damage had been severe. The FS 402 remained taller than the Cauldwell through maturity. Height differences were noticeable between the TLG and No TLG treatments for both varieties by May 12. Harvest samples were taken during the 14-16 June period. Yields are reported on the southeast plot (Area 1) and the undisturbed control area.

Corn was planted on May 1 in a fine, conventional seedbed. The surface was somewhat undulating as a result of wheel traffic in areas of marginal soil strength. A separate undisturbed site to use for these plots was established with the same planting date. Emergence was excellent but early season growth was affected by cool weather showing some early nitrogen deficiency symptoms. These symptoms disappeared in early June. The TLG treatment plants were taller than those plants on the non-ripped side by early June and visible moisture stress was evident on the areas were the TLG was not used. Corn on the TLG treatment did not show visible moisture stress until a few days before pollen shed which occurred in the first week of July. On July 1 0.9" of rain fell which provided some needed moisture at pollination. The non-ripped treatments showed considerable stress variability at pollination from slight to severe stress symptoms. Soil strength profiles in these scraper placed areas also show wide ranging values of penetrometer resistance which may explain the varying stress symptoms observed. Corn harvest samples were taken in September. Support of equipment rapidly became a problem on these plots in the fall.

Soybeans were planted May 8. Subsurface moisture conditions were more favorable than either the Denmark of undisturbed Stoy. Emergence was very good and no early season growth problems occurred. Plots were cultivated in mid-June with the remaining tall weeds walked out in mid-season. Plant growth was vigorous until mid-August. Drought stress was complicated by pathological problems. Considerable leaf drop occurred. Plant growth was slow and pod-fill was affected.

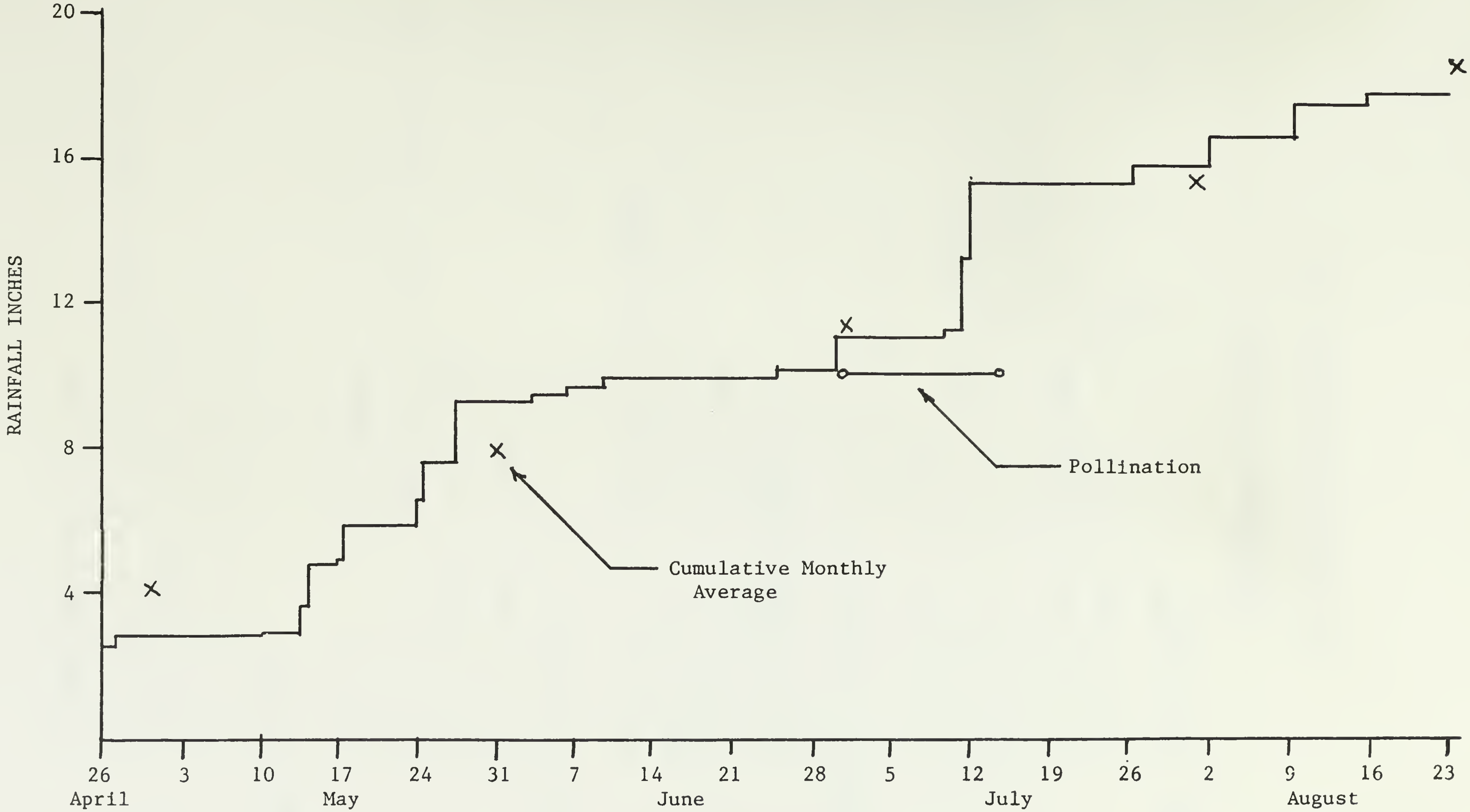
Inspection revealed shallow rooting and the presence of Septoria leaf spot and charcoal rot. These pathogens could have propagated in the grass-legume stand present in the years prior to planting of soybeans. Soybean plots were machine harvested on September 25.

Grain sorghum was planted on June 3. Some plots had emerged weeds present and soil surface was lightly crusted. Roundup was used to control weeds and planting was completed with no additional tillage. Emergence was excellent and no major weed problems occurred during the growing season. The sorghum weathered the June-July dry period with leaf curl present on all plots. By mid-August head size was noticeably larger on the TLG treatment in most plots. Some bird damage was present in early October at harvest time. This was avoided where possible during the machine harvest for yield.

Mean yields across all areas for 1986 show a significant positive yield response to the TLG treatment for all crops. Yields for the TLG treatment were equal to or greater than those observed on the undisturbed Stoy soil for all areas and all crops. Mean yields for the un-ripped scraper treatment were comparable to the undisturbed Stoy for corn, sorghum, and the one area of wheat where yield samples were taken. Soybean yields on the un-ripped scraper treatment were significantly lower than either the TLG or the undisturbed tract.

The hybrid study consisting of four replications of 10 hybrids was planted in Area 1 and the undisturbed tract on May 21. A considerable amount of rain (3") had been received the previous week and the area which had been selected from the TLG block for the hybrid study was extremely wet with some ponded water. An alternate area was selected at the northwest edge of the TLG block which was higher on the landscape and dry enough for tillage. Soil moisture conditions on the scraper area and the undisturbed tract were favorable for planting. Seedling emergence of all hybrids was very good due to adequate moisture and the warm temperatures of late May. Hybrid plants on all soil treatments were showing severe wilting and curling during the dry June 13-July 1 period. Hybrid corn stress symptoms were considerably more severe than the earlier planted corn plots (May 1). By anthesis many plants had blasted tassels and silks were late to emerge. Four inches of rain occurred at pollination (July 10-12) but severe earlier season stress had taken its toll.

Hybrid yield results were considerably lower than yields of the earlier planted corn in Area 1. Significant differences between hybrids within a soil treatment did result although variability was quite high. This is reflected by the fact that the LSD for hybrids within a soil treatment at the 0.05 level of probability is large. Yield means for all hybrids on the TLG are significantly lower than yield means for all hybrids on either the scraper or Stoy. It is quite possible that the alternative site selected for planting in the TLG treatment is not truly representative of its effects. It is likely that this hybrid plot located at the very edge of the field received more subsequent traffic after the TLG operation during land leveling. The penetrometer will be used this spring to evaluate whether this site is comparable to the TLG effect in other areas of this block.



CUMULATIVE RAINFALL 1986

CAPTAIN MINE

PLOT MANAGEMENT RECORD 1986

CAPTAIN TLG PLOTS

CORN Mo17 x B73
LH119 x LH51

Planting date - 1 May

Planting rate - 23,200 seeds / acre

Fertilizer - 200 lbs N, 140 lbs P, 190 lbs K / A

Herbicide - 2.5 pt Dual / 1 lb Atrazine

Insecticide - Furadan

SOYBEANS Williams 82
Union

Planting date - 8 May

Planting rate - 70 lbs / acre

Fertilizer - 140 lbs P, 190 lbs K / acre

Herbicide - 2 pt Dual / 4 qts Amiben

MILO Dekalb 42Y

Planting date - 3 June

Planting rate - 6 lbs / acre

Fertilizer - 130 lbs N, 140 lbs P, 190 lbs K / A

Herbicide - 2 qt Lasso / 1 lb Atrazine

WHEAT FS 402
Caldwell

Planting date - 10 Oct 85

Planting rate - 1.5 bu / acre

Fertilizer - 111 lbs N, 140 lbs P, 190 lbs K / A

Harvest date - 14-17 June

PLOT MANAGEMENT RECORD 1986

CAPTAIN HYBRID STUDY

HYBRIDS:
- Mo17 x B73
- B73 x LH38
- Pioneer 3377
- Lynx LX 4355
- Garst 8344
- Dekalb 656
- Dekalb 636
- Dekalb 672
- FS 8475
- FS 6933

Planting date - 21 May

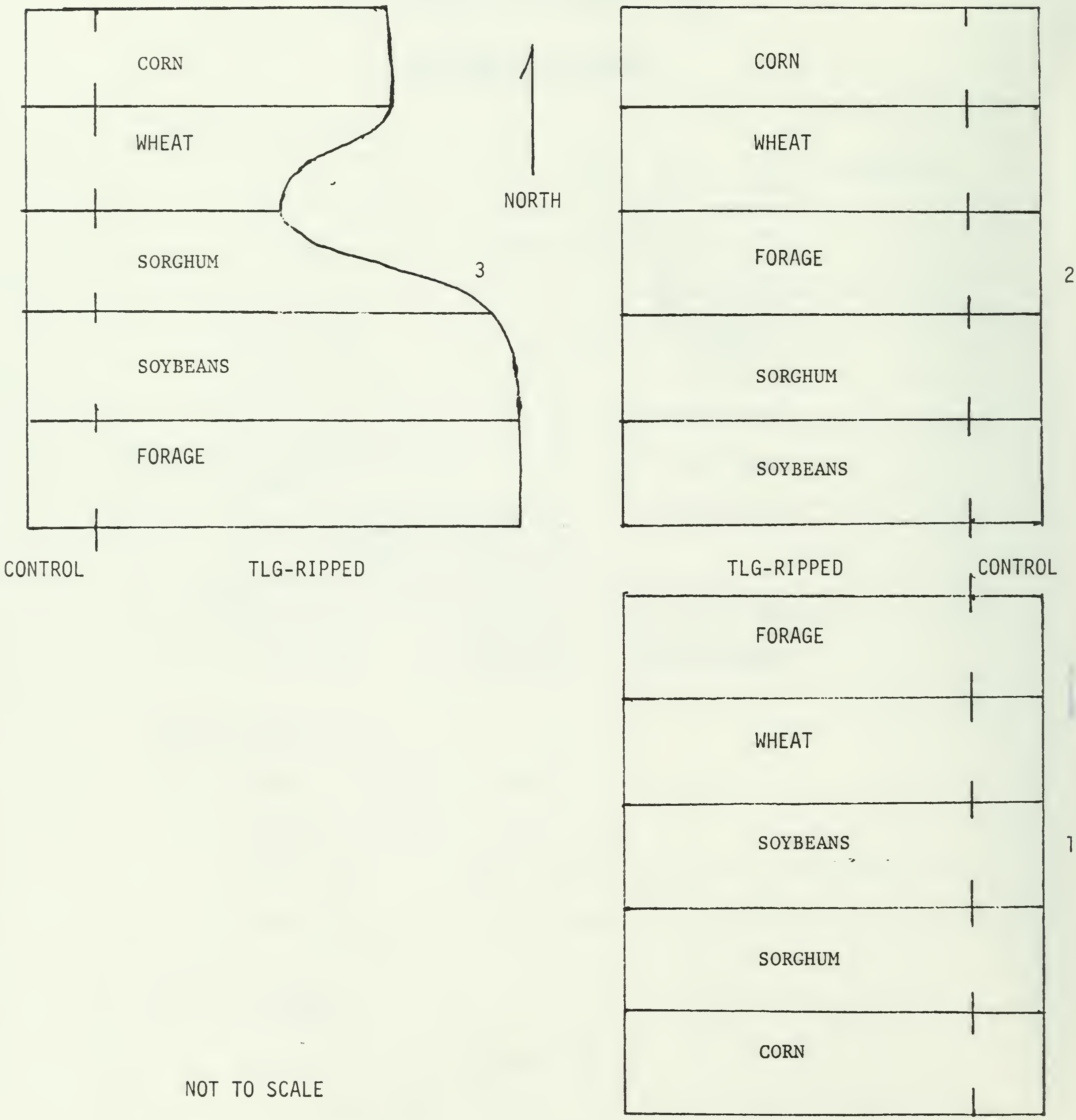
Planting rate - 28,000 seeds/ acre

Fertilizer - 200 lbs N / acre
140 lbs P / acre
190 lbs K / acre

Herbicide - 2.5 pt Dual / 1 lb Atrazine

Insecticide - Furadan

CAPTAIN TLG PLOTS



NOT TO SCALE

DENMARK (LEAHY) MINE 1986

Fall tillage had been prevented by weather conditions in 1985. The sub-surface drainage problems noted in 1985 were present again in the spring of 1986. Although not as severe the problem still required correcting and this was accomplished by the installation of drainage tile in early April. The plots were disced and surface ponding was corrected by land-leveling prior to primary tillage. Fertilizer was spread and tillage completed with a field cultivator on April 16. Herbicides for corn were applied April 26 and preplant incorporated with the field cultivator. Corn was planted April 27 and was followed by a light shower (0.17") the next day. Emergence was slow with several cool days following planting. Without further rainfall emergence was complete by May 7.

With only 0.17" rainfall since April 20 the soybean plots were crusted with very little moisture present in the top 4" of soil. Early tillage and land leveling prior to primary tillage may have contributed to the loss of soil moisture. To conserve moisture, soybeans were planted into the crust and herbicides were surface applied on May 9. Emergence was beginning by 14 May when 0.8" rain was received. May was relatively cool with rainfall 3" above normal levels. Nitrogen deficiency symptoms were observed on all corn plots but symptoms quickly disappeared near the end of the month when warmer temperatures and drier conditions prevailed. Rainfall in June totaled 0.9" with 0.75" falling the first 9 days of the month. Corn grown on the scraper treatment were showing leaf curl by June 13 with all treatments exhibiting visible moisture stress by June 23. Corn on the truck plots was taller than that on the scraper plots by mid-June. Pollination on corn plots started on July 2 when a critical 0.9" rainfall was received. Above normal rainfall fell in late July. Hand samples were taken on September 29.

Soybean plots were also significantly affected by weather stress in 1986. Considerable visible stress had an effect on early vegetative growth and during the pollination period. Grasshoppers became a problem in mid-August and were sprayed on August 22. Soybeans were machine harvested in early September and all plots were chisel plowed in October.

Yield results for 1986 show that the truck w/o traffic treatment corn yields to be significantly higher than the scraper placed and undisturbed treatments. Corn yields for the two truck treatments were comparable. The truck with traffic treatment was not significantly different from the scraper or undisturbed Stoy corn yields. Corn yields for the scraper placed and the Stoy were not significantly different in 1986.

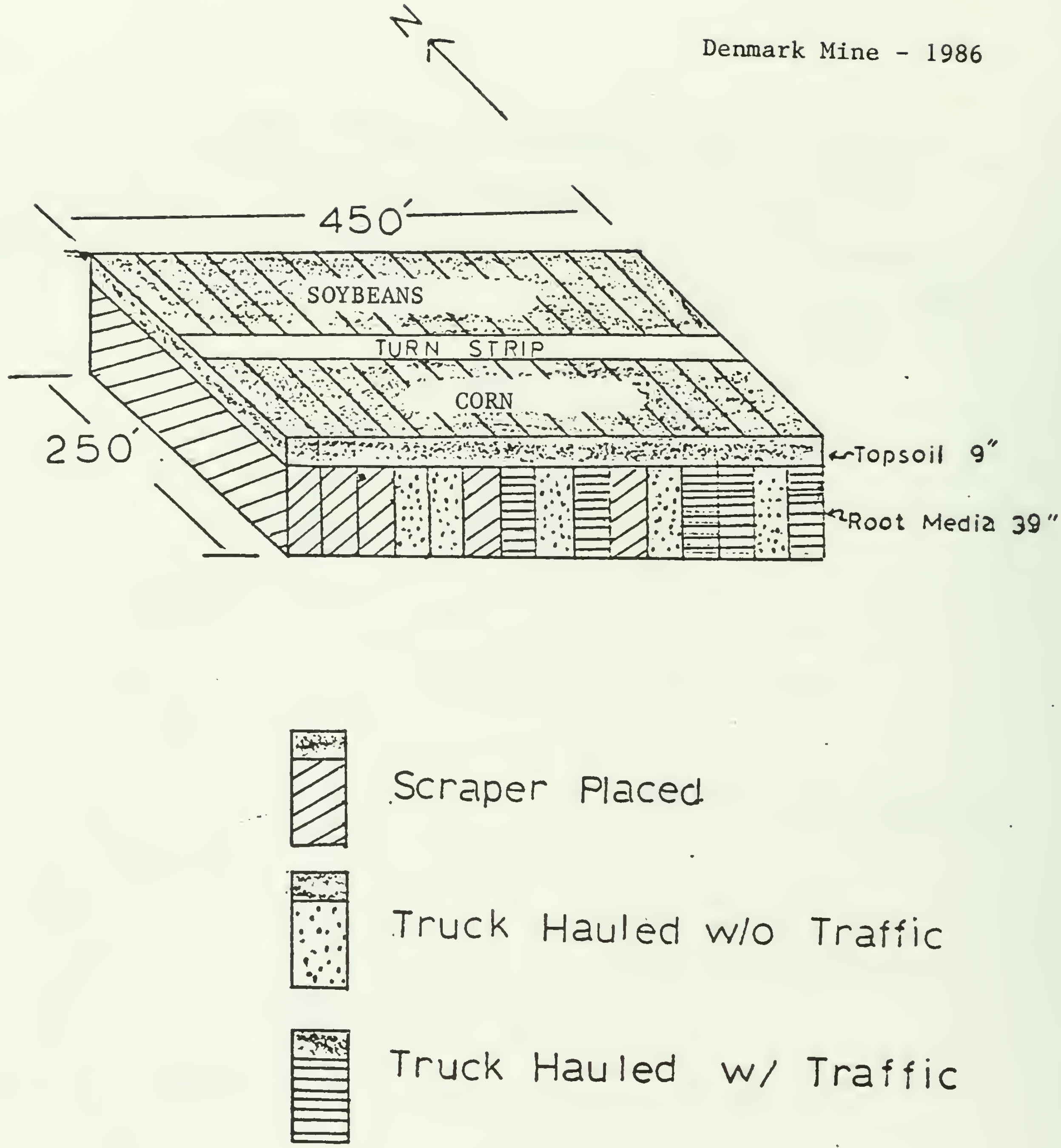
Soybean results show the truck w/o traffic and the undisturbed treatment yields to be comparable. The two truck placed treatment soybean yields were not significantly different but the truck with traffic yields were significantly lower than the Stoy soil and not different from the scraper placed plots.

PLOT MANAGEMENT RECORD 1986

DENMARK MINE

CORN	Mo 17 x B73 B73 x LH38	
	Planting date	- 27 April
	Planting rate	- 23,200 seeds / acre
	Fertilizer	- 200 lbs N / acre 120 lbs P / acre 120 lbs K / acre
	Herbicide	- 2 pt Dual / 2 pt Atrazine
	Insecticide	- Furadan
SOYBEANS	Williams 82 Union	
	Planting date	- 9 May
	Planting rate	- 60 lbs / acre
	Fertilizer	- 120 lbs P / acre 120 lbs K / acre
	Herbicide	- 2 pt Dual / 4 qt Amiben

Denmark Mine - 1986



SUNSPOT MINE

Corn was planted April 24 at Sunspot in 1986 with moisture and tillage conditions good to excellent on both the topsoil and non-topsoil plots. Emergence rates were 85-90% for the topsoil replaced and B horizon only treatments while 70-75% of the seedlings emerged on the dragline spoil only treatment. The growing season at Sunspot was characterized by above normal precipitation and temperatures for May, June and July. A total of 7.8 inches of rain fell in the month of June and 7.3 during July promoting rapid vigorous early vegetative growth on all soil treatments. The month of August had rainfall totals below the normal average with temperatures cooler than normal.

No visible growth differences between the topsoil/B horizon and the topsoil/dragline spoil was observed during May, June or July while rainfall was sufficient to reduce or eliminate any weather induced stress on the crop. During the low rainfall period of August, during the grain fill period, the topsoil/dragline spoil exhibited more moisture induced stress than the topsoil/B horizon. The topsoil/B horizon plots remained green with very minimal leaf curl while the topsoil/dragline spoil plots curled and turned yellow from stress. Ear fill on this treatment was adversely affected.

Excellent corn yields were again achieved in 1986. The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale soil for the fifth time in the previous seven years. The B horizon only mine soil also produced corn yields comparable to the Clarksdale soil while grain yields from the dragline spoil only treatment were significantly lower than any of the other soil treatments studied. These yield relationships were observed in both the main plot and forage plot experiments.

Soybeans in 1986 were planted only on the forage plots due to the corn rooting study being conducted on the main plot area. Soybean yields were very good on the topsoil/B horizon treatment with yields being comparable to those harvested on the Clarksdale area. No significant yield difference resulted between the topsoil/dragline spoil and the B horizon only treatments although both were significantly lower yielders than the topsoil/B and the Clarksdale soil. Yields from the dragline spoil treatment were very low and were severely affected by moisture stress during the pod fill stage in August.

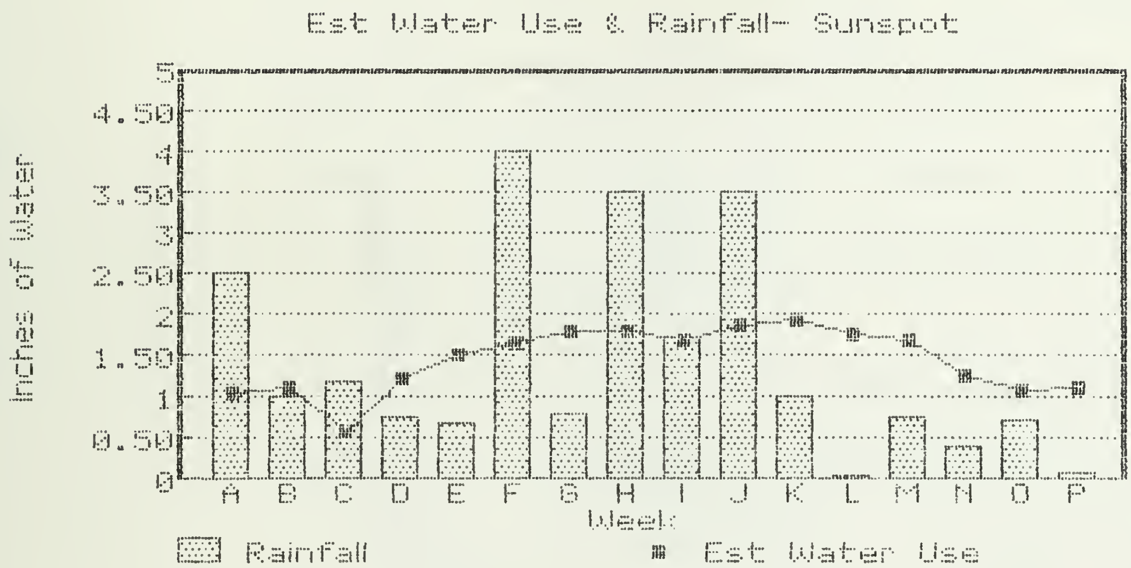
The area which had been ripped in the fall of 1982 by the Kaelble-Gmeinder TLG-12 resulted in a significant positive corn yield response on the topsoil/dragline spoil treatment. Yields on the TLG-topsoil/dragline spoil, however, were still significantly lower than the topsoil/B horizon treatment which was unaffected by the TLG tillage operation.

HAVANA

Week	Ave Max	Ave Min	Mean	Rainfall (in)
May 4-10	78.7	58.6	68.6	0.77
May 11-17	79.3	57.1	68.2	1.03
May 18-24	72.0	45.1	58.6	0.34
May 25-31	77.1	59.0	68.1	0.58
June 1-7	83.6	60.9	72.2	0.70
June 8-14	84.7	64.0	74.4	0.91
June 15-21	88.0	64.0	76.0	0.79
June 22-28	88.1	65.1	76.6	0.88
June 29-July 5	83.9	67.0	75.5	1.72
July 6-12	89.3	69.3	79.3	5.24
July 13-19	89.7	70.4	80.1	0.69
July 20-26	87.3	66.0	76.7	0.04
July 27-Aug 2	88.1	65.7	76.9	0.76
Aug 3-9	81.4	60.3	70.8	0.41
Aug 10-16	80.4	58.9	69.6	0.73
Aug 17-23	86.4	59.9	73.1	0.10
Aug 24-30	79.9	50.9	65.5	0.49
Aug 31-Sept 6	82.9	52.9	67.9	0.00
Sept 7-13	76.7	50.7	63.7	2.31
Sept 14-20	79.1	57.4	68.3	1.74
Sept 21-27	81.3	66.9	74.1	4.80

	Ave Max	Ave Min	Mean	Depart from normal	Days over 90	Pptn.	Depart from normal
May	76.1	53.7	64.9	3.3	0	4.11	0.45
June	86.1	63.8	75.0	3.8	5	3.96	0.24
July	88.0	68.0	78.0	3.0	11	7.77	3.73
Aug	82.2	57.4	69.8	-3.3	2	1.73	-1.94
Sept	80.6	58.5	69.6	4.0	3	9.76	6.28

ESTIMATED WEEKLY WATER USE AND RAINFALL AT SUNSPOT MINE

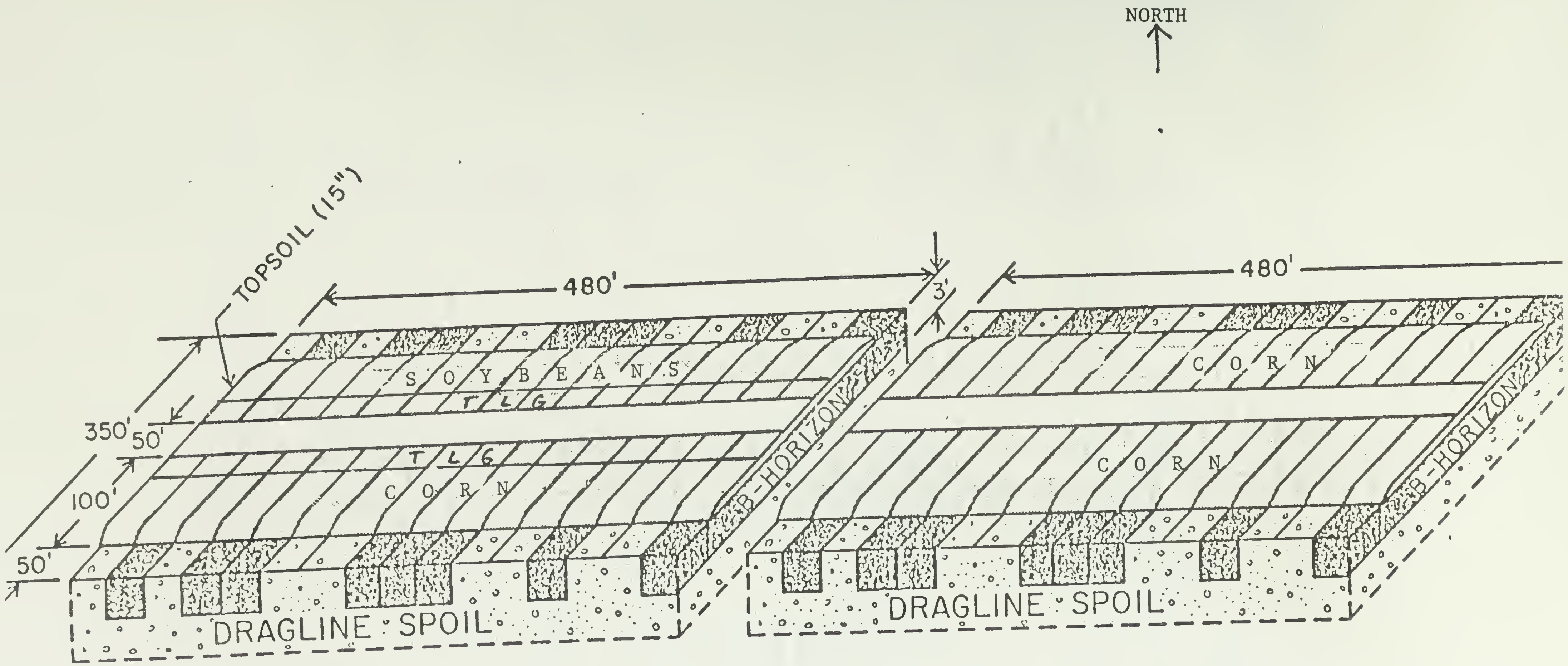


Week	Date	Est Weekly Water Use	Rainfall
A	May 4-10	1.06	2.50
B	May 11-17	1.13	1.03
C	May 18-24	0.60	1.20
D	May 25-31	1.23	0.75
E	Jun 1-7	1.51	0.70
F	Jun 8-14	1.65	4.01
G	Jun 15-21	1.79	0.79
H	Jun 22-28	1.80	3.56
I	Jun 29- Jul 5	1.68	1.72
J	Jul 6-12	1.89	3.50
K	Jul 13-19	1.94	1.00
L	Jul 20-26	1.76	0.04
M	Jul 27- Aug 2	1.70	0.76
N	Aug 3-9	1.28	0.41
O	Aug 10-16	1.09	0.73
P	Aug 17-23	1.12	0.10

PLOT MANAGEMENT RECORD 1986

SUNSPOT

CORN	Mo17 x B73 B73 x LH38		
	Planting date	-	24 April and 15 May
	Planting rate	-	26,000 seeds / acre
	Fertilizer	-	250 lbs N / acre 70 lbs P / acre 70 lbs K / acre
	Herbicide	-	3 pt Dual / 2 pt Atrazine
	Insecticide	-	Furadan
SOYBEANS	Williams 82 Fayette		
	Planting date	-	22 May
	Planting rate	-	60 lbs/acre
	Fertilizer	-	70 lbs P / acre 70 lbs K / acre
	Herbicide	-	3 pt Dual / 4 qt Amiben



Sunspot - 1986

NORRIS MINE

Corn plots were planted April 24 under favorable moisture and weather conditions. Emergence rates were 85-90% and very adequate stands were achieved on both the mined land and the undisturbed Sable soil treatments. The irrigation experiment was phased out in 1986 and only topsoil/wheel spoil and wheel spoil only treatment comparisons were made. Weather in 1986 was quite favorable for crop production with above normal rainfall and temperatures in June and July with some moderate weather stress experienced in August. Tensiometer data (graphs following this writeup) indicate that available soil moisture levels were quite adequate in the root zone for all soil treatments in the 1986 growing season.

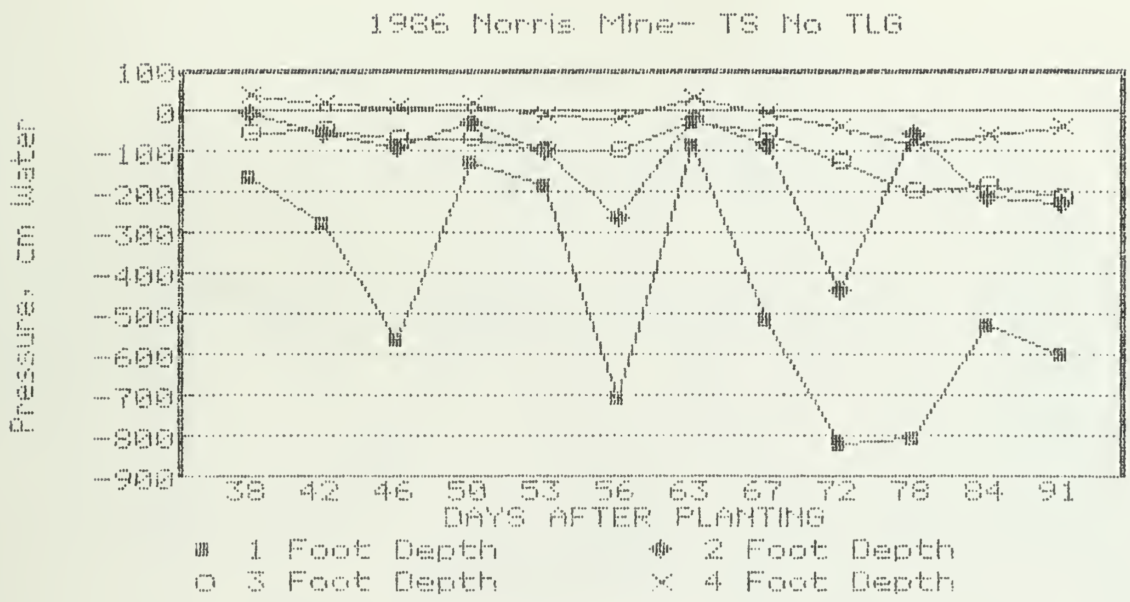
Excellent corn and soybean yields resulted in 1986 with corn yields produced on both the topsoil replaced and wheel spoil only treatments comparable to that grown on the undisturbed Sable soil. Soybean yields from the soybean variety study were also comparable to the undisturbed site with the Golden Harvest 1285 and the Pella varieties the highest yielders from the study group.

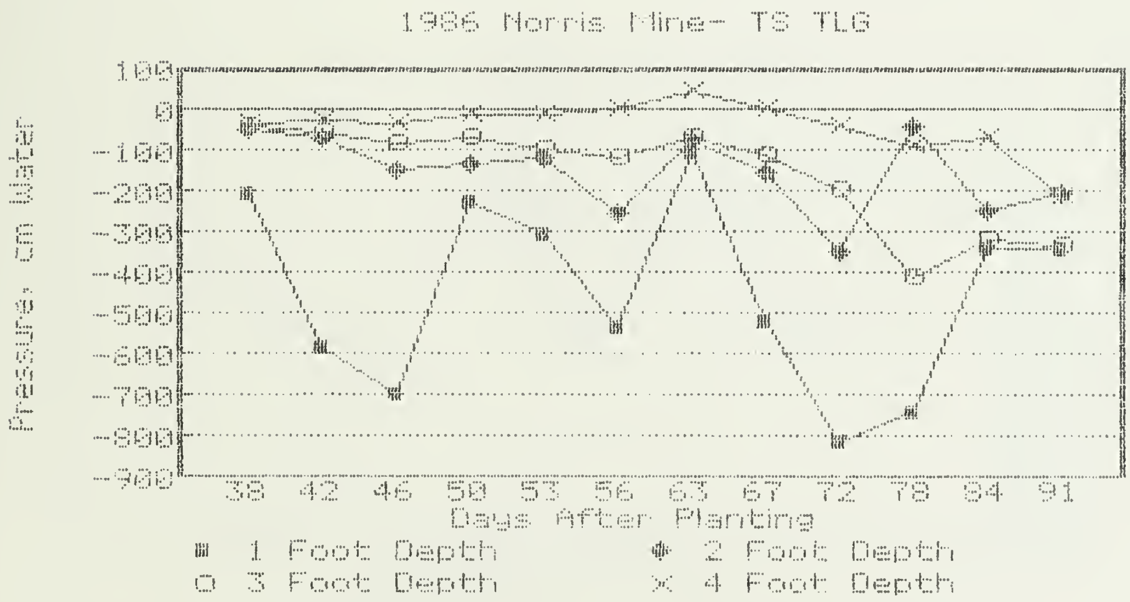
The TLG treatment resulted in a significant corn yield increase for the wheel spoil treatment in 1986 but no response to the deep tillage treatment occurred on the topsoil replaced plots. Response to the replacement of topsoil was non-significant for either the TLG or No TLG treatment areas. Plant height differences were observed between the taller topsoil plants and the shorter plants on the wheel spoil only but no height differences were observed between the TLG and No TLG within either the topsoil or wheel spoil treatments.

The 1986 hybrid study contained 10 selected genotypes and was planted on May 13 due to the unavailability of the cone planter at the time the other plots were planted. Mean yields for all hybrids combined for a soil treatment show the grain yields for the topsoil/wheel spoil and the Sable soil to be not significantly different. The wheel spoil only treatment yields were significantly lower than either the topsoil or Sable. Because of the later planting date and the delayed pollination date of the hybrids on this soil treatment the wheel spoil hybrid yields were adversely affected to a higher degree by low August rainfall than the corn plots planted on April 24.

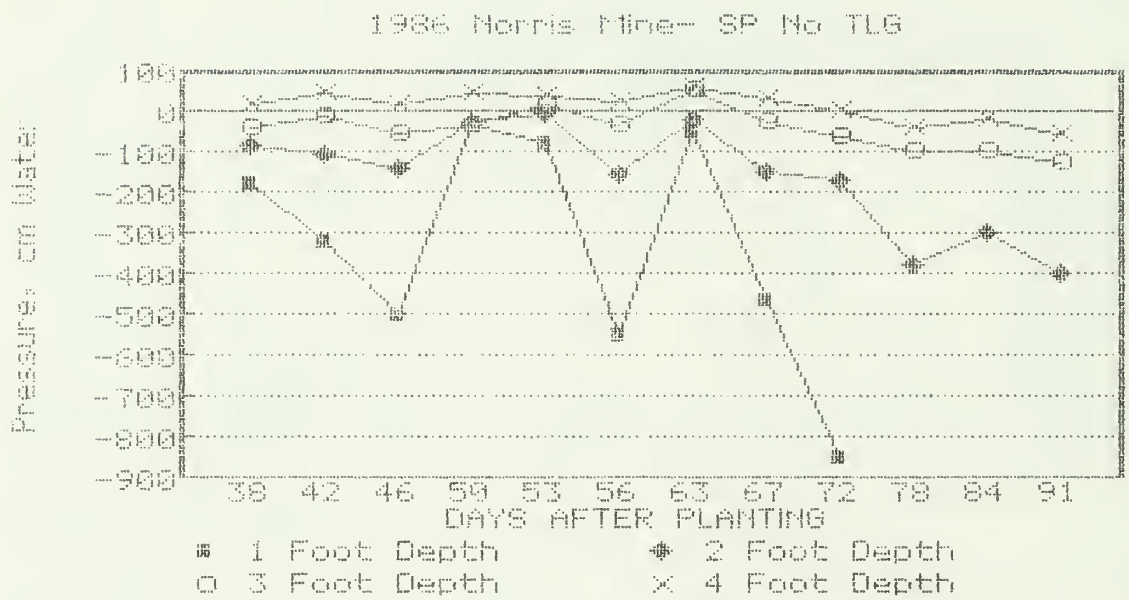
Due to differential settling that has occurred over years at this site the topsoil wedge was not evaluated in 1986. Water ponding was frequent due to the above normal rainfall in June and July introducing uncontrollable bias of the data into the experiment.

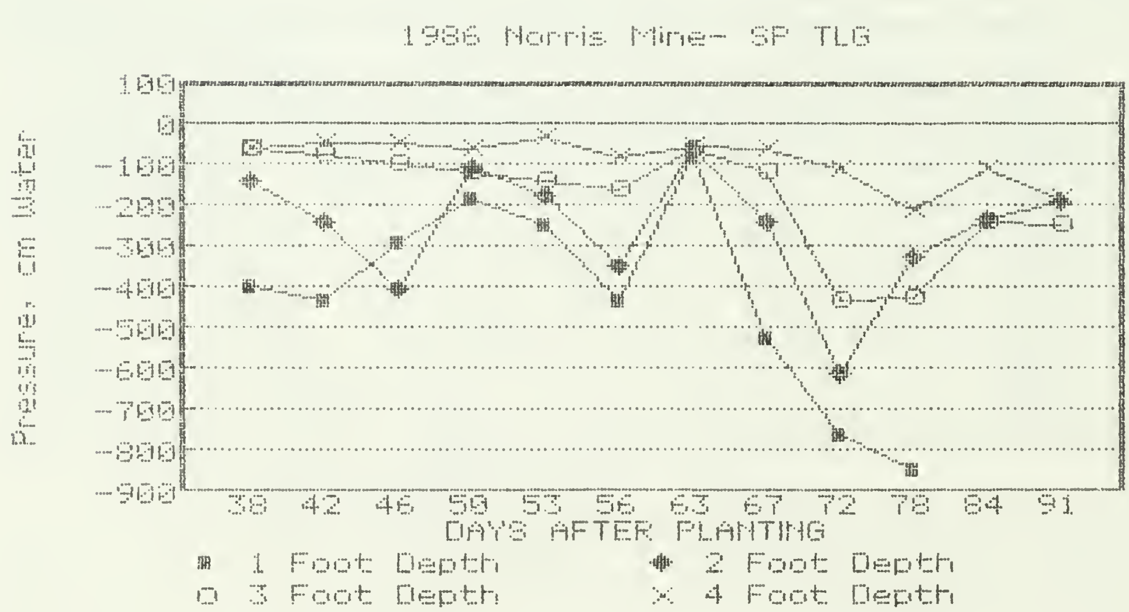
1986 NORRIS MINE TENSIOMETER DATA



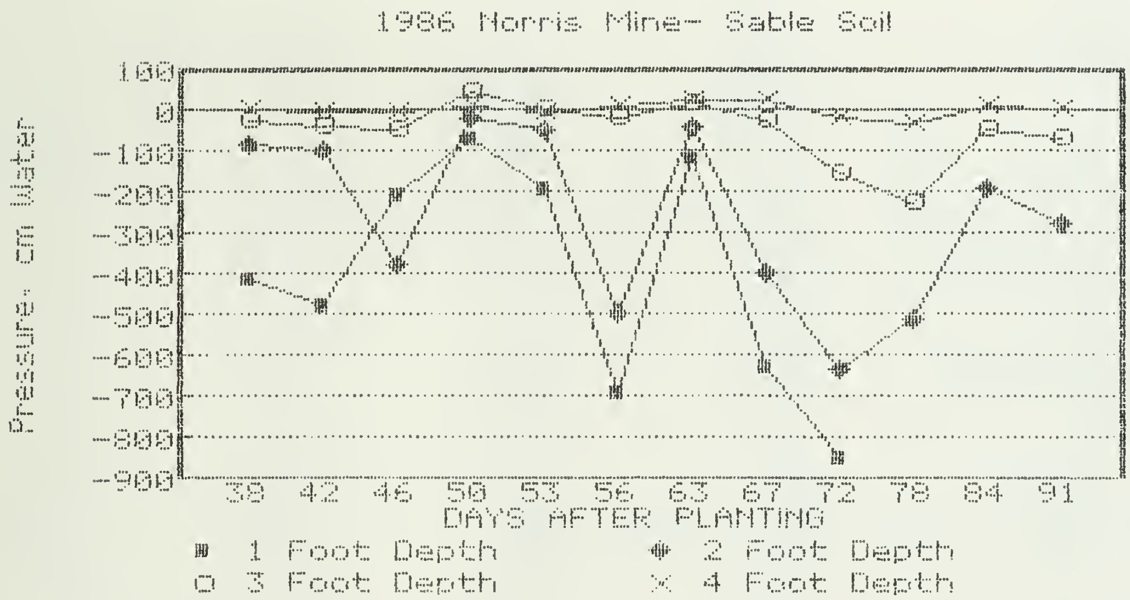


1986 NORRIS MINE TENSIOMETER DATA





1986 NORRIS MINE TENSIOMETER DATA

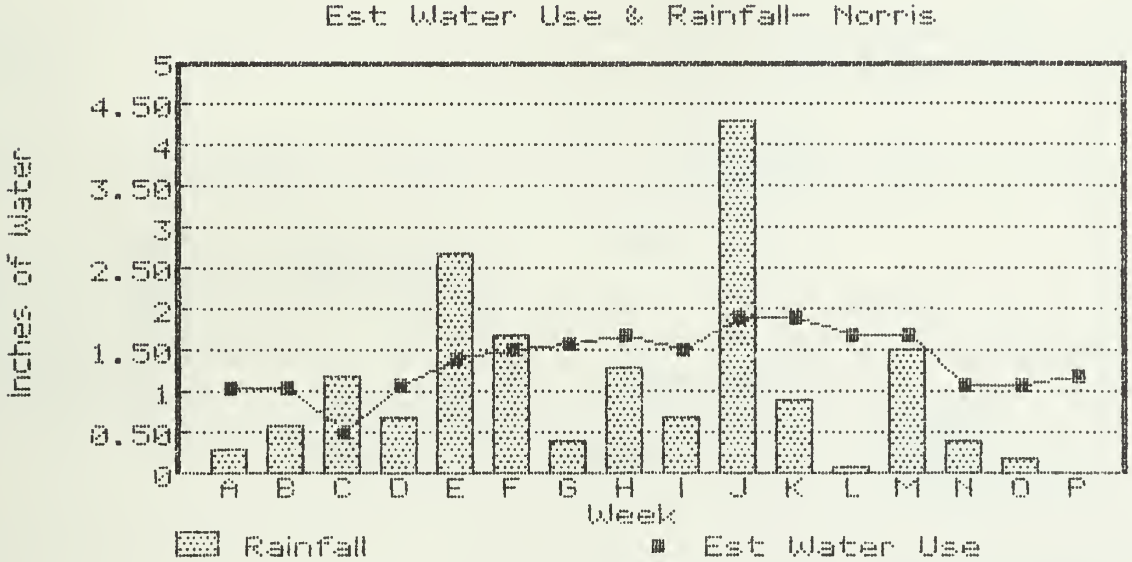


PEORIA

Week	Ave Max	Ave Min	Mean	Rainfall (in)
May 4-10	78.6	57.0	67.8	0.31
May 11-17	77.7	57.7	67.7	0.56
May 18-24	68.9	46.7	57.8	1.19
May 25-31	76.3	58.9	67.6	0.71
June 1-7	81.0	60.4	70.7	2.71
June 8-14	81.1	63.9	72.5	1.72
June 15-21	84.3	63.7	74.0	0.36
June 22-28	85.0	64.1	74.6	1.26
June 29-July 5	81.1	64.9	73.0	0.69
July 6-12	87.6	69.0	78.3	4.33
July 13-19	89.0	70.7	79.9	0.87
July 20-26	88.4	68.9	78.6	0.05
July 27-Aug 2	86.4	65.6	76.0	1.46
Aug 3-9	79.0	60.6	69.8	0.40
Aug 10-16	78.7	61.6	70.1	0.20
Aug 17-23	85.6	61.7	73.7	0.00
Aug 24-30	76.9	53.4	65.2	1.15
Aug 31-Sept 6	81.1	56.0	68.6	0.00
Sept 7-13	74.6	53.4	64.0	0.88
Sept 14-20	76.6	60.0	68.3	2.00
Sept 21-27	81.6	67.7	74.7	2.27

	Ave Max	Ave Min	Mean	Depart from normal	Days over 90	Pptn.	Depart from normal
May	74.5	53.8	64.1	2.5	0	3.63	-0.21
June	82.9	63.1	73.0	1.8	4	6.53	2.65
July	87.0	68.5	77.7	2.7	8	6.79	2.80
Aug	80.1	59.1	69.6	-3.5	0	1.88	-2.13
Sept	79.2	60.6	69.9	4.3	0	5.91	2.28

ESTIMATED WEEKLY WATER USE AND RAINFALL AT NORRIS MINE

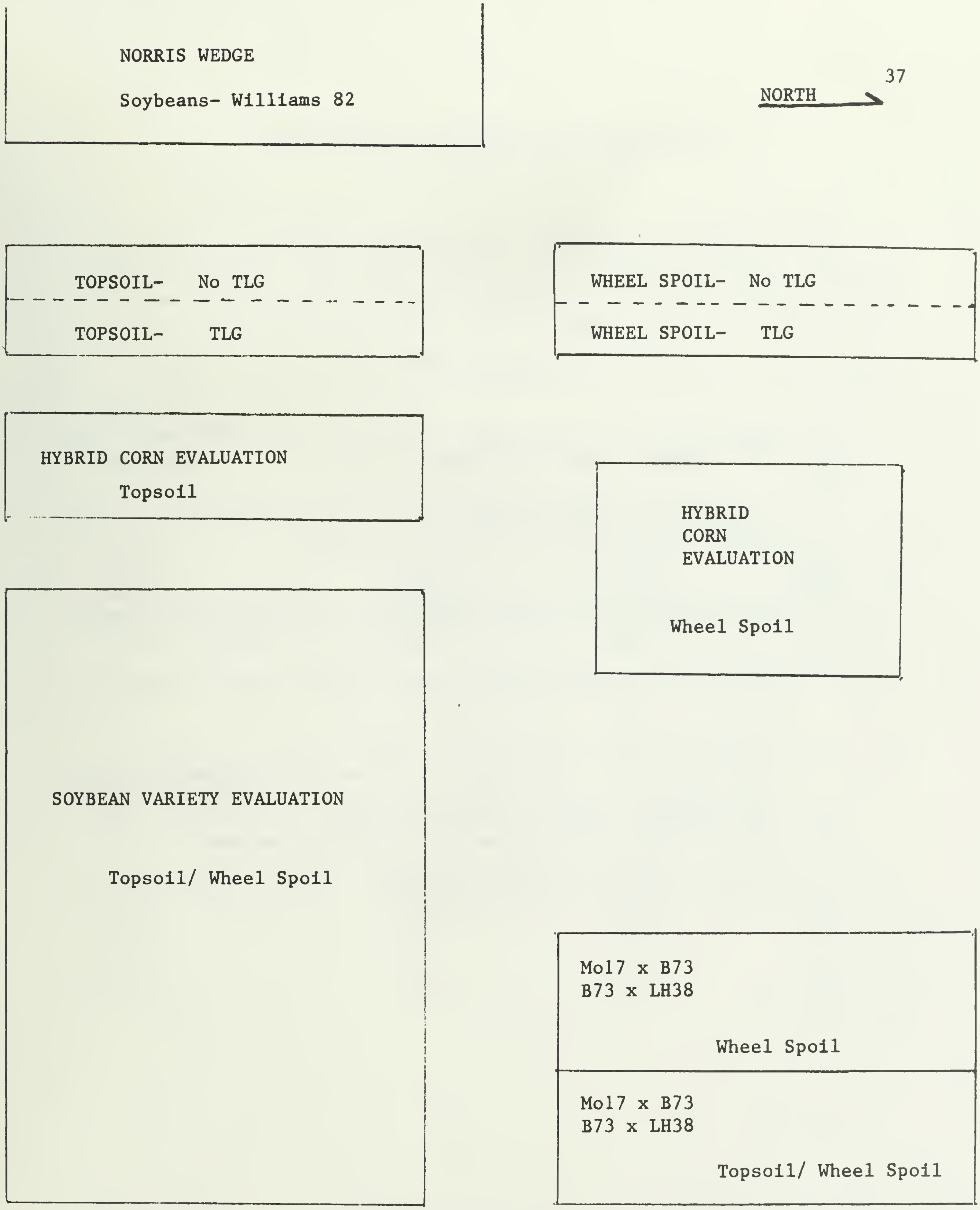


Week	Date	Est Weekly Water Use	Rainfall
A	May 4-10	1.06	0.31
B	May 11-17	1.06	0.56
C	May 18-24	0.50	1.20
D	May 25-31	1.12	0.71
E	Jun 1-7	1.38	2.71
F	Jun 8-14	1.51	1.72
G	Jun 15-21	1.67	0.36
H	Jun 22-28	1.68	1.26
I	Jun 29- Jul 5	1.54	0.69
J	Jul 6-12	1.86	4.33
K	Jul 13-19	1.96	0.90
L	Jul 20-26	1.75	0.05
M	Jul 27- Aug 2	1.61	1.46
N	Aug 3-9	1.12	0.40
O	Aug 10-16	1.10	0.20
P	Aug 17-23	1.20	0.00

PLOT MANAGEMENT RECORD 1986

NORRIS

HYBRID CORN PLOTS	10 Hybrids	
	Planting date	- 13 May
	Planting rate	- 28,000 seeds/ acre
	Fertilizer	- 240 lbs N / acre 120 lbs P / acre 120 lbs K / acre
	Herbicide	- 3 pt Dual / 2 pt Atrazine
	Insecticide	- Furadan
TLG & Exp I CORN	Mo17 x B73 B73 x LH38	
	Planting date	- 24 April
	Planting rate	- 26,000 seeds / acre
	Fertilizer	- 240 lbs N / acre 120 lbs P / acre 120 lbs K / acre
	Herbicide	- 3 pt Dual / 2 pt Atrazine
	Insecticide	- Furadan
SOYBEANS	Williams 82 Fayette Pella GH 1285	
	Planting date	- 9 May
	Planting rate	- 60 lbs / acre
	Fertilizer	- none
	Herbicide	- 3 pt Dual / 4 qt Amiben



1986 NORRIS PLOTS

SUMMARY OF STATISTICAL PROCEDURES

Experimental designs of plots constructed for this project include: completely randomized, randomized complete blocks, and regression. Soils form the main treatment factor at all sites. Hybrid or variety is a split effect on all but those plots having a wedge design for regression analysis.

The following stepwise procedure was used to analyze data:

1. Homogeneity of variances was tested for treatment and split effect populations.

2. If variances were homogeneous, an analysis of variance was used to test for significant differences between treatments and split effects.

3. If variances were heterogeneous, a Students t test was used to determine significant differences between yield means by treatment and split effects.

4. A t test was also used to make comparisons between mined land and undisturbed tracts

5. Regressions were tested for best fit to linear, quadratic, and log models. On the Captain wedge slope and intercept were used to test differences between treatments. A pooled LSD was used to determine the depth at which projected differences became significant. A t test was used to determine significant differences between yields from the topsoil and spoil benches at Norris mine.

UNIVERSITY OF ILLINOIS FIELD PLOTS ON MINED LAND, 1986

SUNSPOT

Corn

Main Plots:

Soil Trt	Mo17 x B73	B73 x LH38	AVE.
	yield, bu/a		
TS/BH	178.9	192.3	185.6 a /1
TS/SP	125.0	129.8	127.4 b
BH Only	174.2	178.3	176.3 a
SP Only	101.9	96.6	99.3 c
Undisturbed	201.8	183.7	192.8 a

Forage Plots:

Soil Trt	Mo17 x B73	B73 x LH38	AVE.
TS/BH- TLG	206.1	206.4	206.2 a
TS/BH	197.5	201.1	199.3 ab
TS/SP- TLG	153.5	166.2	159.9 c
TS/SP	128.4	135.3	131.9 d
BH Only	177.1	191.9	184.5 b
SP Only	95.5	85.3	90.4 e
Undisturbed	201.8	183.7	192.8 ab

/1 The letter following yield values are for significance groupings using the LSD/ t test procedure at the 0.05 level. The comparisons apply only within each column and should not be compared across experiments or subgrouping of experiments.

SUNSPOT

Soybeans

Forage Plots:

Soil Trt	Williams	Fayette	AVE.
	------------- yield, bu/a ----------		
TS/BH- TLG	42.2	43.0	42.6 a
TS/BH	43.9	40.1	42.0 a
TS/SP- TLG	28.4	30.9	29.6 b
TS/SP	28.7	25.2	26.9 b
BH Only	30.7	27.9	29.3 b
SP Only	15.8	14.0	14.9 c
Undisturbed	43.0	44.6	43.8 a

CAPTAIN MIX PLOTS

Corn

Soil Trt	Mo17 x B73	LH119 x LH51	AVE.
	----------- yield, bu/a	----------------	
A/3	105.8	115.3	110.6 a
A/10	114.8	115.8	115.3 a
A/15	102.1	115.2	108.6 a
A/20	92.8	104.4	98.6 a
M10	65.4	72.6	69.0 b
M20	105.4	109.0	107.2 a
Undisturbed	15.5	47.2	31.3 c

CAPTAIN WEDGE

Corn

Soil Trt	Root Media Thickness	Mo17 x B73 yield, bu/a
	22"	22.3 ab
Topsoil/	30"	13.6 b
Root Media	*37"	35.8 ab
	*44"	42.0 a
	22"	23.8 bc
Root Media	30"	15.0 c
Only	*37"	37.5 ab
	*44"	45.3 a

	Topsoil/Root Media	Root Media Only
	--------- yield, bu/a	------------
TLG Ripped	38.9 a	41.4 a
Unripped	17.9 b	19.3 b

* TLG Ripped

CAPTAIN TLG

Corn

Area	Trt	Mo17 x B73	LH119 x LH51	AVE.
		------------- yield, bu/a	---------------	
1	Scraper	58.8	87.5	73.1 b
1	TLG	97.7	102.3	100.0 a
	Undisturbed	66.4	69.0	67.7 b
2	Scraper	54.0	68.9	61.5 b
2	TLG	108.8	147.6	128.2 a
	Undisturbed	66.4	69.0	67.7 b
3	Scraper	13.9	18.6	16.2 b
3	TLG	63.0	73.6	68.3 a
	Undisturbed	66.4	69.0	67.7 a
All	Scraper	42.2	58.3	50.3 b
All	TLG	89.8	107.8	98.8 a
	Undisturbed	66.4	69.0	67.7 b

Soybeans

		Williams	Union	AVE.
1	Scraper	17.0	18.2	17.6 b
1	TLG	29.8	28.2	29.0 a
	Undisturbed	29.8	30.3	30.0 a
2	Scraper	19.8	18.6	19.2 b
2	TLG	32.6	34.9	33.7 a
	Undisturbed	29.8	30.3	30.0 a
3	Scraper	22.6	20.7	21.6 b
3	TLG	29.8	32.0	30.9 a
	Undisturbed	29.8	30.3	30.0 a
All	Scraper	19.8	19.9	19.8 b
All	TLG	30.7	31.7	31.2 a
	Undisturbed	29.8	30.3	30.0 a

CAPTAIN TLG

Sorghum

Area	Trt	Dekalb 42Y
1	Scraper	76.9 a
1	TLG	82.9 a
	Undisturbed	75.7 a
2	Scraper	75.1 b
2	TLG	94.9 a
	Undisturbed	75.7 b
3	Scraper	40.7 b
3	TLG	69.0 a
	Undisturbed	75.7 a
All	Scraper	64.2 b
All	TLG	82.3 a
	Undisturbed	75.7 ab

Wheat

		Cauldwell	FS 402	Mean
		-------------	yield	---------------
1	TLG	59.4	51.9	55.7 a
1	Scraper	49.3	48.5	49.0 b
	Undisturbed	49.5	48.4	48.9 b

1986 CAPTAIN HYBRID STUDY

Soil Trt	Genotype	Yield, bu/a
TLG:	Garst 8344	46.1
	Pioneer 3377	32.5
	Dekalb 636	27.9
	B73 x LH38	26.9
	Dekalb 672	24.8
	Dekalb 656	23.6
	Lynx 4355	22.8
	FS 8475	19.5
	Mo17 x B73	11.2
	FS 6933	10.2
	LSD (0.05)	30.8
	Mean	24.6
Scraper:	Pioneer 3377	52.5
	Dekalb 656	46.9
	Garst 8344	45.0
	FS 6933	41.9
	Dekalb 672	40.8
	Dekalb 636	39.2
	Lynx 4355	35.4
	FS 8475	21.5
	B73 x LH38	21.4
	Mo17 x B73	20.3
	LSD (0.05)	23.2
	Mean	36.4
Stoy:	Pioneer 3377	66.5
	FS 8475	50.9
	Dekalb 672	48.3
	Garst 8344	47.5
	B73 x LH38	38.6
	Mo17 x B73	36.6
	FS 6933	32.3
	Dekalb 636	29.1
	Lynx 4355	27.9
	Dekalb 656	25.7
	LSD (0.05)	30.9
	Mean	40.3

DENMARK

Corn

Soil Trt	Mo17 x B73	LH119 x LH51	AVE.
	---------------- yield, bu/a		--------------
Truck w/o traffic	50.5	76.5	63.5 a
Truck with traffic	42.4	53.4	47.9 ab
Scraper placed	25.2	49.4	37.3 b
Undisturbed	15.5	47.2	31.4 b

Soybeans

Soil Trt	Williams	Union	AVE.
	---------------- yield, bu/a		--------------
Truck w/o traffic	22.8	22.7	22.7 ab
Truck with traffic	18.1	17.5	17.8 bc
Scraper placed	16.2	17.5	16.3 c
Undisturbed	28.6	27.8	28.2 a

NORRIS

Corn

Exp. I:

Soil Trt	Mo17 x B73	B73 x LH38	AVE.
	------------- yield, bu/a		----------
Topsoil/ Wheel Spoil	199.1	206.3	202.7 a
Wheel Spoil Only	165.9	165.6	165.7 b
Undisturbed	180.5	187.2	183.8 b

TLG Exp:

Soil Trt	Mo17 x B73	B73 x LH38	AVE.
	------------- yield, bu/a		-----------
Topsoil/ Spoil- TLG	199.6	174.4	187.0 ab
Topsoil/ Spoil- No TLG	191.2	171.8	181.5 ab
Wheel Spoil- TLG	210.7	183.5	197.1 a
Wheel Spoil- No TLG	180.3	175.7	178.0 b
Undisturbed	180.5	187.2	183.8 ab

Soybeans

Variety	Topsoil/ Wheel Spoil	Sable Soil
	--------------- yield, bu/a	----------
Williams 82	46.2 b	44.4 b
Fayette	45.9 b	46.0 b
Pella	51.8 a	47.0 b
G.H. 1285	49.4 ab	56.7 a

1986 NORRIS HYBRID STUDY

Soil Trt	Genotype	Yield, bu/a
Topsoil/ Wheel Spoil:	B73 x LH51	209.8
	LH119 x LH51	197.5
	B73 x LH123	194.4
	Mo17 x B73	186.1
	LH74 x LH123	181.9
	NK 9581	178.9
	LHE136 x LH24	174.6
	B73 x LH38	173.9
	GRE 82-10	166.8
	ANS 83-17	157.5
	LSD (0.05)	29.6
	Mean	182.0
Wheel Spoil:	B73 x LH38	165.5
	GRE 82-10	162.1
	B73 x LH123	160.0
	LHE136 x LH24	159.0
	LH74 x LH123	158.2
	ANS 83-17	157.9
	Mo17 x B73	153.8
	LH119 x LH51	151.5
	NK 9581	145.8
	B73 x LH51	140.4
	LSD (0.05)	33.9
	Mean	155.4
Sable:	B73 x LH123	222.4
	B73 x LH51	218.6
	LH119 x LH51	212.4
	NK 9581	199.8
	LH74 x LH123	199.6
	LHE136 x LH24	186.7
	GRE 82-10	183.4
	Mo17 x B73	180.1
	B73 x LH38	172.1
	ANS 83-17	152.8
	LSD (0.05)	29.3
	Mean	192.8

1986 NORRIS HYBRID STUDY

Genotype	Soil Trt	Yield, bu/a	Pollination	Plant Ht
Mo17 x B73	PL	180.1	69.5	106.3
	TS	186.1	70.5	111.5
	SP	153.8	70.5	99.8
B73 x LH38	PL	172.1	66.0	101.3
	TS	173.9	66.5	103.5
	SP	165.5	69.0	97.2
LHE136 x LH24	PL	186.7	65.0	106.8
	TS	174.6	66.5	104.7
	SP	159.0	73.0	98.2
B73 x LH123	PL	222.4	65.0	108.2
	TS	194.4	68.5	120.0
	SP	160.0	72.2	96.6
B73 x LH51	PL	218.6	67.0	105.2
	TS	209.8	70.0	129.2
	SP	140.4	70.2	94.3
LH119 x LH51	PL	212.4	66.5	104.3
	TS	197.5	67.2	103.6
	SP	151.5	71.0	90.8
LH74 x LH123	PL	199.6	67.0	98.2
	TS	181.9	66.5	104.5
	SP	158.2	71.5	95.3
NK 9581	PL	199.8	66.5	106.2
	TS	178.9	68.5	113.0
	SP	145.8	70.0	95.3
GRE 82-10	PL	183.4	65.0	106.0
	TS	166.8	66.6	109.0
	SP	162.1	72.6	93.8
ANS 83-17	PL	152.8	65.0	101.7
	TS	157.5	68.0	103.0
	SP	157.9	71.6	95.5
LSD for Soil Trt Comparisons For A Single Hybrid (0.05)		16.2	1.4	3.4
All Hybrids	PL	192.8	66.2	104.4
	TS	182.0	67.5	110.2
	SP	155.4	71.2	95.7
LSD for Soil Trt Comparisons Across All Hybrids (0.05)		10.2	0.8	2.9

RIVER KING YIELD SUMMARY 1979-85

Soybeans

Soil Trt	1978	1979	1980	1981	1982	1983	1984	1985	79-83 Ave.	81-83 Ave.
	----------	----------	----------	----------	Yield, bu/a	----------	----------	----------	----------	----------
Main Plot:										
TS/SP	7	24a	12b	28a	24a	3	--	--	18	18
SP Only	9	14b	19a	18b	12b	2	--	--	13	13
TS/Scraper		14b	10b	19b	23a	0	--	--	13	14
Forage Plot:										
TS/SP				29a	29a	4	--	--		21
SP Only				24a	29a	4	--	--		19
Undisturbed					34	13				23

Corn

Soil Trt	1978	1979	1980	1981	1982	1983	1984	1985	78-85 Ave.	81-85 Ave.
Main Plot: (21,000 Pop)										
TS/SP	30a	53b	12a	109a	87b	14a	60b	62ab	54	66
SP Only	40a	67a	9a	101a	66c	24a	52b	52 b	52	59
TS/Scraper		45b	1b	87b	59c	0	18c	20 c	33	37
Undisturbed					137a	16a	106a	84a		
Main Plot: (26,000 Pop)										
TS/SP				113a	92b	8a	42b			64
SP Only				112a	76c	11a	47b			62
Undisturbed					137a	16a	106a			
Forage Plot:										
TS/SP				114a	87b	26a	85a			78
SP ONly				103a	70c	26a	75a			69
Undisturbed					137a	16a	106a			

SUNSPOT YIELD SUMMARY 1979-86

Soybeans

Soil Trt	1979	1980	1981	1982	1983	1984	1985	1986	79-86 Ave.	80-86 Ave.
Main Plots:	----------	----------	----------	Yield, bu/a	----------	----------	----------	----------	----------	----------
TS/BH	18a	36a	46a	48a	0	33b	52a	--	33	36
TS/SP	16ab	33ab	45a	41ab	0	27c	38b	--	29	31
BH Only	15b	29b	33b	38 b	0	26c	34c	--	26	27
SP Only	7c	21c	25c	26c	0	14d	19d	--	16	17
Clarksdale		37a	39ab	46a	26	42a	49a			40
Forage Plots:										85-86
TS/BH							58a	42a		50
TS/BH-TLG							53b	43a		48
TS/SP							44cd	27b		36
TS/SP-TLG							41d	30b		36
BH Only							45c	29b		37
SP ONly							15e	15c		15
Clarksdale							49bc	44a		46

Corn

Soil Trt	1979	1980	1981	1982	1983	1984	1985	1986	79-86 Ave.	80-86 Ave.
Main Plots:										
TS/BH	62a	80a	124b	168a	0	122ab	141a	186a	110	116
TS/SP	62a	50b	103c	154b	0	79c	86c	127b	83	88
BH Only	69a	53b	94cd	137c	0	112b	114b	176a	94	96
SP Only	20b	26c	80d	89d	0	56d	60c	99c	54	58
Clarksdale		88a	146a	174a	59	135a	156a	193a		134
Forage Plots:										85-86
TS/BH							167a	199ab		183
TS/BH-TLG							166a	206a		186
TS/SP							111b	132d		135
TS/SP-TLG							110b	160c		135
BH Omly							119b	185b		152
SP Only							52c	90e		71
Clarksdale							156a	193ab		174

CAPTAIN MIX PLOT YIELD SUMMARY 1981-86

Soybeans

Soil Trt	1981	1982	1983	1984	1985	1986	Ave.
	Yield, bu/a						
A/3	35a	49a	18a	31ab	45a	--	35
A/10	29bc	38b	14ab	31ab	43a	--	31
A/15	26c	40b	15ab	32a	43a	--	31
A/20	27bc	41b	13ab	32a	40ab	--	30
10' MIX	25c	39b	11b	27ab	36b	--	27
20' MIX	31b	43ab	12ab	27b	35b	--	29
Undisturbed	22c	48a	15ab	0	36b	--	24

Corn

Soil Trt	1981	1982	1983	1984	1985	1986	Ave.
A/3	113a	144abc	72a	125a	109ab	111a	111
A/10	83c	152ab	52ab	113ab	93c	115a	102
A/15	105ab	121d	69ab	115a	110a	109a	105
A/20	92bc	130cd	53ab	108ab	96bc	99a	96
10' MIX	56d	145ab	47ab	98b	76d	69b	82
20' MIX	81c	140bc	40b	99b	81cd	107a	92
Undisturbed	123a	160a	58ab	0	67d	31c	74

CAPTAIN WEDGE YIELD SUMMARY 1979-85

Corn

Topsoil/ Root Media

Depth of Media	1979	1980	1981	1982	1983	1984	1985
	Yield, bu/a						
3"	81	0	37	63	0	0	0
6"	69	0	37	46	0	0	0
10"	77	0	40	65	0	0	0
13"				45	0	0	
15"			39				1
19"	90	0					
22"	89	0	51	84	0	0	19
25"				72	0	0	
30"			51	59	0	0	
32"	89	0		51	0	0	24
37"	86	0	43				55
42"				52	0	0	
44"	92	0	50	50	0	0	47

Root Media Only

Depth of Media	1979	1980	1981	1982	1983	1984	1985
3"	60	0	31	80	0	0	0
6"	68	2	39	60	0	0	0
10"	61	0	52	78	0	0	0
13"				74	0	0	
15"		1	58				12
22"	82	5	68	100	0	0	26
25"				94	0	0	
30"		1	60	71	0	0	
32"	81			67	0	0	28
37"	82	0	56				71
42"				78	0	0	
44"	72	5	73	60	0	0	56

CAPTAIN WEDGE YIELD SUMMARY 1979-85

Soybeans

Topsoil/ Root Media

Depth of Media	1979	1980	1981	1982	1983	1984	1985
	Yield, bu/a						
2"		0	9	16	0	0	
3"	19						14
6"	22	0	11	18	0	0	12
10"	23	0	12	16	0	0	12
15"		0	14	18	0	0	
19"	31						15
22"	30	0	15	22	0	0	20
30"		0	13	24	0	0	
32"	32						17
35"	28	0					
37"		0	18	25	0	0	27
44"		0	17	26	0	0	27
45"	27						

Root Media Only

Depth of Media	1979	1980	1981	1982	1983	1984	1985
2"		0	9	15	0	0	
3"	10						16
6"	12	0	12	18	0	0	19
10"	11	0	11	18	0	0	24
15"		0	14	20	0	0	
19"	14						25
22"	16	0	18	23	0	0	29
30"		0	15	22	0	0	
32"	10						22
35"	13	0					
37"		0	20	27	0	0	31
44"		0	19	26	26	0	24
45"	12						

NORRIS TOPSOIL WEDGE YIELD SUMMARY 1979-85

Corn

Soil Trt	Depth	1979	1980	1981	1982	1983	1984	1985
		------------------- Yield, bu/a -------------						
TS Bench	18"	109	2	158	176	0	66	77
	24"	114	1	156	161	0	54	79
	22"	113	0	184	136	0	37	67
	20"	93	0	147	156	0	20	50
	18"	100	0	177	133	0	20	51
	16"	92	2	157	159	0	42	55
Topsoil	14"	105	6	158	156	0	45	63
Wedge	12"	83	5	158	147	0	59	56
	10"	73	12	140	155	0	57	60
	8"	77	20	138	138	0	57	63
	6"	63	11	161	142	0	44	59
	4"	46	8	144	140	0	51	49
	2"	51	17	143	151	0	61	56
SP Bench	0	55	42	128	129	13	53	72
Undisturbed		156	124	173	152	70	183	142

Soybeans

Soil Trt	Depth	1979	1980	1981	1982	1983	1984
TS Bench	18"	17	20	42	42	4	17
	24"	17	19	44	41	2	19
	22"	16	19	39	44	2	19
	20"	14	20	44	40	2	17
	18"	9	19	40	42	2	15
	16"	14	17	47	40	4	18
	14"	14	15	45	46	6	19
	12"	19	16	49	42	5	20
	10"	18	14	43	43	4	20
	8"	22	15	46	44	4	24
	6"	16	14	45	44	3	19
	4"	16	12	45	40	5	20
	2"	10	11	42	38	5	18
SP Bench	0	12	6	40	30	2	13
Undisturbed		37	40	58	49	38	37

NORRIS IRRIGATION YIELD SUMMARY 1979-85

Irrigation Frequency of Corn on Topsoil/ Wheel Spoil

Irrig Trt	1980	1981	1982	1983	1984	1985	Ave.
	Yield, bu/a						
2" / Week	164a	164a	164a	184a	186a	146ab	168
1" / Week	140b	165a	158a	118b	175a	148a	151
Unirrigated	16c	164a	164a	13d	117b	126b	100
Undisturbed	124b	173a	152a	70c	183a	142ab	140

Irrigation Frequency of Soybeans on Topsoil/ Wheel Spoil

Irrig Trt	1980	1981	1982	1983	1984	1985	Ave.
2" / Week	39a	47b	52a	54a	41a	47b	47
1" / Week	36a	47b	53a	42ab	42a	47b	44
Unirrigated	35a	44b	51a	18c	29b	53a	38
Undisturbed	40a	58a	49a	38b	37a	51a	45

Topsoil/ Wheel Spoil vs Wheel Spoil- Irrigated & Unirrigated

Trt	1979	1980	1981	1983	Ave.	1982	1984	Ave
Irrig TS	191a	166a	175a	193a	181	57a	35a	46
Unirrig TS	155b	70d	165a	20c	102	57a	26ab	42
Irrig SP	142b	144b	105b	169a	140	47b	30ab	39
Unirrig SP	100c	89c	109b	70b	92	43b	22b	32

DENMARK (LEAHY) YIELD SUMMARY 1985-86

Corn

Soil Treatment	1985	1986	Ave.
	-------- Yield, bu/a	-------	
Truck hauled w/o traffic	98 ab	64 a	81
Truck hauled with traffic	85 bc	48 ab	66
Scraper placed	74 c	37 b	55
Undisturbed	115 a	31 b	73

Soybeans

Soil Treatment	1985	1986	Ave.
	-------- Yield, bu/a	--------	
Truck hauled w/o traffic	29 b	23 ab	26
Truck hauled with traffic	24 b	18 bc	21
Scraper placed	26 b	16 c	21
Undisturbed	36 a	28 a	32

PENETROMETER STUDIES SPRING 1986

This past year we collected data from; Captain TLG, Norris TLG, Denmark, Consol Burning Star #4, Freeman Fidelity, and for Neil Patterson's study. Penetrometer profiles for the Captain TLG plots were taken from all three areas. Table 1 reflects the effects of the TLG. Area 1 showed somewhat lower penetrometer resistance for treated areas, but none of the differences were statistically significant. Area 2 had the lowest resistance in the unripped soils of the three areas. The TLG did significantly reduce resistance in the 10-18 in. segment. Area 3 has the most dramatic differences with the un-ripped ground being the highest and the TLG being the lowest. A significant difference was found even in the 27-35 in. segment.

The TLG plots at the Norris site were sampled on both topsoil and spoil. The TLG was successful in significantly lowering soil strength in segment 2 and 3 across both topsoil and spoil, Table 2. Interestingly penetrometer resistance in the 19-26 in. segment of the un-ripped topsoil was significantly higher than that of the un-ripped spoil at that depth. This depth is just below the depth of topsoil placement by scrapers. This peak can be seen in Fig 2a.

Penetrometer data were taken at all harvest sites on the Denmark plots. There are three soil treatments at this site;

a scraper placed soil and two soils built with rear dump trucks, one having all traffic on the base level and the other having truck traffic on top of the soil. There were no significant differences among soils in the south set of plots. The truck-with-no-traffic soils had significantly lower soil strengths than the scraper-built soils in the north set of plots, Table 3. The truck-with-traffic soils were intermediate in soil strength between the other two soils, but not statistically distinguishable from either. The scraper-built soils at this site have lower soil strength than do most scraper-placed materials.

Data taken at Burning Star # 4 was on a TLG treated scraper area and an adjacent area of scraper placed root media. Table 4 shows a significant lowering of resistance in segments 2 and 3 for the TLG treatment.

At Fidelity three comparison areas were evaluated in topsoil over wheel spoil materials. One area was a block of TLG treated ground divided into scraper placed topsoil and dozer placed topsoil. The second was in scraper placed topsoil with and without a TLG treatment. The third area was where this TLG block went across a topsoil berm with readings taken both in and out of the TLG area on the berm. Scrapers built the berm and dozers pushed the topsoil out. This entire area was in wheat and fairly dry down to about 18 inches especially in the un-ripped area. In Table 5 the berm had the highest readings and the TLG did reduce the resistance within the operating depth of the TLG. The dozer vs. scraper TLG showed no significant difference at any depth. The TLG vs. no TLG on the scraper topsoil showed no differences except in segment 2.

The TLG was effective in reducing soil strength, both in areas where the topsoil had been spread by dozers and in areas where a topsoil berm had been placed with scrapers for subsequent spreading over adjacent areas. Soils directly under the berm and with no TLG treatment were significantly higher in soil strength at all depths than soils in adjacent areas. The TLG treatment successfully corrected the berm-induced compaction to a depth of about 27 inches, but not below that. Hence, soils under the berm remained more compacted below 27 inches in depth than adjacent soils, even after TLG treatment.

The topsoil berm, spread with dozers, technique is intended to control compaction by keeping scraper traffic off as much of the land surface as possible. Observations elsewhere have generally indicated that scraper spreading of topsoil does induce compaction, but only in the top foot or so of material below the replaced A horizon material. That would put most of the scraper-induced compaction within a depth range which could be reached by the TLG. The 1986 Fidelity data supports that expectation in that after TLG treatment, there was no significant difference in soil strength between soils having dozer replaced topsoil and those having scraper placed.

This study needs additional verification during the 1987 season, because of rather critical implications. Should the 1986 Fidelity conclusions hold, it would appear that berming the topsoil for scraper spreading would be advisable only where no subsequent TLG treatment was planned. That being because the TLG is capable of correcting the damage caused by scrapers in direct placement of topsoil, but is not capable of completely correcting the damage caused by the berm placement and/or weight.

Table 1

Captain TLG Area

Area 1

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	-------Penetrometer Resistance, PSI---------			
Scraper	485.12 a	402.59 a	284.86 a	311.73 a
TLG	357.08 a	306.77 a	242.78 a	284.34 a
LSD(0.05)	238.20	172.40	143.20	227.88

Area 2

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	-------Penetrometer Resistance, PSI---------			
Scraper	275.43 a	288.62 a	229.28 a	203.95 a
TLG	160.30 b	190.96 a	254.16 a	176.78 a
LSD(0.05)	109.20	188.54	272.51	147.60

Area 3

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	-------Penetrometer Resistance, PSI---------			
Scraper	556.98 a	525.00 a	445.87 a	435.39 a
TLG	112.89 b	142.74 b	319.42 b	367.48 a
LSD(0.05)	233.44	132.60	112.20	72.60

Segment	Depth(approx.)
Seg 2	10-18 in.
Seg 3	19-26 in.
Seg 4	27-35 in.
Seg 5	36-44 in.

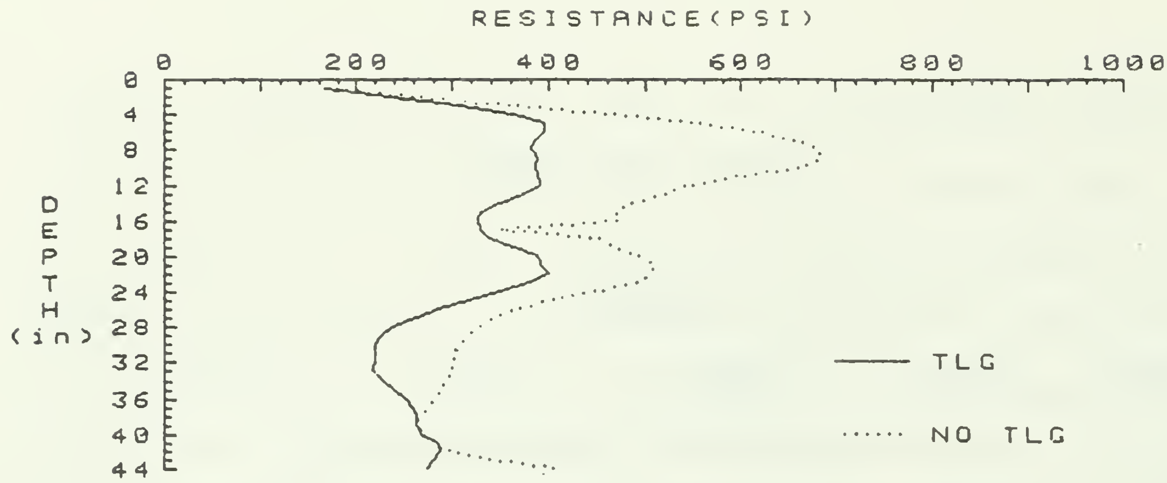


Fig 1a. Captain TLG Area 1

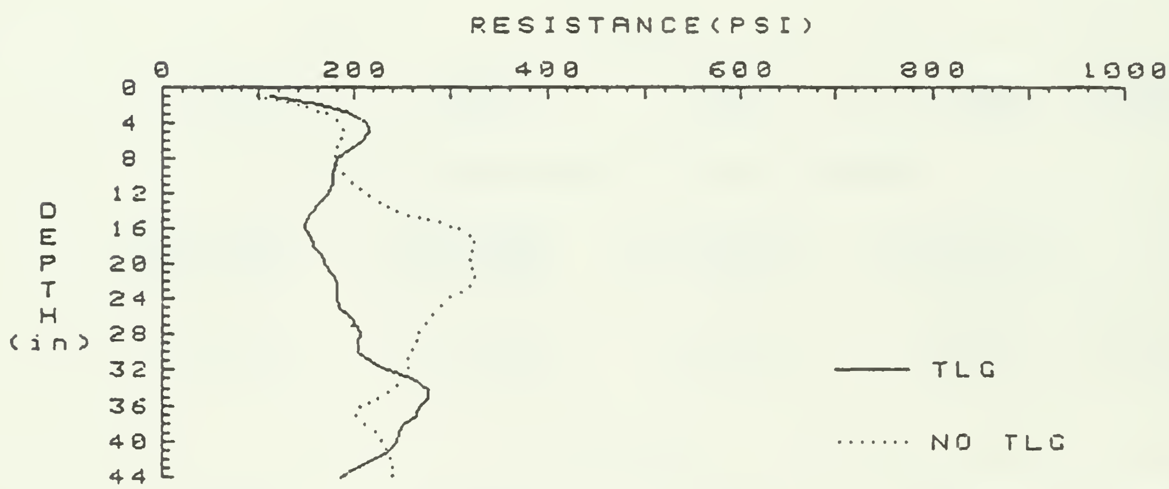


Fig 1b. Captain TLG Area 2

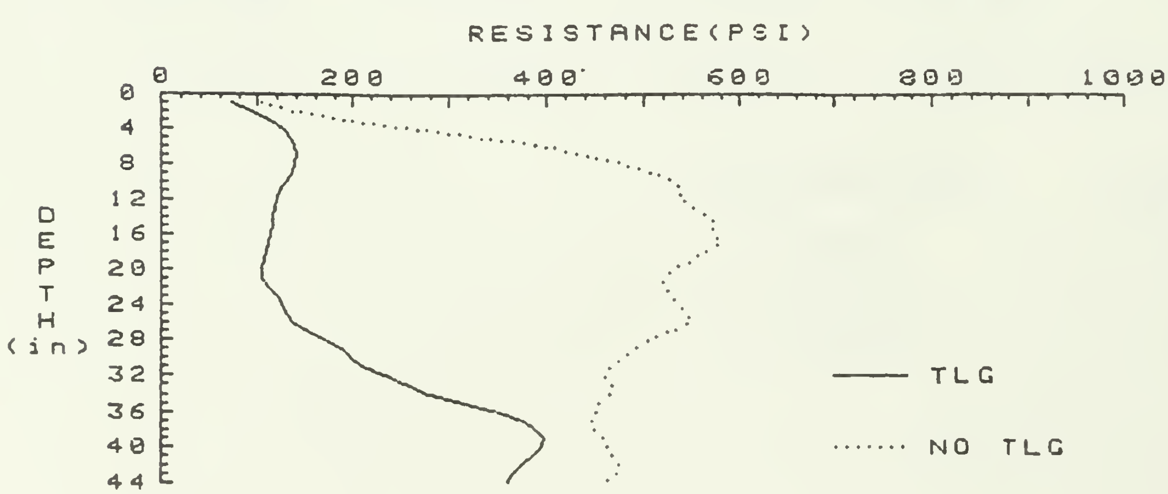


Fig 1c. Captain TLG Area 3

Table 2

Norris TLG

Treatment	Seq 2	Seq 3	Seq 4	Seq 5
	-------Penetrometer Resistance, PSI---------			
TS CON	278.36 a	461.17 a	424.19 ab	339.00 a
SP CON	271.22 a	285.00 b	342.60 ab	356.87 a
SP TLG	152.35 b	162.29 c	279.09 b	307.74 a
TS TLG	115.77 b	103.68 c	435.32 a	369.91 a
LSD(0.05)	65.11	97.70	148.40	145.10

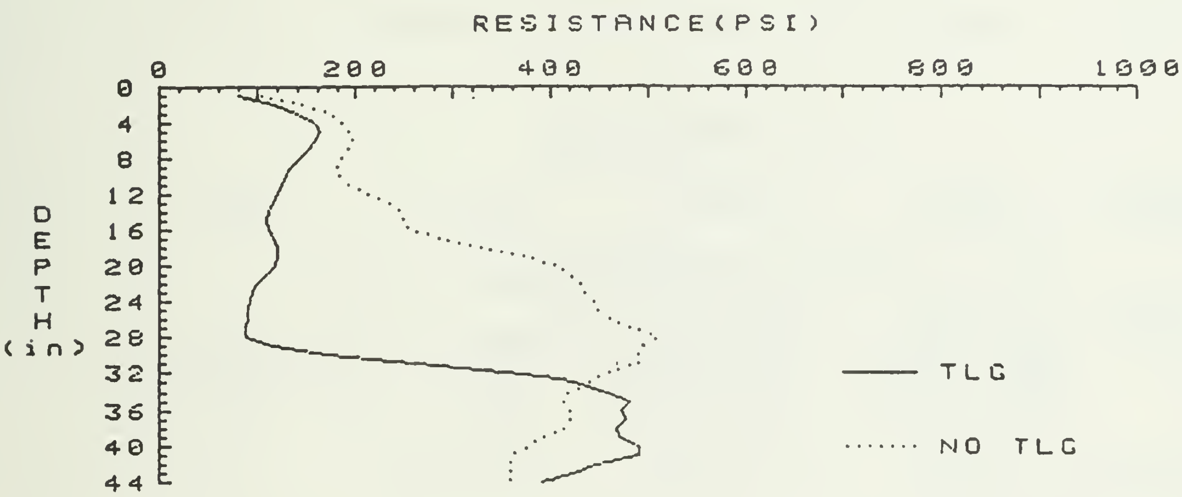


Fig 2a. Norris TLG Topsoil/Spoil

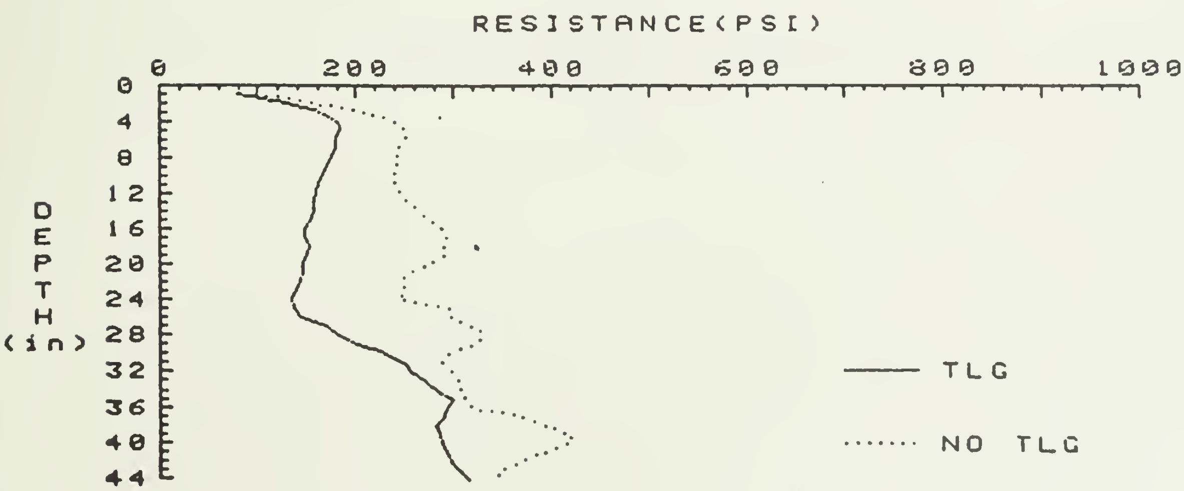


Fig 2b. Norris TLG Spoil only

Table 3

Denmark

North Side

Treatment	Seq 2	Seq 3	Seq 4	Seq 5
	-------Penetrometer Resistance, PSI---------			
Scraper	269.64 a	240.92 a	224.72 a	235.48 a
TWT	193.46 ab	199.74 ab	181.30 ab	206.65 a
TNT	182.46 b	167.64 b	158.12 b	173.11 a
LSD(0.05)	82.53	61.49	64.73	81.48

South Side

Treatment	Seq 2	Seq 3	Seq 4	Seq 5
	-------Penetrometer Resistance, PSI---------			
Scraper	222.88 a	232.18 a	214.06 a	202.00 a
TWT	231.45 a	217.61 a	193.11 a	188.88 a
TNT	156.87 a	187.27 a	145.01 a	122.79 a
LSD(0.05)	86.02	70.95	82.26	81.68

TWT - Truck with traffic
TNT - Truck no traffic

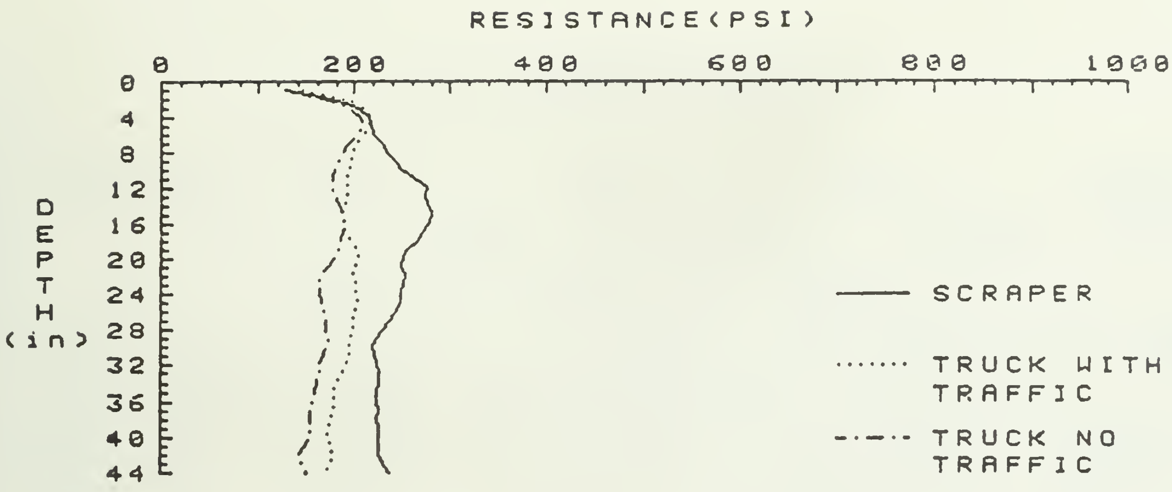


Fig 3a. Denmark North side

Fig 3b. Denmark South side

Table 4

Consol Burning Star #4

Treatment	Seq 2	Seq 3	Seq 4	Seq 5
	-------Penetrometer Resistance, PSI---------			
Scraper	459.73 a	438.49 a	416.79 a	378.22 a
TLG	158.89 b	189.73 b	344.13 a	363.70 a
LSD(0.05)	76.85	112.20	161.25	161.86

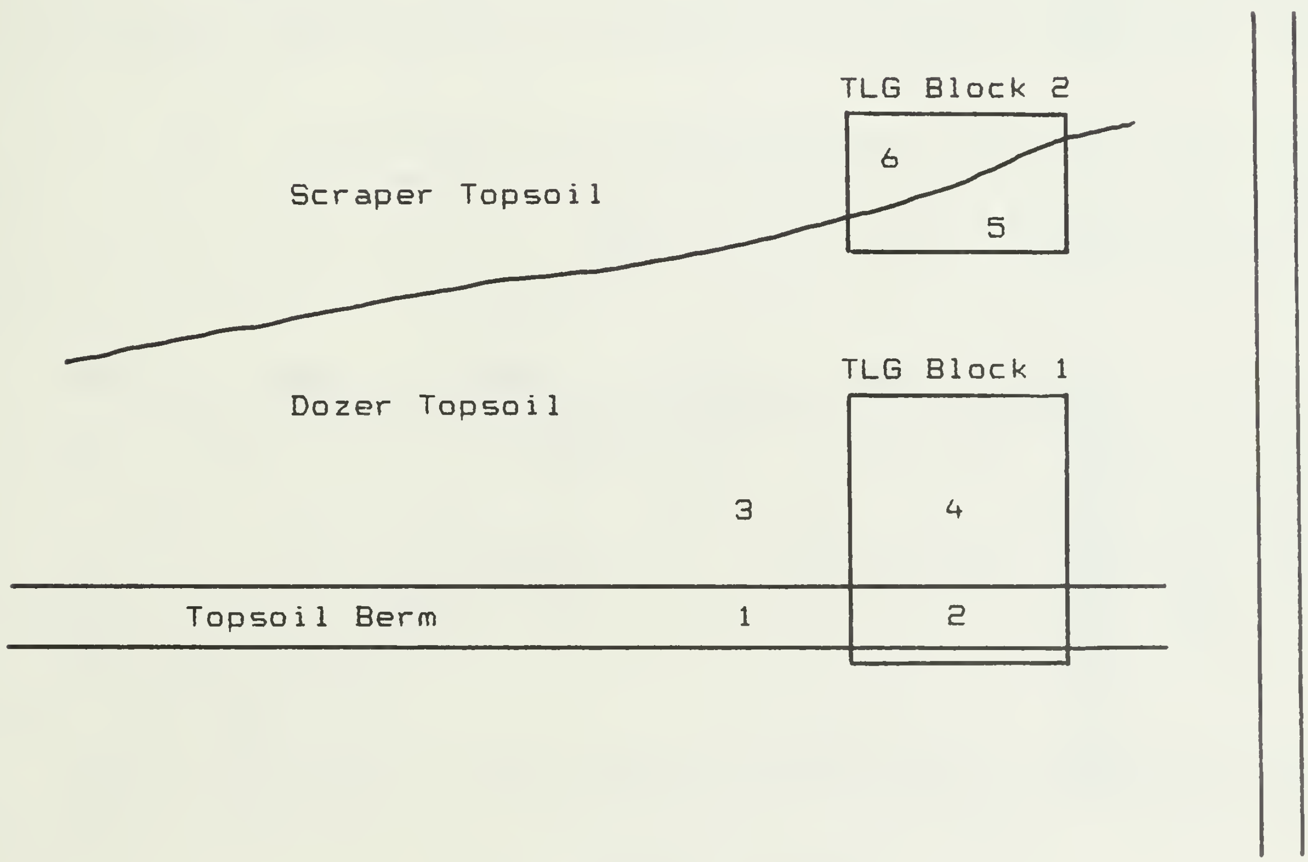
Fig 4. Burning Star #4 TLG

Table 5

Freeman Fidelity

Treatment	Seq 2	Seq 3	Seq 4	Seq 5
	-------Penetrometer Resistance, PSI------------			
BER CON	1146.40 a	640.80 a	506.80 a	395.85 a
WSP CON	820.60 b	447.34 b	289.56 bc	269.59 bc
WSP TLG	540.60 c	320.26 bc	176.07 c	149.66 d
BER TLG	400.00 cd	248.05 c	375.95 b	331.71 ab
DOZ TLG	288.30 d	186.37 c	267.21 bc	236.91 cd
SCR TLG	286.70 d	278.64 c	282.51 bc	209.19 cd
LSD(0.05)	198.80	137.50	115.89	78.69

1 - BER CON - Topsoil Berm no TLG
2 - BER TLG - Topsoil Berm TLG - Block 1
3 - WSP CON - Dozer Topsoil no TLG
4 - WSP TLG - Dozer Topsoil TLG - Block 1
5 - DOZ TLG - Dozer Topsoil TLG - Block 2
6 - SCR TLG - Scraper Topsoil TLG - Block 2



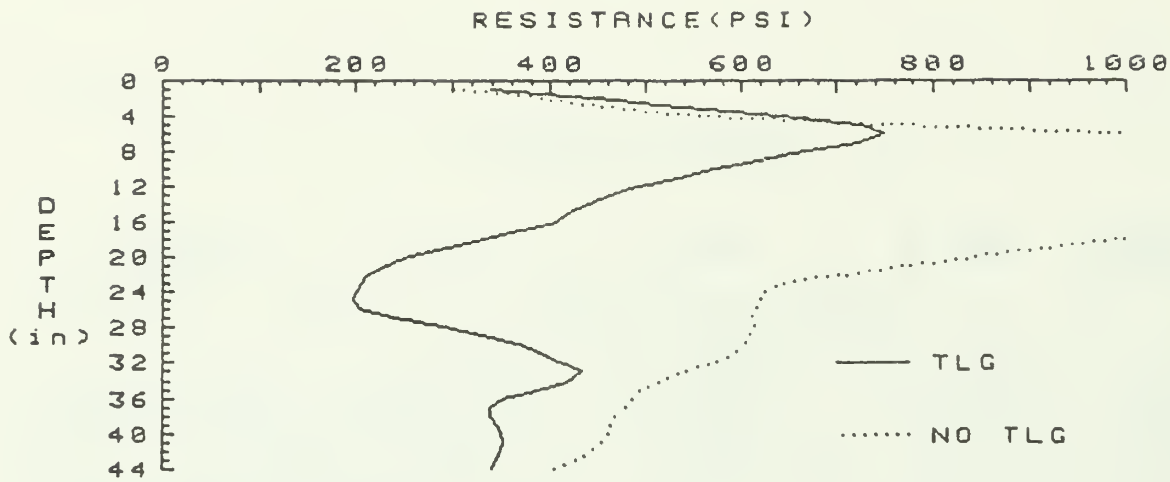


Fig 5a. Fidelity Berm

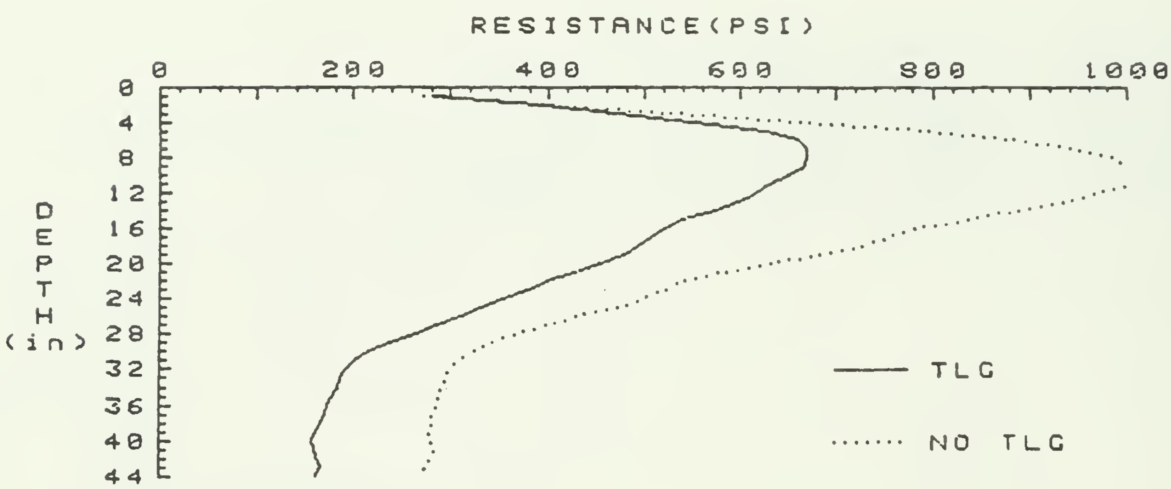


Fig 5b. Fidelity Dozer TS/WS

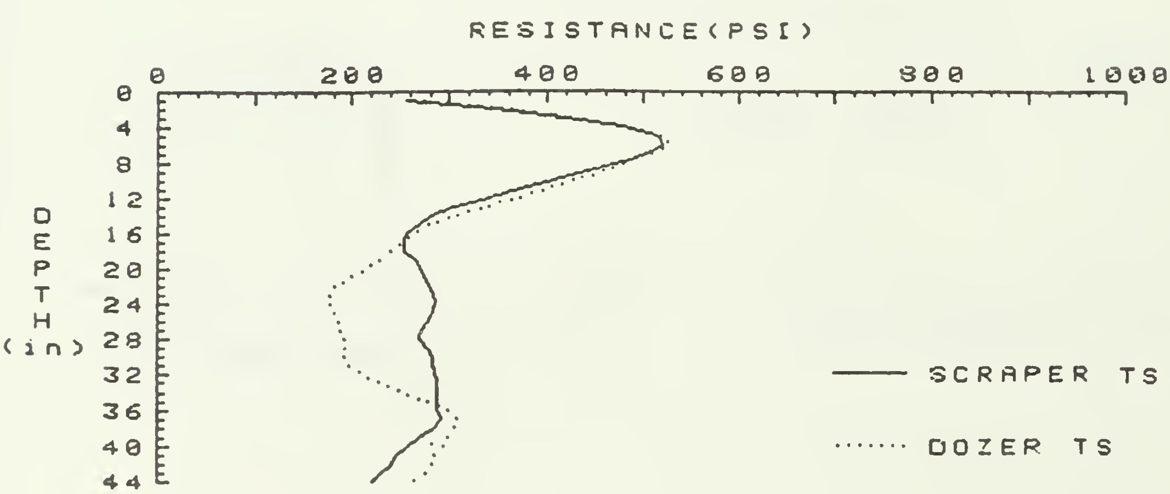


Fig 5c. Fidelity TLG

NEUTRON PROBE DATA, 1986

Neutron probe readings relate to volumetric water content. Hence the data can be used more directly than tensiometer data (which represents soil moisture tension) to the amount of water extracted from a soil over given time periods. Access tubes were installed and monitored from June 23 through July 21 at four sites to evaluate the effects of alternative soil construction methods and of TLG treatment.

The Captain Wedge:

The soils at this site were built with scrapers in 1978. Corn and soybeans have been grown on these soils from 1979 to the present. Crop performance has been poor, particularly in seasons with less rainfall and/or higher temperatures than normal. Excavation of root systems and penetrometer studies have indicated that soil strength is excessive due in part to compaction as the soils were constructed. A 40 foot strip along the deep end of the wedge on both sides of the turn strip was treated with the TLG in August of 1984, to evaluate the effectiveness of the TLG in alleviating that excess compaction.

Tables A1 - A3 present the neutron probe data for this site in 1986. The actual volumetric water content at a particular point in time is less meaningful than the amount of water that is extracted from the soil by the crop during a period of low rainfall when the crop was dependent upon soil stored water. The most meaningful approach to interpretation is to note the change in separation between the two lines on each graph, because any change in separation represents a difference in the amount of water actually extracted by the crop.

The most interesting time period is from June 23 to July 11, because that was a period of low rainfall such that the corn went into stress. The crop was largely dependent on whatever water it could extract from the soil. Substantial rainfall between July 11 and July 21 removed the stress factor and provided water from outside the soil.

The one foot depth was low in water content and very little water was extracted from either soil during this period (Fig. A1). Available water from this depth had already been largely used before June 23. At the two foot depth (Fig. A2), the TLG treated soil supplied about 0.06 (cc water/cc soil) as opposed to about 0.04 cc/cc for the nontreated soil. There was very little if any difference between the two soils in the amount of water supplied from the three foot depth.

Captain TLG, East end:

So far, the story looks pretty interesting, but data for the TLG effect comparison from the east end of the Captain mine suggest an opposite effect (Fig., B1 - B4). At this site the amount on water extracted from the two soils at the one and two foot depths is very similar, but more water was extracted from the nonTLG than from the TLG treated soils at the three and four foot depths. The difference in amount of water extracted was small at both sites.

Captain Mix 20' vs. A/20':

In the Captain Mix 20' vs. A/20' comparison (Fig. C1 - C5), it is evident that more water was extracted from the Mix 20' soil than from the A/20' soil at the two and three foot levels, but the opposite was true at the four and five foot levels. That is not a contradiction, however. The total amount of water extracted from the two soils is not conspicuously different, only the depth from which it was extracted. Unlike the wedge plots, corn on these plots did not show stress during the 86 season, indicating that both soils furnished a reasonably adequate supply of water. Previous work has revealed compaction and restricted rooting in the zone immediately below the replaced topsoil in the A/20' soil, with no comparable compacted zone in the Mix 20' soil. Hence it is not surprising that corn extracted less water at that depth on the former than on the latter. Both soils generally have a comparably favorable rooting environment at the four and five foot depths, hence corn on the A/20' soil was readily able to extract the balance of its needed water from those depths.

Denmark Plots:

The most conspicuous difference among treatments (scraper, truck-with-traffic, and Truck-without-traffic) is that the scraper built soils were consistently lowest in total volumetric water content (Fig. D1 - D4). Only the two foot depth segment shows much water extraction, and at that depth the amount extracted was greatest for the truck-without-traffic soils and least for the scraper soils.

Captain Mix vs. Captain Wedge:

Figures E1 - E5 were formed by superimposing the Wedge plot data on the Mix data. The Mix plot curves have considerably more slope at the two, three, and four foot depths than do the Wedge plot curves, indicating that they have furnished more water during the critical time period.

Summary:

This neutron probe data leaves us short of being able to draw conclusions of consequence, but it is sufficiently interesting to justify a follow-up study in 1987. Data taking in the 1987 phase of the study will begin about June 1 rather than in late June. The earlier beginning will enable more complete documentation of the differences in water extraction among treatments.

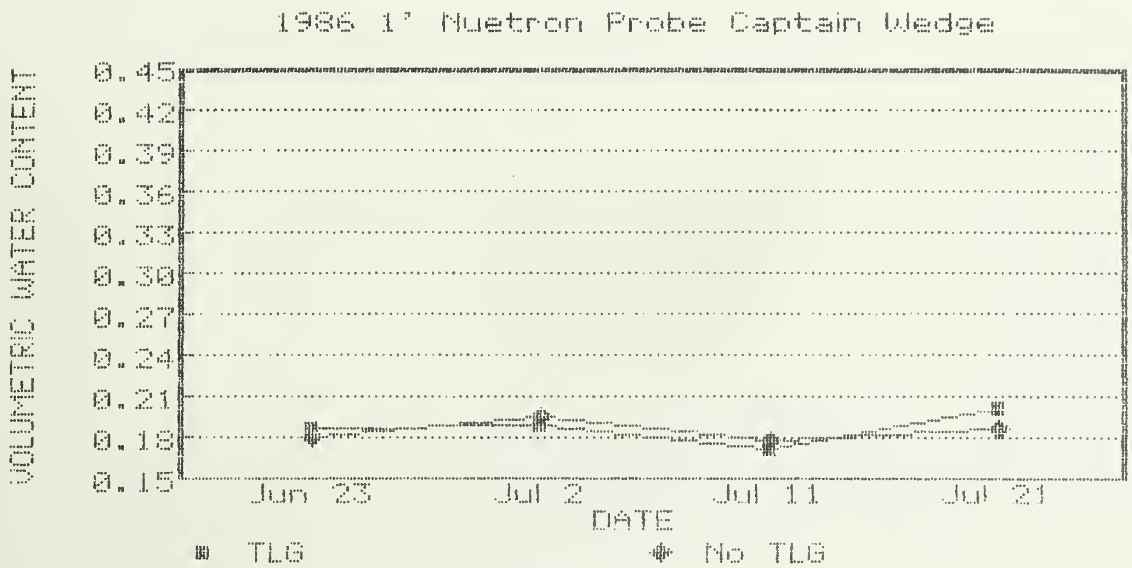


Fig. A1

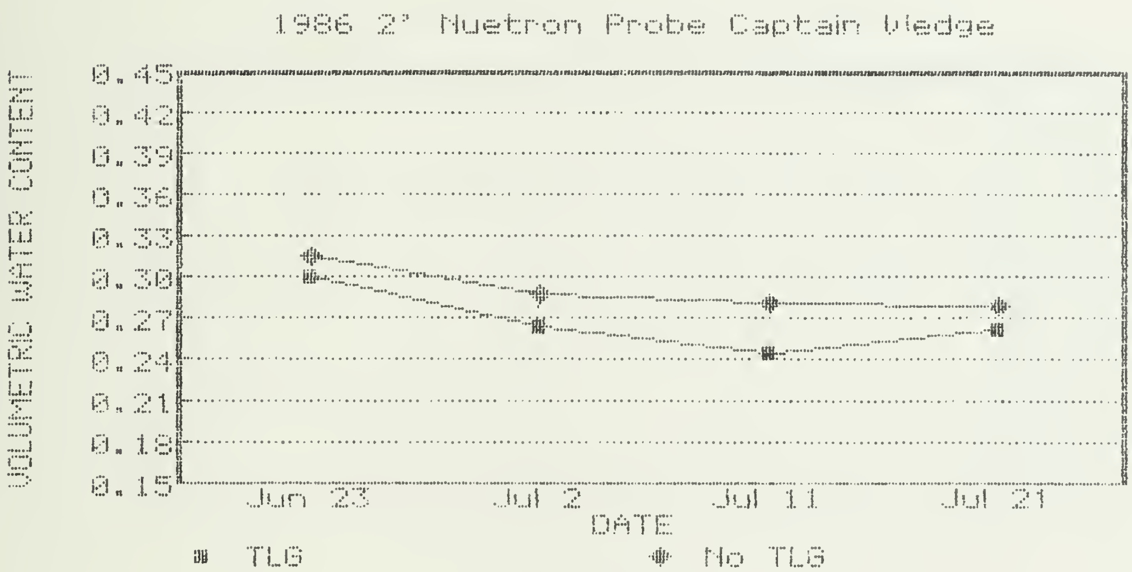


Fig. A2

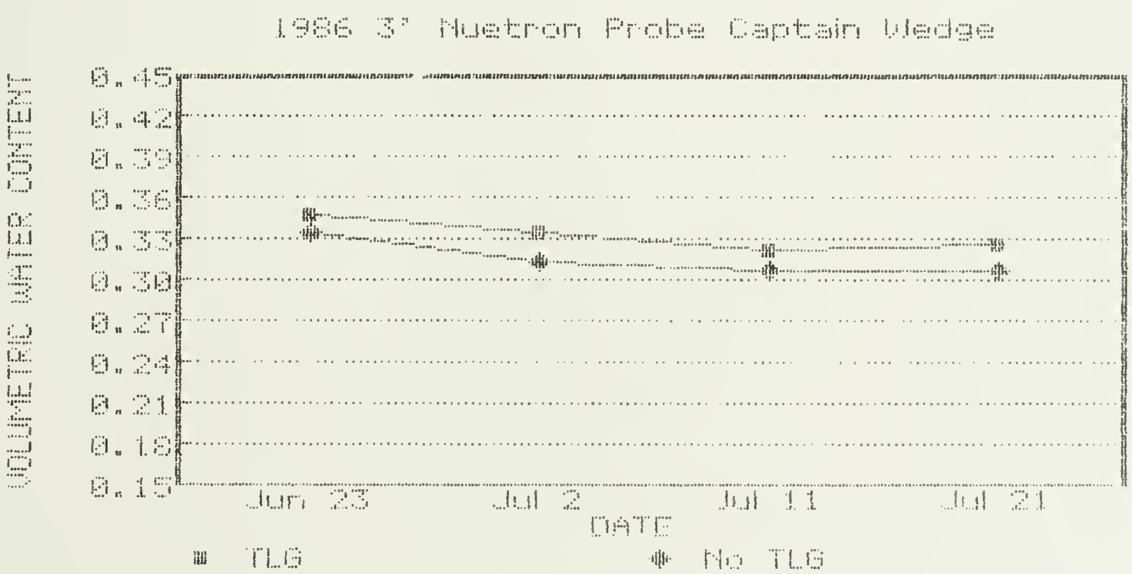


Fig. A3

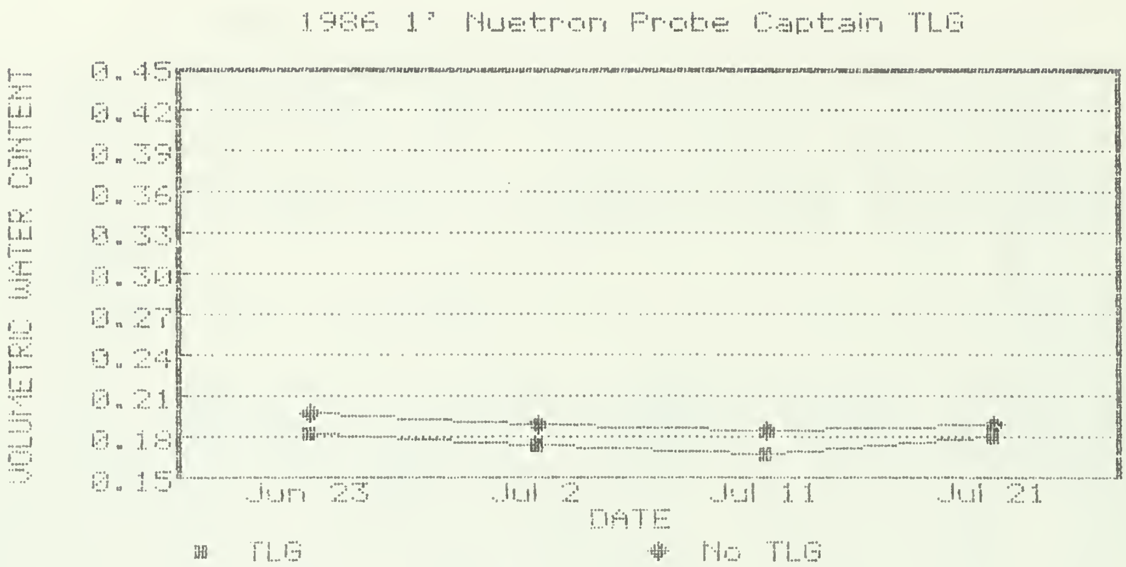

1986 1' Nuetron Probe Captain TLG
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
TLG
No TLG

Fig. B1

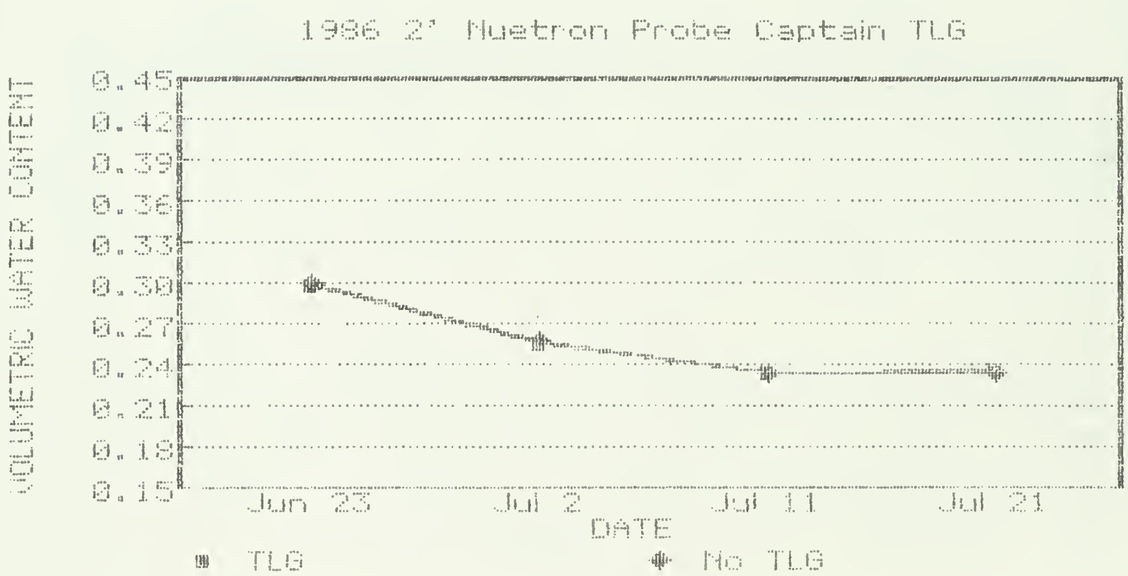

1986 2' Nuetron Probe Captain TLG
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
TLG
No TLG

Fig. B2

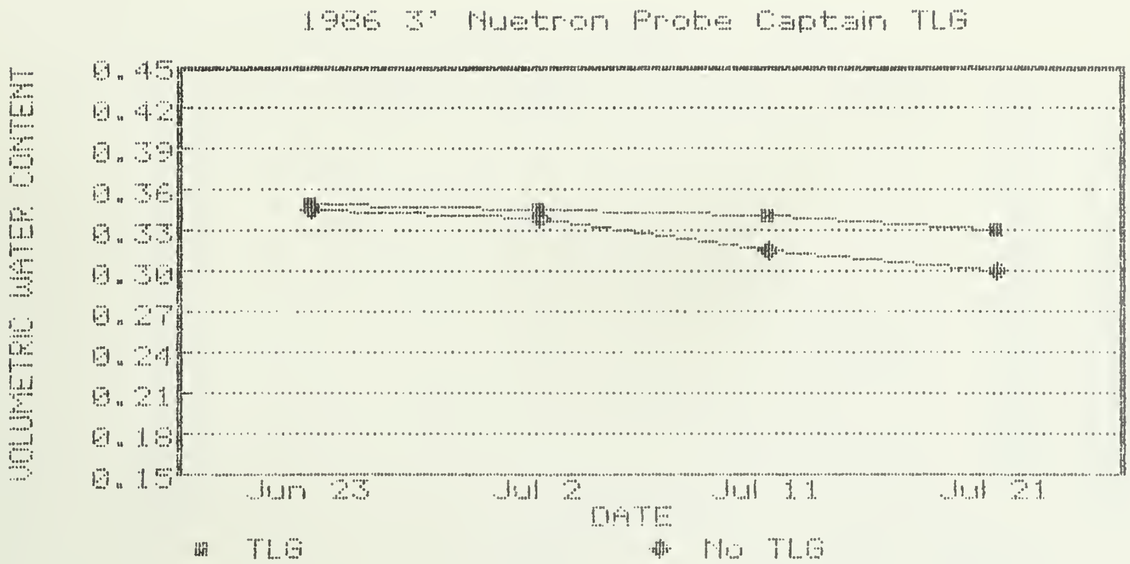
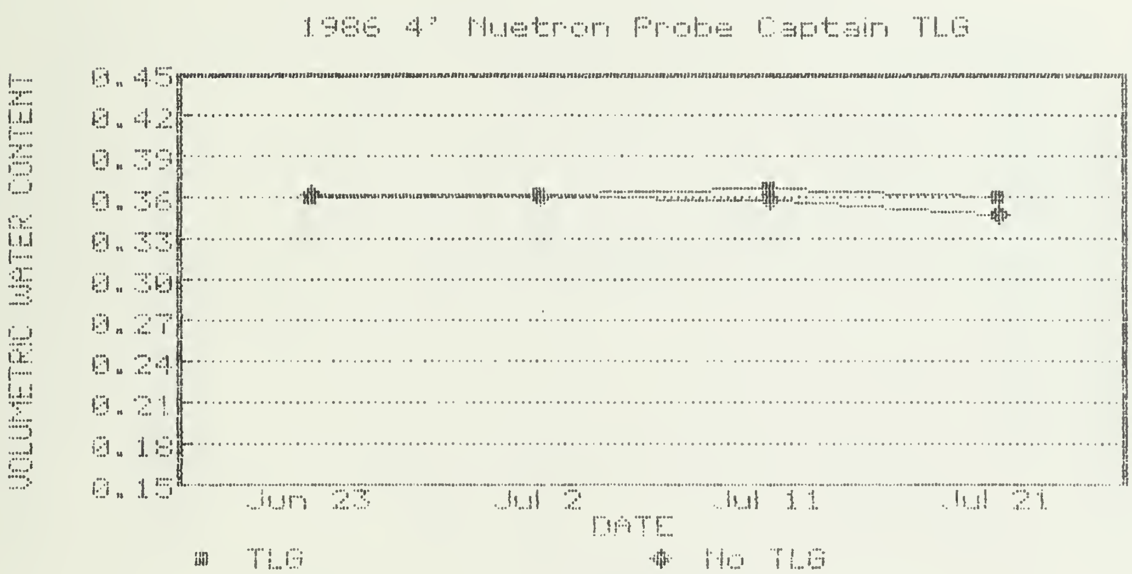

1986 3' Nuetron Probe Captain TLG
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
TLG
No TLG

Fig. B3


1986 4' Nuetron Probe Captain TLG
VOLUMETRIC WATER CONTENT
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0.39
0.36
0.33
0.30
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0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
TLG
No TLG

Fig. B4

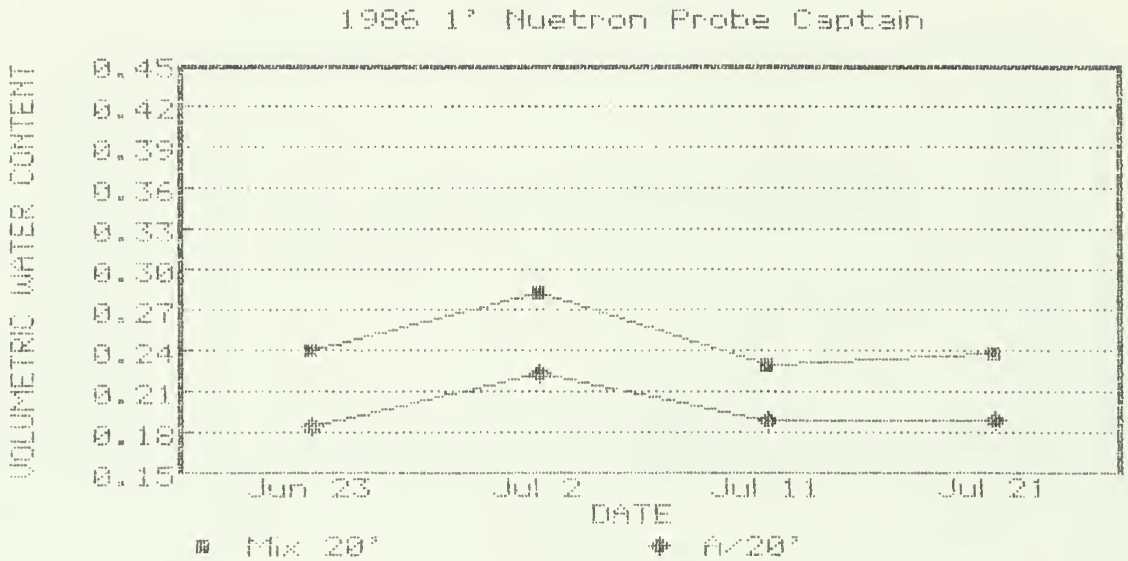


Fig. C1

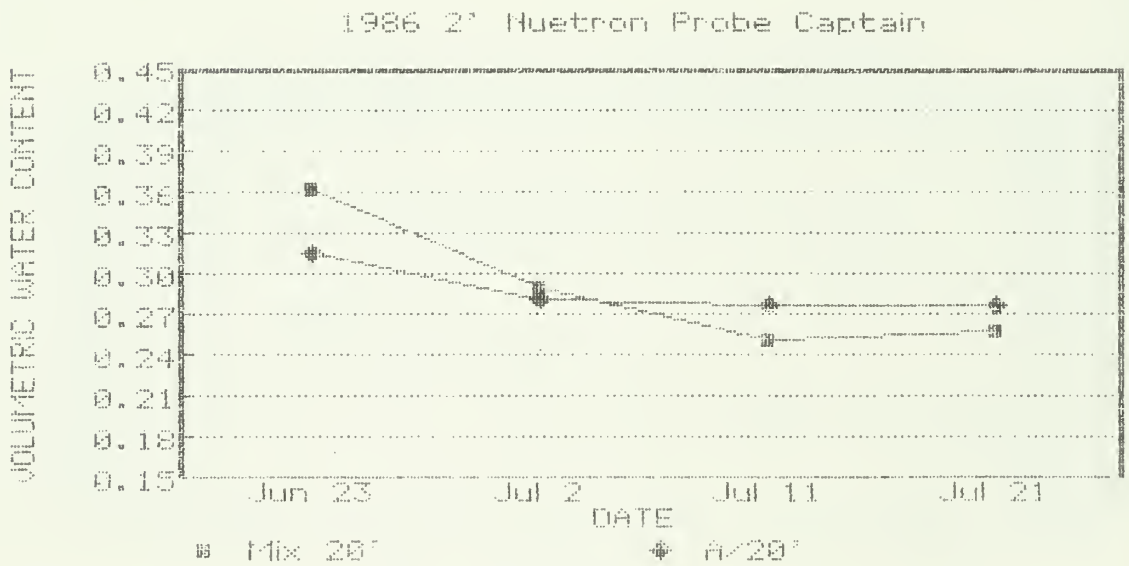


Fig. C2

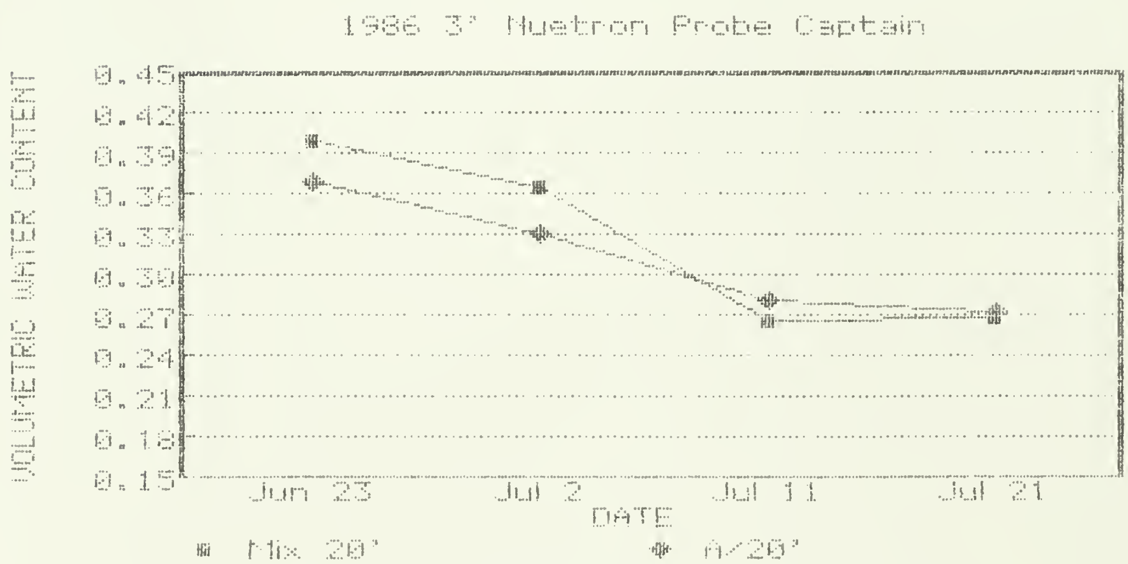


Fig. C3

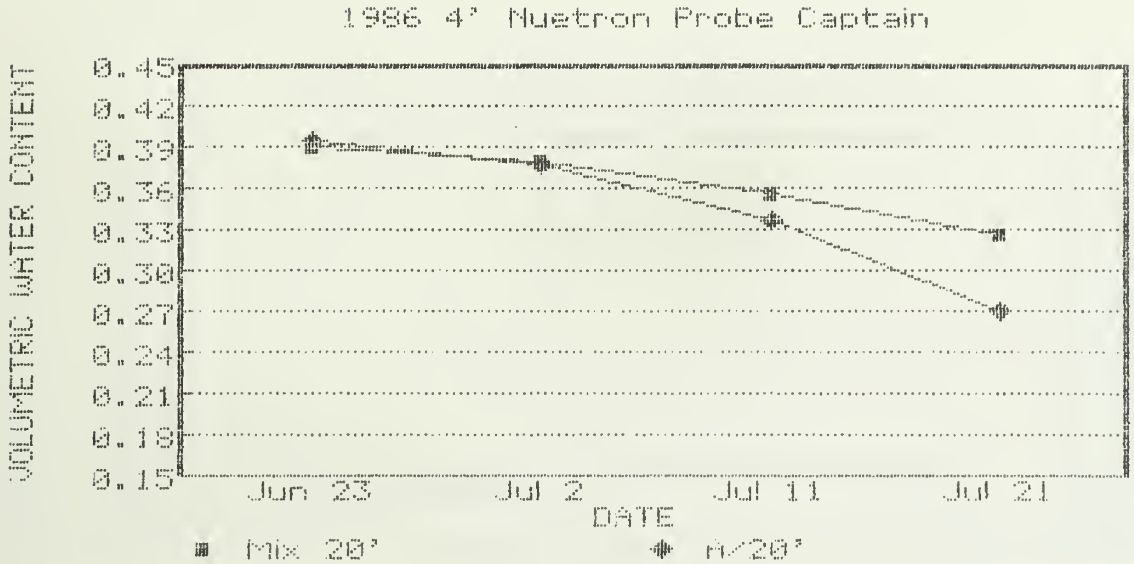
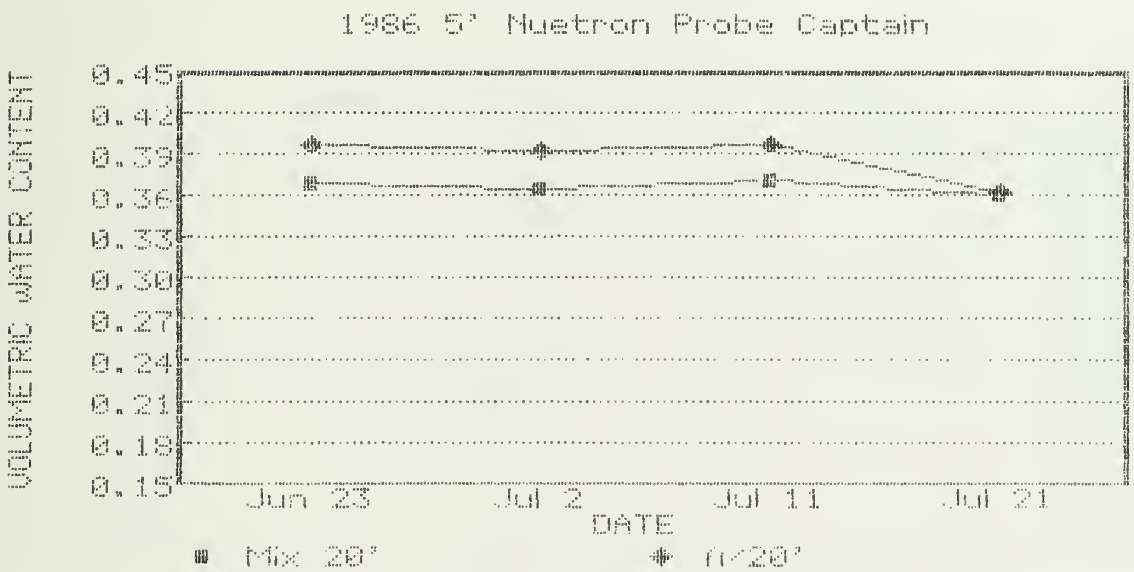

1986 4' Nuetron Probe Captain
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Mix 20'
A/20'

Fig. C4


1986 5' Nuetron Probe Captain
VOLUMETRIC WATER CONTENT
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0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Mix 20'
A/20'

Fig. C5

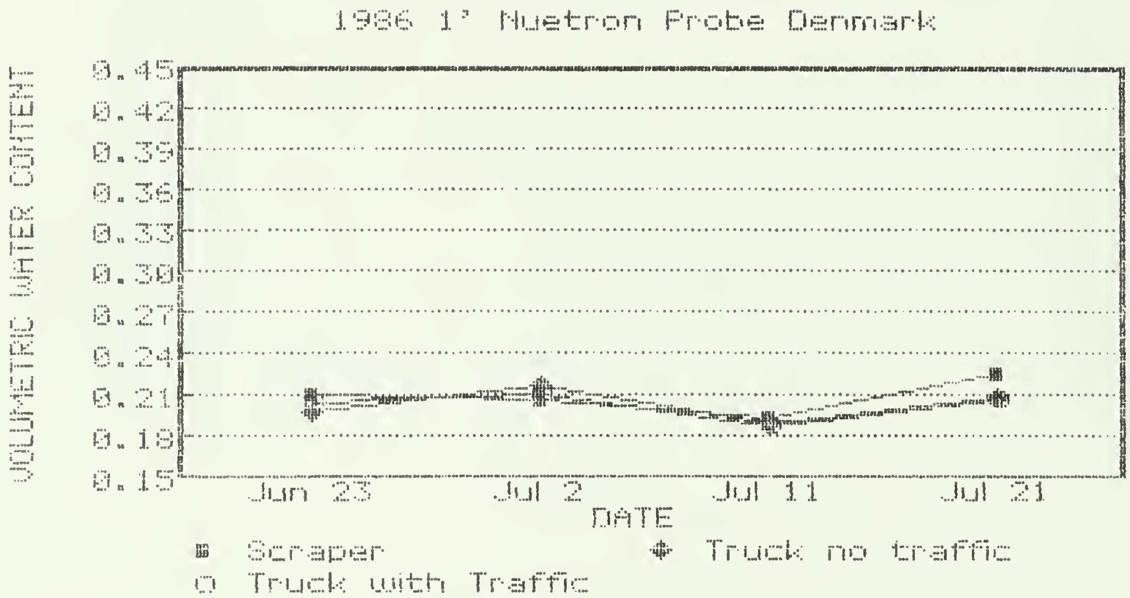

1986 1' Nuetron Probe Denmark
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Scraper
Truck no traffic
Truck with Traffic

Fig. D1

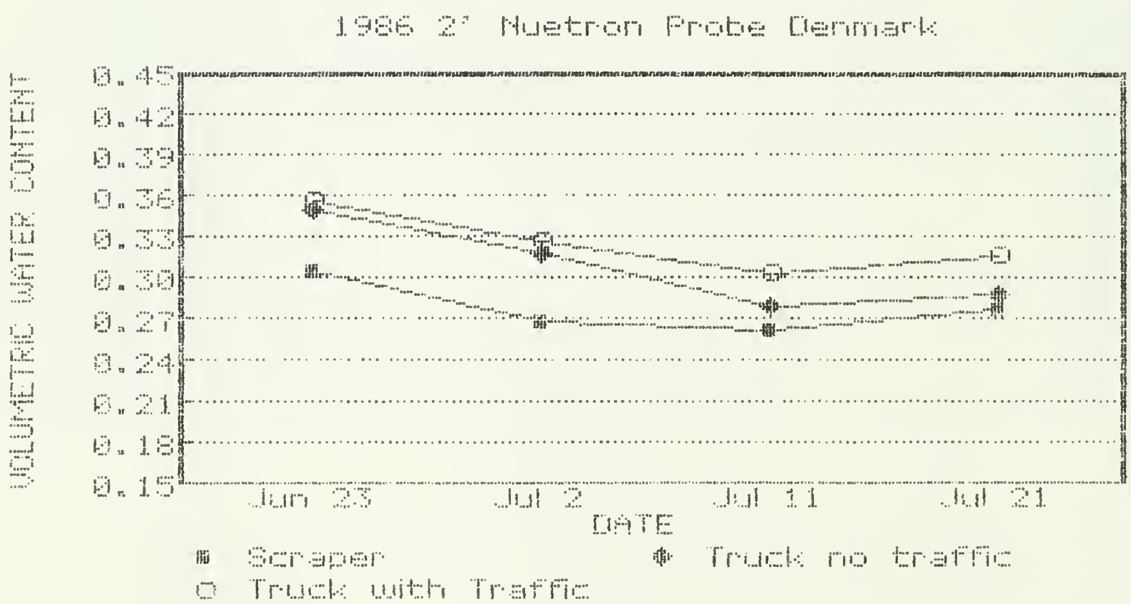

1986 2' Nuetron Probe Denmark
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Scraper
Truck no traffic
Truck with Traffic

Fig. D2

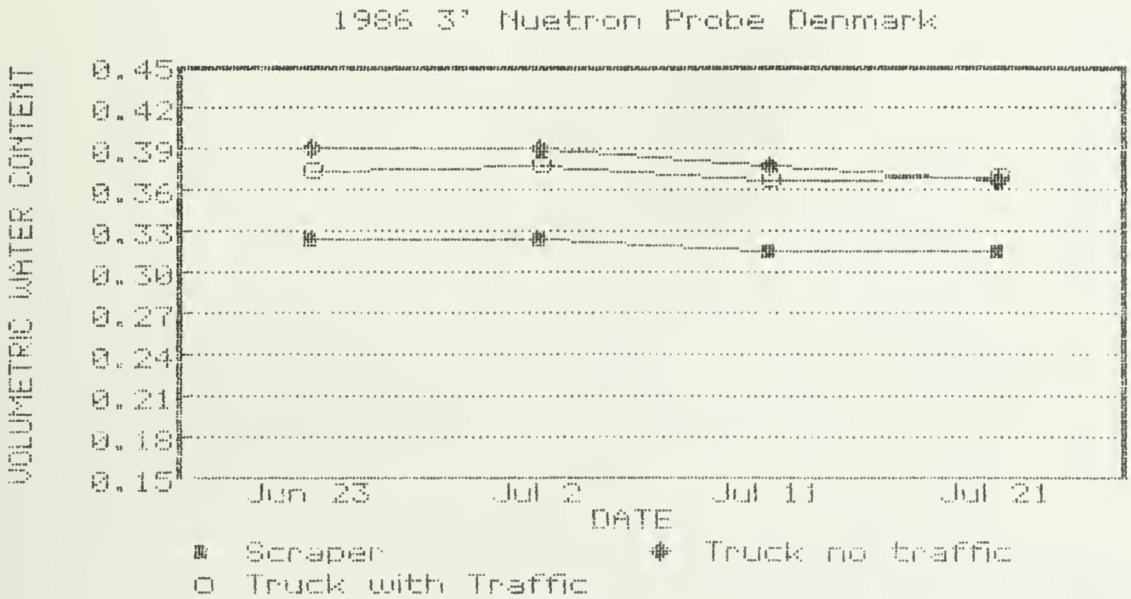
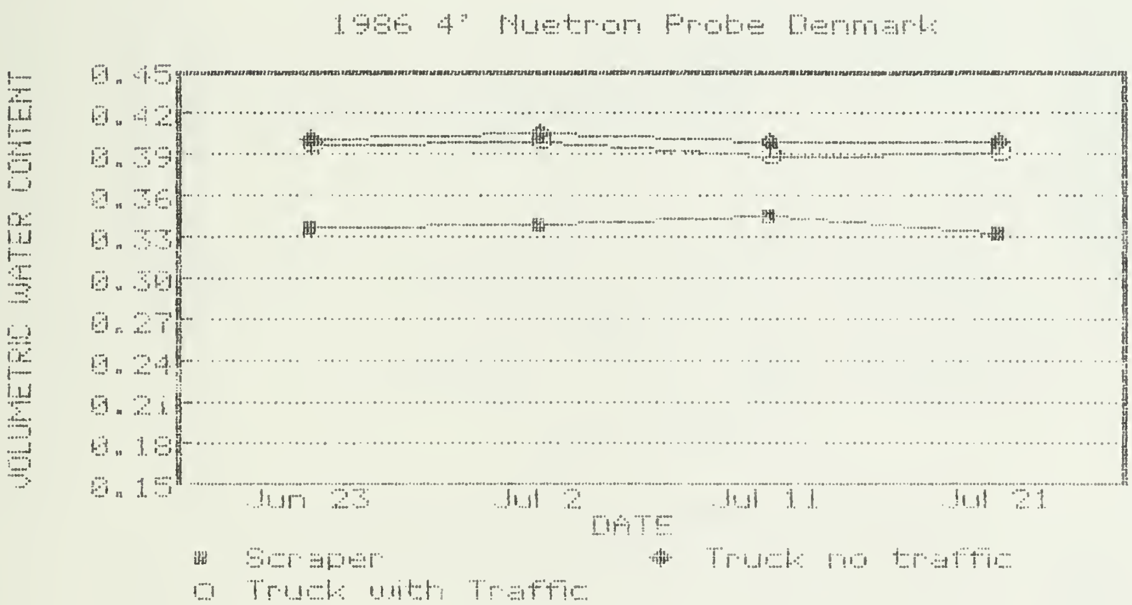

1986 3' Nuetron Probe Denmark
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Scraper
Truck no traffic
Truck with Traffic

Fig. D3


1986 4' Nuetron Probe Denmark
VOLUMETRIC WATER CONTENT
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0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Scraper
Truck no traffic
Truck with Traffic

Fig. D4

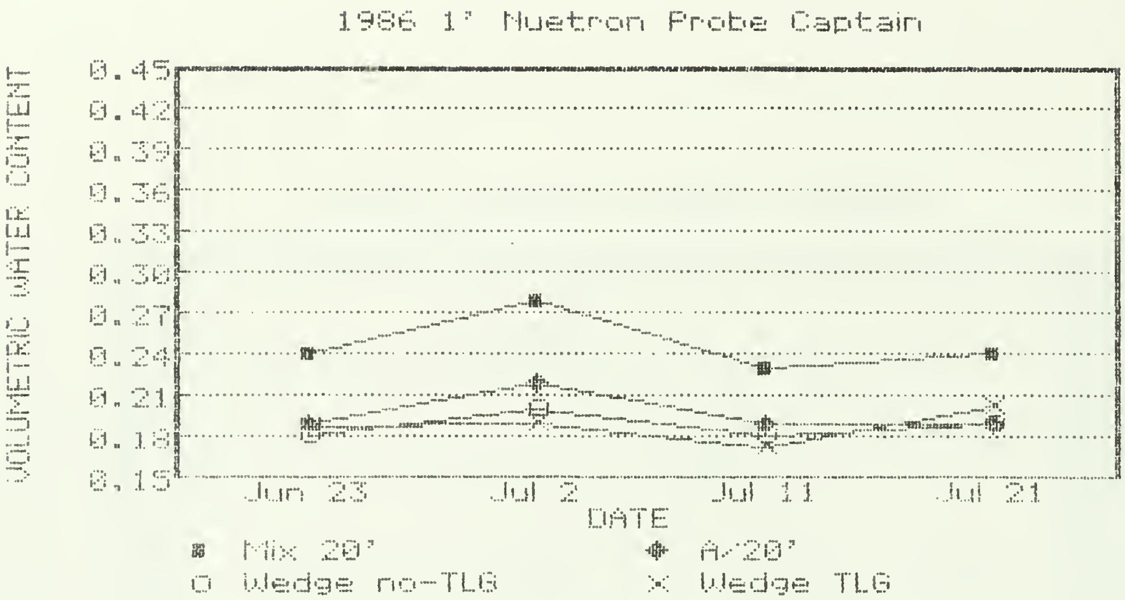

Fig. E1

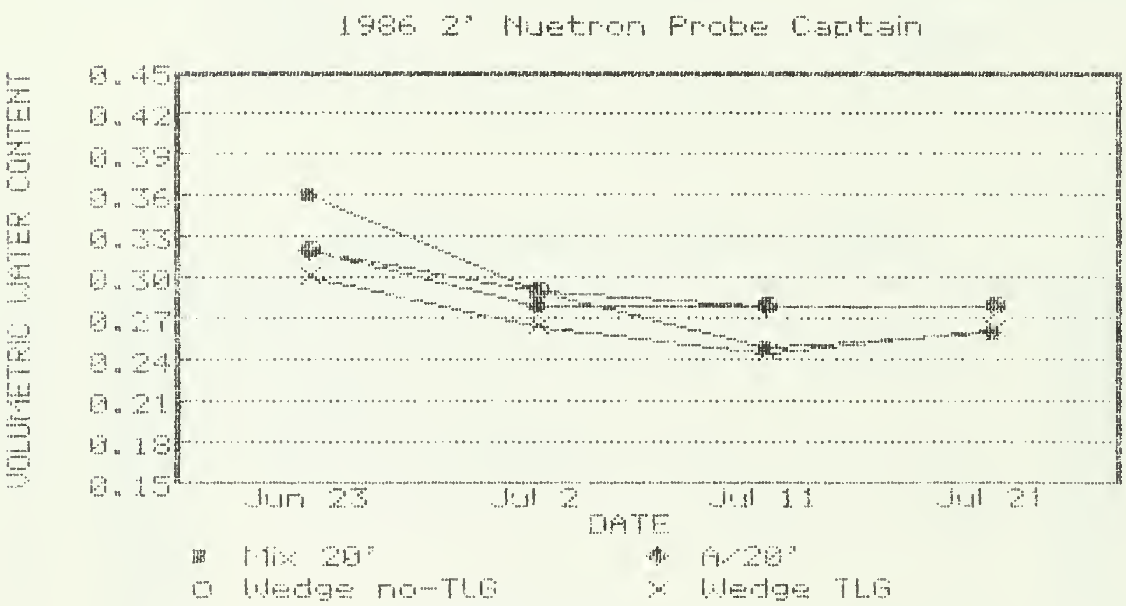

Fig. E2

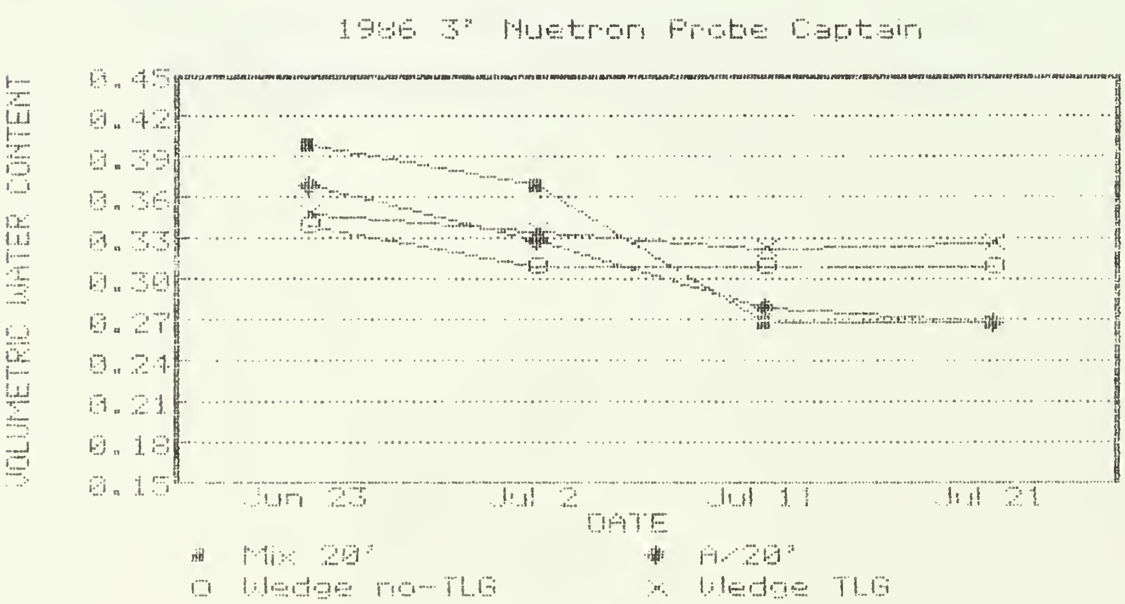

Fig. E3

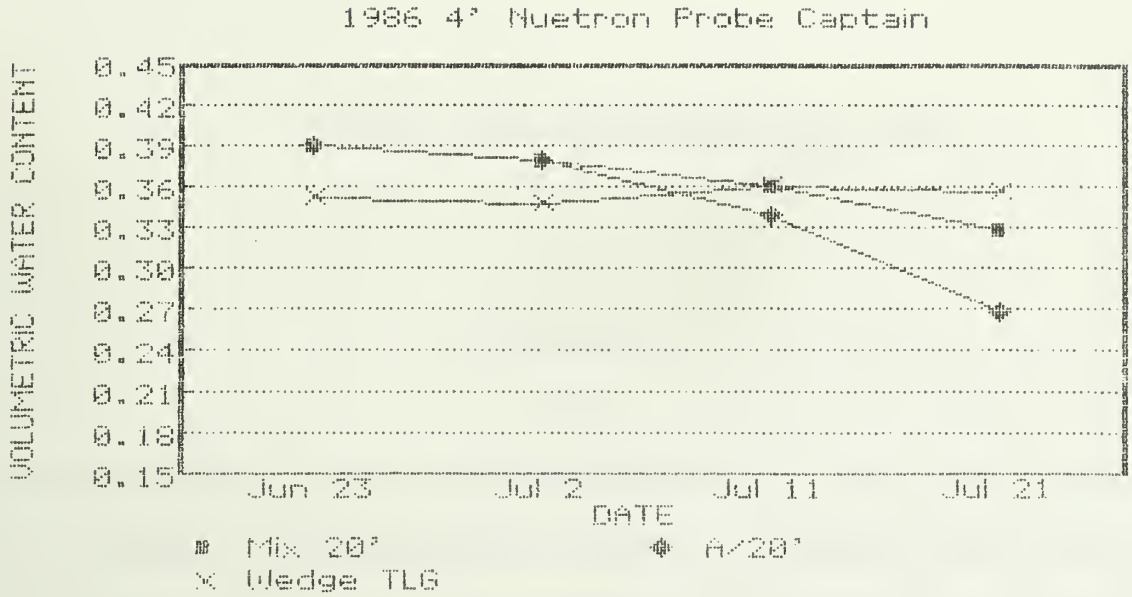
1986 4' Nuetron Probe Captain
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Mix 20'
A/20'
Wedge TLG

Fig. E4

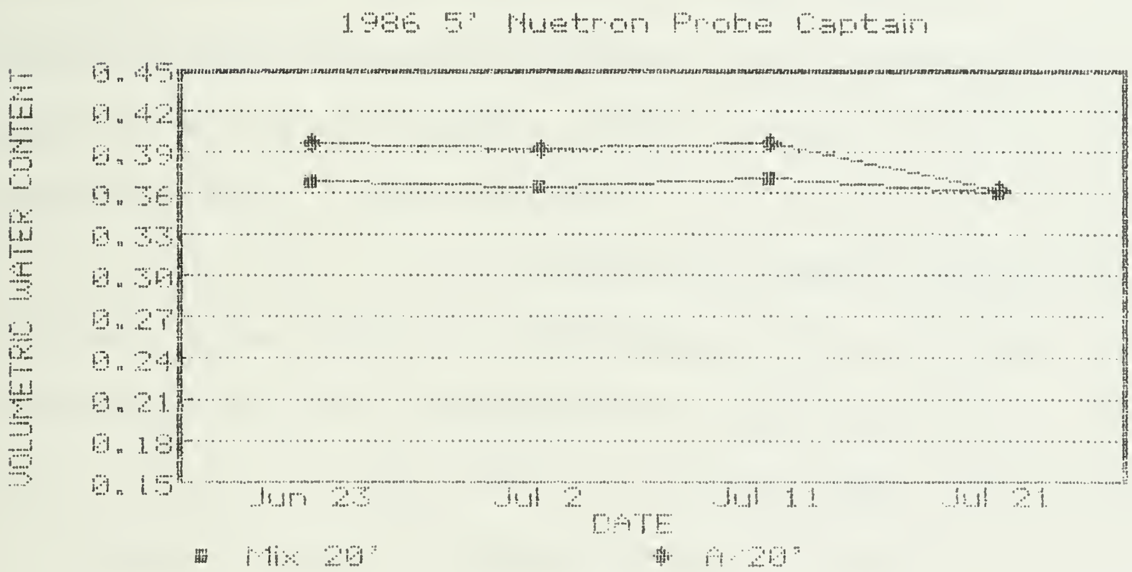
1986 5' Nuetron Probe Captain
VOLUMETRIC WATER CONTENT
0.45
0.42
0.39
0.36
0.33
0.30
0.27
0.24
0.21
0.18
0.15
Jun 23
Jul 2
Jul 11
Jul 21
DATE
Mix 20'
A/20'

Fig. E5

SOIL PROPERTIES AND CORN YIELDS

N. T. Patterson

Harvest sites at the Sunspot, River King, and Captain mixed plots were chosen for study based on their having consistently high or low corn yields over the two to three years for which yield data is available for the same sites. Approximately ten high and ten low yield sites were chosen at each mine based on these criteria. The soil from each 5 by 20 foot harvest site will be characterized to determine why the yields are consistently high or low.

Four recording cone penetrometer readings were taken at each site in late spring to early summer. Soil moisture data was taken at the same time.

Two soil cores were taken at each site during late spring, summer, and fall. The cores for Sunspot and River King have been described and the Captain cores will be described. These descriptions include structural and materials classification. Structural classification includes size of aggregates, degree of cleavage by desiccation cracking, and degree of exploration by roots. Materials classified include topsoil, B-horizon material, and spoil. Spoil includes all kinds of overburden - including topsoil, B-horizon material, glacial till. paleosols, shale, sandstone, and coal.

Chemical and mechanical analyses will be done on the materials. In topsoil sites, topsoil will be divided into upper and lower units when there is a significant difference in uniformity, color, or structure. The upper topsoil is generally more uniform, lighter in color, and has finer aggregate size than the lower topsoil. The underlying spoil or B-horizon will also be analyzed after being divided into upper and lower units. The upper unit will be analyzed completely. The lower one may be analyzed later, but only chemically - not for particle size distribution if the spoil or B-horizon material appears to be of the same material.

All the data will be analyzed to determine which physical and chemical properties at which depths in the soil are most strongly correlated with the corn yields. Weather data will also be analyzed to determine the combined effects of weather - especially precipitation - and soil characteristics on corn yields.

TLG STUDY AT CAPTAIN MINE

C. L. Hooks

These plots have allowed the monitoring of several crops over a large area of conventionally reclaimed land. There has also been a test of the effects of deep tillage with the TLG-12. It has been shown in prior years that productivity can vary greatly due to reclamation method. Corn yields from previously tested scraper placed treatments have generally been very low and have not exhibited as much within treatment variability as has been observed on the 60 acres of TLG plots. This has been evident in plant height and stress symptoms observed throughout the growing season on several crops. Data from the penetrometer profiles show the highest soil strength levels in Area 3. Visible stress signs were more severe in Area 3 than Area 1 or Area 2. The yields also coincide with this trend showing corn yields on non-ripped plots varying from near failure to comparable to undisturbed soil corn yields. A knowledge of the physical variability of a reclaimed soil should indicate the need and relative effectiveness of deep tillage operations. The effects of the TLG-12 can be observed in plant height differences as well as drought stress signs.

In 1986 yields on the TLG treatment for corn, soybeans, sorghum and wheat were comparable to the yields obtained on the undisturbed site. It is assumed that the corn yield response is primarily due to improvement of an unfavorable soil physical condition. The yield response shown in Area 2 is the result of a slight physical improvement of a soil with more favorable physical conditions. Perhaps better root exploitation of a more productive soil profile was allowed by the TLG-12. The yield response seen in Area 3 appears to be the most dramatic and encouraging increase in production due to deep tillage.

Management of deep tilled soils is still a learning experience but a few things have been determined. Deep tillage, when properly effected, loosens and fractures a compacted soil to a depth nearly 3 feet (TLG-12). Soil beneath this depth may still be compacted. The fluff resulting may average 8". Percolation will dramatically increase. Subsurface water movement will occur and result in ponding or surface seepage when a slope is not deep-tilled to the toe. Tiling can relieve this where required.

Surface drainage should be corrected and land leveling completed prior to deep tillage. Limestone, if required, and any buildup applications of P and K should also be applied prior to deep tillage. The surface should be smoothed and a cover crop seeded prior to rainfall.

One can expect these soils to be high in subsurface moisture in the spring and fall. Planting a crop to remove early season moisture and no-till planting in spring may be desirable. These soils have been highly susceptible to recompaction due to high moisture.

Results of the TLG have been encouraging. During the 1986 growing season visible moisture stress was observed in corn grown on the unripped treatment in early June while corn grown on the TLG treatment did not exhibit visible moisture stress until two weeks later. Corn grown on both of these treatments, however, did exhibit more stress than corn grown nearby on the conveyor-spreader placed mix plots which showed very minimal stress this growing season.

Operation and management of the TLG plots at Captain Mine are a cooperative effort. The planting and yield sampling have been provided by the University of Illinois. The primary tillage, harvest, seasonal labor, and material costs have been provided by Arch of Illinois.

CORN RESPONSE TO DEEP TILLAGE ON SURFACE-MINED PRIME FARM LAND IN WESTERN ILLINOIS

R. E. Dunker, I. J. Jansen and S. L. Vance

(Abstract of Paper in Progress)

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 (fine-silty, mixed, mesic, Typic Haplaquoll) was used as an unmined comparison. The use of the TLG-12 which has an effective tillage depth of approximately 75 cm was successful in significantly lowering penetrometer resistance in the 23-46 cm and the 46-68 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 the TLG-12 treatment 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.

1985-86 NORRIS TLG

Yield,bu/a

Soil Trt	1985	1986	Ave.
TS TLG	164.8 ab	186.9 ab	174.7 a
TS CON	117.4 c	181.5 ab	145.9 b
SP TLG	131.9 bc	197.1 a	160.9 ab
SP CON	127.6 bc	178.0 b	150.0 b
PL CON	176.3 a	183.9 ab	179.7 a
LSD (0.05)	38.6	17.5	22.4

% Barren Plants

Soil Trt	1985	1986	Ave.
TS TLG	18.5 ab	-1.9 ab	9.4 ab
TS CON	23.8 a	3.1 ab	14.6 a
SP TLG	4.1 c	-11.8 b	-2.9 c
SP CON	0.2 c	4.2 a	2.0 bc
PL CON	10.5 bc	1.1 ab	6.3 ab
LSD (0.05)	11.7	15.4	9.0

Pollination, days after planting

Soil Trt	1985	1986	Ave.
TS TLG	71.6 c	74.7 d	73.1 d
TS CON	72.8 b	78.0 c	75.4 c
SP TLG	72.8 b	80.5 b	76.6 b
SP CON	74.4 a	83.2 a	78.8 a
PL CON	70.8 c	75.0 d	72.9 d
LSD (0.05)	1.1	1.6	0.9

Shelling %

Soil Trt	1985	1986	Ave.
TS TLG	80.4 a	87.4 a	83.5 a
TS CON	76.3 b	87.2 a	81.2 b
SP TLG	78.7 ab	87.2 a	82.5 b
SP CON	77.4 ab	85.9 a	81.3 b
PL CON	80.6 a	87.7 a	83.8 a
LSD (0.05)	1.7	1.7	2.2

Penetrometer Resistance, PSI

Soil Trt	9-18"	18-27"	27-36"	36-44"
TS TLG	115.8 b	103.7 c	435.3 a	369.9 a
TS CON	278.4 a	461.2 a	424.2 ab	339.0 a
SP TLG	152.3 b	162.3 c	279.1 b	307.7 a
SP CON	271.2 a	285.0 b	342.6 ab	356.8 a
LSD (0.05)	65.1	97.7	148.4	145.0

1986 ABSTRACTS, PUBLICATIONS, THESES

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Recording Cone Penetrometer Developed in Reclamation Research

C. L. Hooks and I. J. Jansen

Recording Cone Penetrometer Developed in Reclamation Research[1]

C. L. Hooks and I. J. Jansen[2]

ABSTRACT

A constant rate cone penetrometer has been developed for use in a strip mine reclamation project at the Univ. of Illinois. The device is capable of recording soil strength profiles to a depth of 112 cm. (44 in.). It utilizes a tractor-mounted hydraulic coring machine as a source of movement. A chart recorder and data acquisition system are operated by 12 V DC electrical power. The penetrometer is effective in detecting soil layers where compaction is likely to inhibit root system development. It is useful in measuring soil strength in mine soils where the amount and depth of compaction may vary due to reclamation methods. Differences in soil strength may prove to be a clue to crop performance on reclaimed land.

Additional Index Words: **surface mining, mine soils, penetrometer, soil strength, compaction.**

Hooks, C.L., and I.J. Jansen. 1986. Recording cone penetrometer developed in reclamation research. Soil Sci. Soc, Am. J. 50:10–12.

Excellent rowcrop production is being achieved in years having favorable weather on land carefully reclaimed after strip mining. Susceptibility to weather stress has been a problem on most reclaimed land during less favorable years. Soil compaction and consequent restricted root system development appears to be a major problem.

Reclamation practices vary in the methods of soil excavation, transportation, and horizonal placement. The depth of compaction will vary depending on the equipment used in these operations. Various traffic zones and horizonal interfaces can also be created that may impede root growth and affect water movement. These zones are highly variable and may occur in a very narrow portion of the profile at depths well below 60 cm. A method is needed to effectively measure physical differences among newly constructed soils which will affect root system development.

Soil strength, as measured by a penetrometer, provides a parameter for evaluation of newly constructed soils which may vary due to reclamation methods. Variations in soil strength may be a clue to crop performance.

Cone penetrometers have been used to measure soil strength in agricultural and engineering applications for many years. Improvements of the dial gauge, handheld models have included mechanical chart recording (e.g., Hendrick, 1969; Howson, 1977). An electronic chart recording penetrometer has also been developed (Prather et al., 1970). Continuous recording of data can detect abrupt changes in soil strength (Anderson et al., 1980). Constant velocity recording penetrometers with digital data output have been developed and are used in academic and industrial research.

Since compaction is often below the effect of conventional tillage equipment, a strength profile of over 100 cm is desirable. A few recording penetrometers have been developed to reach these depths (Carter, 1967). To compare the effects of reclamation methods on soil strength, a power operated, constant velocity, cone penetrometer was constructed.

Fig. 1. Penetrometer installed on Giddings coring machine with modified foot supports.

MATERIAL AND METHODS

The penetrometer was constructed to utilize a three point tractor-mounted Giddings coring machine as a source of movement. Initially, the auxiliary hydraulic flow control of the tractor was used to set the rate of movement of the mast cylinder. The standard rate of 2.9 cm/s could be achieved with this method. The foot support system was modified to avoid compressing the soil surface near the probe (Fig. 1). The feet provide a stable platform and eliminate movement due to the tractor tires.

The recording cone penetrometer was constructed with currently available components that include a portable chart recorder (Watanabe, Model SR6512) and a 454 kg (1000 lb) capacity load cell (Transducers, Inc. Model 62H). The probe and load cell are shown in Fig. 2. The recorder, controller, and mounting bracket are shown in Fig. 3. The probe consists of a square frame around the load cell constructed of 7.5 cm (3 in) heavy structural channel. A section of 3.75 cm (1.5 in) schedule 80 pipe was welded to the top of the frame. This will accept a standard coring tool cap and allow quick attachment to the coring machine. A guide sleeve containing two linear ball bearings was attached below the load cell. The shaft is commercial C–60 case hardened 1.9 cm. (¾ in) rod. A 30° right circular cone point of 6.45 cm^2 (1 in^2) cross-sectional area was fabricated from 1060 steel, welded to the

[1] Contribution from the Dep. of Agronomy, Univ. of Illinois, Urbana, IL 61801. Received 12 Dec. 1984. Approved 8 Aug. 1985.

[2] Associate Agronomist, and Professor of Pedology, Univ. of Illinois, respectively.

Fig. 2. Penetrometer mounting frame in travel position with load cell and probe.

shaft, and hardened. A standard 1.61 cm^2 (0.5 in^2) point on a 1.27-cm (0.5 in) diam rod was used in initial tests. Due to the rod length and high loads, excessive bending was encountered. The larger cone and shaft was selected for stability. The recorder operates on 10 to 15 V DC. The input voltage for the load cell is limited to 10 V DC. A controller and wiring harness were constructed to allow the use of charging voltage from a truck or tractor. It consists of a SPST toggle switch, a panel gauge (0–25 V DC) and a 50-ohm potentiometer. The mounting bracket was constructed to slip over the breather plug in the oil reservoir of the coring machine and rotate down tightly into position (Fig. 3). About 5-min setup time is required to attach the probe, slip on the bracket, insert the recorder and controller, and connect the wiring harness. The shaft, free-floating in the linear bearings, rests against the load cell during penetration and output is recorded constantly in millivolts. Initial tests have utilized the internal timed chart drive of the recorder. The recorder has the added capability of external chart drive. This will allow the chart to be accurately synchronized with the probe movement. The timed chart drive has been sufficient for preliminary tests. In the spring of 1984 the system was modified to include digital recording of output data. A positioning cylinder with a Kelly rod was also added to reduce setup time for each profile. A two-circuit hydraulic system was installed. One circuit provides full flow and pressure for return cycles and soil coring. The second circuit provides controlled pressure and flow rate for penetrometer measurements.

RESULTS AND DISCUSSION

Tests at the Univ. of Illinois and two Southern Illinois mine sites have shown that compaction zones in fill areas can be easily located without excavation. Results are repeatable and have been confirmed by excavation and core sampling. The sensitivity of the probe is about ± 0.017 MPa. One person in the field

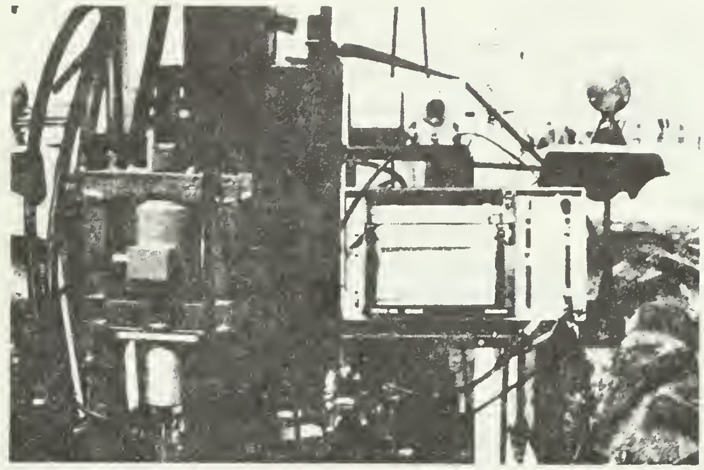

Fig. 3. Mounting bracket with controller and recorder, as mounted on Giddings coring machine.

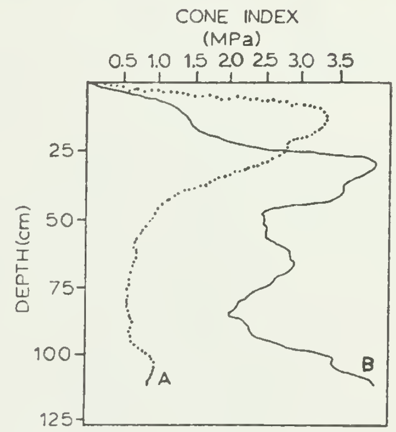

Fig. 4. Single representative cone index profiles of two reclaimed strip mine soils: (A) Topsoil over wheel-excavated/belt placed material, and (B) Topsoil over scraper-placed material.

may average about 3 to 5 min per recorded profile. Having a second person cuts the time requirement in half.

Fig. 4 represents a single representative profile from two mine soils originating from different materials handling methods. High variability between profiles is generally observed in the top 20 to 40 cm of the soil. Profile A indicates a compacted zone at a depth of about 15 cm. Excavation revealed this zone with corn (*Zea mays* L.) roots limited to dessication cracks. Below this interface, soil material was loose with abundant, visible pore space. Corn roots were able to penetrate the narrow interface and explore the profile to > 1.5-m depth.

Profile B indicates high strength at the topsoil interface (30 cm) and high values (> 2.0 MPa) throughout the profile below. Excavation revealed massive structure in the lower profile. Below the topsoil, corn roots were limited to dessication cracks and were not found below 50 cm. The corn on this plot failed to produce grain in the 1983 and 1984 seasons due to severe drought stress. The corn grown in nearby plots represented by profile A produced favorable yields in these years.

Since penetrometer measurements are moisture sensitive (Terry, 1953), moisture content profiles were taken along with penetrometer profiles. The moisture factor was minimized by taking data early in the season when all lower profiles were about 20 to 25%.

The constant-rate recording cone penetrometer is easy to use and fast enough to enable collection of a large number of replicates. Though the penetrometer has its limitations (Mulqueen et al., 1977), it may prove useful to compare relative strength differences in reclaimed soils. Numerous other applications are foreseen.

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USE OF A CONE PENETROMETER TO EVALUATE SOIL RECONSTRUCTIVE METHODS AFTER SURFACE MINING FOR COAL [1]

S. L. Vance, C. L. Hooks and I. J. Jansen

A constant rate recording cone penetrometer was used to measure soil strength to a depth of 112 cm. The study looked at several soil replacement methods used in prime farmland reclamation after surface mining for coal. The effects of a deep tillage treatment used to reduce compaction down to a maximum depth of 91 cm was also evaluated. Soil strength in reconstructed soils was found to be greatly affected by the amount of grading required to complete reclamation. The range of soil strength values measured went from less than 1.0 MPa resistance for a method requiring almost no grading to over 3.0 MPa for soils constructed with scrapers type traffic. Traffic resulting from topsoil replacement with scrapers can increase soil strength significantly down to the 55 cm depth. Results from this study showed that soil strength values decreased with decreasing traffic as follows: Scraper systems had the highest soil strength with truck hauled systems next and the conveyor spreader system which requires the least grading to have the lowest soil strength levels of the systems studied. The effect of deep tillage by the Kaeble-Gmeinder TLG-12 machine was found to be effective in reducing soil strength values to less than 3.0 MPa in the top 62 cm. The effect of the TLG-12 was less noticeable when used in soils with fairly low soil strengths prior to treatment.

[1] Abstract of paper presented at 1986 American Society of Agronomy Annual Meeting, Nov. 30 - Dec 5, 1986. New Orleans, Louisiana.

Rowcrop Response to Topsoil Replacement and Irrigation on Surface-mined Land in Western Illinois[1]

R. E. Dunker and I. J. Jansen[2]

Abstract

Corn (Zea mays L.) and soybeans (Glycine max (L.) Merr) grown on newly constructed mine soils in west-central Illinois were studied over a six year period. The objective of this research was to evaluate yield response of disturbed soils to topsoil replacement and irrigation.

Two constructed soils, one with 45 cm of topsoil replaced over wheel spoil and one consisting of graded wheel spoil only were studied. Both soils are Typic Udorthents. An abandoned incline lake supplied good quality water to a solid set irrigation system which was randomly placed within each soil treatment. A nearby unirrigated tract of undisturbed Sable silty clay loam (fine-silty, mixed, mesic, Typic Haplaquoll) was used as an unmined comparison.

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A substantial yield response of both corn and soybeans grown on the mined land resulted in years having stressful weather during critical periods of growth, but no yield response to supplemental water occurred under years with favorable weather. Topsoil replacement showed a positive yield response under irrigation in three of the four years that corn was grown and in one of the two years for soybeans. Without irrigation topsoil response was positive in two of the four years for corn and one of two for soybeans.

Corn yields ranged from 7,780 to 10,860 kg/ha for the undisturbed site, 1,250 to 10,360 kg/ha for the unirrigated topsoil, and 4,390 to 6,840 kg/ha for unirrigated wheel spoil. Soybeans were less sensitive to weather variables than corn during the years studied and yields ranged from 2,485 to 3,080 kg/ha for the Sable soil, 1,750 to 3,580 kg/ha for unirrigated topsoil, and 1,480 to 2,700 for the unirrigated wheel spoil.

Rowcrop Response to Topsoil Replacement and Irrigation on Surface-mined Land in Western Illinois

R. E. Dunker and I. J. Jansen

Reclamation practices and topsoil replacement as required by Public Law 95-87 (1977) may involve extensive traffic by large earth moving equipment creating several compaction zones resulting in poor physical soil properties. The benefits from replacing the high quality A horizon from the premine agricultural soils may be offset by root restricting layers resulting from the method by which it is replaced. These properties which restrict root growth undoubtedly have an effect on the plants ability to take up water and nutrients making rowcrops grown on mined land more susceptible to temperature and moisture stress during the growing season than crops growing on nearby undisturbed soils (Meyer, 1983).

Many areas strip mined for coal have a sizeable amount of acreage in ponds and final cut lakes left from the mining process and appear well suited for irrigation development where water quality is satisfactory. Water on surface-mined land in Illinois totals over 14,000 acres, with over 12,000 being lakes developed in final cuts and abandoned inclines (Gibbs and Evans, 1978). These lakes have generally been recognized as wildlife management or recreational resources while their potential to provide good quality water for agricultural purposes has not been fully developed.

Previous research concerning yield performance of row crops on reclaimed surface-mined land has resulted in wide ranging yield responses depending upon reclamation techniques, management, and weather. In a national survey (Nielsen and Miller, 1980) corn yields were reported to be highly variable depending on original soil, fertility, initial planting of legumes and grasses, soil replacement, weather variability, and age of spoil. Corn yields from Illinois, Ohio, and Pennyslvania ranged from 4% less to 90% less than adjacent undisturbed soils. Jansen et al. (1985b) studied the yield response of corn and soybeans to topsoil replacement at two mine sites in southern Illinois over a four year period. Yields of 8,000 kg/ha of corn and 2,400 kg/ha of soybeans were achieved on reclaimed lands in the best growing seasons, but yields were very poor in years of moisture and temperature stress. Severe compaction caused by methods of soil construction was identified as the major cause of poor crop performance during the years of stress. Soybeans responded favorably to topsoil replacement at both locations. Corn yields were higher on the topsoil replaced treatments at one of the locations over all years but no yield differences resulted between the topsoil and no topsoil treatments at the other site.

Soil replacement and thickness of soil materials was studied at the Captain mine in southern Illinois and at the Norris mine in western Illinois (Jansen, et al., (1985a). The Captain wedge, which was designed to evaluate scraper placed root media thickness (0 to 120 cm) with and without topsoil replaced, resulted in crop failures in two of the five years studied due to shallow rooting of corn and weather stress. Yields of both corn and soybeans increased with increasing root media thickness to about the 60-80 cm depth.

No response was observed at greater root media depths since roots were not exploiting depths deeper than 80 cm. The Norris topsoil wedge with topsoil thicknesses ranging from 0 to 60 cm resulted in a significant positive yield response to increasing topsoil depth for corn but not for soybeans. Year by year results showed positive relationships to topsoil thickness in years of favorable weather, while negative responses to topsoil thickness resulted in years of moisture stress. Dunker et al. (1982) has shown that irrigation can be used to reduce or eliminate this stress factor and promote satisfactory corn yield response on surface-mined land the first two years after reclamation.

The objective of this research was to evaluate yield response of corn and soybeans to topsoil replacement with and without irrigation on recently reclaimed mine soils. The use of irrigation as a treatment allows for yield differences associated with the different soil treatments to be evaluated as well as variation reflected by weather differences.

Study area and methods

Corn (Zea mays L.) and soybeans (Glycine max (L.) Merr) were rotated over a six year period from 1979 to 1984 at the Consolidation Coal Company's Norris Mine in west-central Illinois. Two constructed soils, one with 45 cm of topsoil replaced over wheel spoil and one consisting of graded wheel spoil only, were studied. Both soils are Typic Udorthents. Field plots were constructed in the fall of 1978 by the mine under favorable moisture conditions using a bucket wheel excavator to unconsolidated soil materials and bulldozers for final grading. Topsoil was replaced with scrapers. The wheel spoil at the Norris site consists of a mixture of leached loess, calcareous loess, calcareous glacial till, and some soft shale fragments. The pre-mine soils which characterize this wheel spoil are in the Sable-Ipava soil association group of Illinois. These soils are highly productive dark colored soils developed under prairie vegetation with thick A horizons high in organic matter, a desirable medium textured B horizon, and an underlying C horizon favorable for plant growth (Fehrenbacher et al., 1977). Table 1 shows representative chemical and textural properties of the topsoil and wheel spoil at the time of plot construction. An undisturbed tract of Sable silty clay loam (fine-silty, mixed, mesic, Typic Haplaquoll) located nearby was used as an unmined comparison, but was not irrigated.

Irrigation from solid-set sprinklers using impact type revolving sprinkler heads applied 0.83 cm water per hour at a pressure of 2.46 kg/cm2. Irrigated and unirrigated plots were completely randomized within each soil treatment block. The sprinklers had a 360 degree application pattern and it was necessary to restrict this to 180 degrees when irrigated plots were adjacent to an irrigated treatment. This was accomplished by fabricating water collectors from plastic containers. The sprinkler stream was caught in the plastic container for one-half of each revolution and the water was channeled through a drain pipe to underground drain tile and returned to the lake. A floating centrifugal pump located in the abandoned incline lake provided irrigation water of good quality to irrigation systems. Soluble salts (390 ppm), pH (8.2),

Table 1. Chemical and textural properties of topsoil and wheel spoil at Norris Mine at the time of plot construction.

Core #	Depth	Soil material	pH	Bray P_1	Bray P_2	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases Na	Exchangeable bases K	Organic C	Particle size distribution (mm) Coarse >2.0	Sand 2.0-.05	Silt .05-.002	Clay <.002
	10^{-3}m			mg kg^{-1}		-- cmole(+)kg^{-1} soil--				------------------g kg^{-1}------------------				
1	0-45	Topsoil	5.1	99	57	12.8	3.5	0.1	0.4	18.2	0	24	734	242
1	46-71	W. Spoil	6.5	12	55	11.7	6.8	0.2	0.5	1.9	41	55	622	282
1	72-120	W. Spoil	6.8	12	51	10.6	6.1	0.2	0.4	1.9	18	123	603	256
2	0.50	Topsoil	4.9	84	33	12.8	4.9	0.2	0.5	14.4	0	20	662	318
2	51-78	W. Spoil	7.0	5	49	10.9	4.7	0.2	0.4	1.5	10	331	391	268
2	79-120	W. Spoil	7.2	5	52	10.1	4.4	0.2	0.4	0.8	18	248	462	272

Ca (64 ppm), Mg (26 ppm), Na (18 ppm), and Boron (.15 ppm) all meet recommended maximum concentration limits for continuous irrigation in the Midwest as reported in the National Academy of Sciences report on water quality (1972).

Irrigation treatments were initiated when tensiometers were showing soil tension levels at the -60 KPa of soil water pressure at the one foot depth. Application rate for corn was 1.9 cm applied twice per week in 1979 and 1.3 cm applied three times per week in subsequent years to allow for better infiltration of water by the wheel spoil plots and reduce runoff. When rainfall occurred, irrigations were adjusted, if possible, so that rainfall plus irrigation per week did not exceed the 3.9 cm total rate. Soybean irrigation rate was 1.9 cm rainfall plus irrigation per week. Irrigations were terminated when black layer formation in the kernel appeared in corn and after pod-fill in soybeans.

Grain yield samples were selected at random within the middle four rows of the eight row plot in each of the four replications. Grain yield estimates were based on the amount of shelled grain after adjusting for variation in the moisture content of corn to 15.5 % and soybeans adjusted to 12.5 % moisture. Fertilizer rates, seeding rates, and management practices used in this study are described in Table 2.

Results

Irrigation Response. Yield response of both corn and soybeans to irrigation on mined land was in direct relationship to temperature and moisture stress. Both topsoil and wheel spoil treatments produced a significant corn yield response to irrigation during the 1979, 1980, and 1983 growing seasons while no measurable response occurred in the minimal stress year of 1981 (Table 3). Figure 1 graphically presents departures from normally occurring temperature and rainfall values during the 1979-84 growing seasons at the Norris mine. The 1979 growing season was characterized by cooler than normal temperatures with below average rainfall early and late in the growing season but above average precipitation in July. In contrast temperatures in 1980 and 1983 were well above normal throughout most of the growing season and crop water use was at its highest demand when precipitation levels were lowest. Temperatures were 33 to 38 C during pollination with very little precipitation from two weeks before until one week after pollination. The 1981 and 1982 seasons had near normal temperatures with adequate rainfall resulting in little or no temperature or moisture stress during those growing seasons. Consequently no irrigation response occurred for either corn in 1981 or soybeans in 1982. Significant positive soybean yield responses to irrigation resulted in 1984 for both the topsoil and wheel spoil treatments due to well below normal rainfall during the critical pod-filling period of mid-August to mid-September.

Table 2. Description of field plots at Norris Mine.

	1979	1980,81,83	1982,84
Plot size	7.6 x 16.9 m	7.6 x 16.9 m	7.6 x 16.9 m
Fertilizer	268 kg N/ha 134 kg P/ha 134 kg K/ha	302 kg N/ha 151 kg P/ha 151 kg K/ha	17 kgN/ha 67 kg P/ha 117 kg K/ha
Crop	Corn	Corn	Soybeans
Hybrid/ Variety	Mo17 x B73	Mo17 x B73	Williams
Planting rate (seeds/ha)	64,220	73,112	375,000
Row spacing	76 cm	76 cm	76 cm
Planting date	30 May	1980: 16 May 1981: 8 May 1983: 18 May	1982: 11 May 1984: 18 May
Herbicide (l/ha)	4.7 butylate 2.3 atrazine	2.6 metolachlor 2.3 atrazine	2.6 metolachlor 9.2 chloramben
Insecticide	carbofuran	chlorpyrifos carbofuran	sevin
Tillage	No fall 3 discings	Fall chisel 2 discings	Fall chisel 2 discings

Table 3. Corn and soybean yields at Norris Mine in response to irrigation and topsoiling.

Treatment	CORN					SOYBEAN		
	1979	1980	1981	1983	Mean	1982	1984	Mean
	-----	-----	-----	-----	$kg\ ha^{-1}$	-----	-----	-----
Irrigated Topsoil	11990	10420	10990	12120	11370	3580	2350	2965
Unirrigated Topsoil	9730	4390	10360	1250	5975	3580	1750	2665
Irrigated Wheel Spoil	8910	9040	6590	10610	8790	2950	2010	2480
Unirrigated Wheel Spoil	6280	5590	6840	4390	5620	2700	1480	2090
Undisturbed Sable Soil	9790	7780	10860	4360	8200	3080	2485	2780
LSD (0.05)	1641	1076	800	1720	595	370	510	310
CV (%)	11.6	17.7	11.6	23.7	16.9	7.0	23.8	16.1

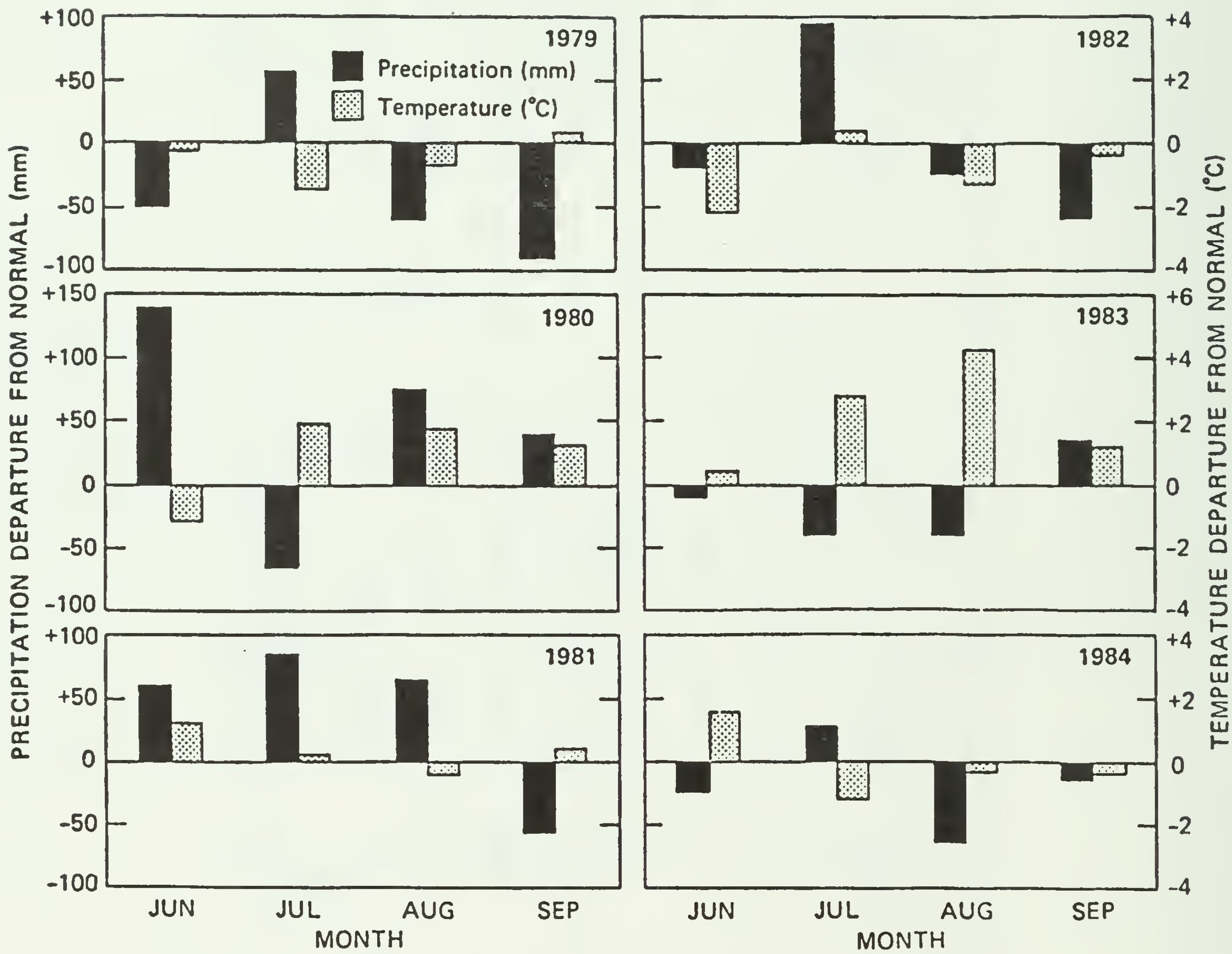

Figure 1. Temperature and precipitation departures from normal for the 1979-1984 growing seasons at Norris Mine.

Irrigation results in the overall years analysis show a significant positive response by corn for both the topsoil and wheel spoil treatments although the rate of increase was different. Corn grown on the topsoil treatment increased yields by 90% with irrigation while wheel spoil yields increased 56% over the unirrigated treatment. The two year soybean mean yields resulted in no response to irrigation for the topsoil treatment while irrigated wheel spoil soybean yields were significantly greater than the unirrigated spoil. Irrigated corn and soybeans produced yields comparable to the undisturbed Sable soil on both the topsoil and wheel spoil in every year but one. The irrigated wheel spoil in 1981 was unable to attain the undisturbed yield level. Soil moisture tension levels for the unirrigated treatments (Figure 2) show that the soil profile was at or near the saturation point for most of the growing season resulting in the low yields. Because of the above average precipitation which occurred at frequent intervals the wheel spoil had considerable difficulty with infiltration. Ponding was frequent and drainage was slow. In an earlier study at this location Lah (1980) measured very low saturated hydraulic conductivities for this wheel spoil of 12.84 cm/day compared to 28.34 cm/day for the topsoil material.

Topsoil replacement. Yield results (Table 3) show a significant positive response to topsoil replacement under irrigation for corn in three of the four years and in one of the two years for irrigated soybeans. Without irrigation topsoil replacement resulted in a significant positive yield response for corn in 1979 and 1981 (lower stress years) and a negative yield response to topsoil replacement during the higher stress years of 1980 and 1983. One reason that

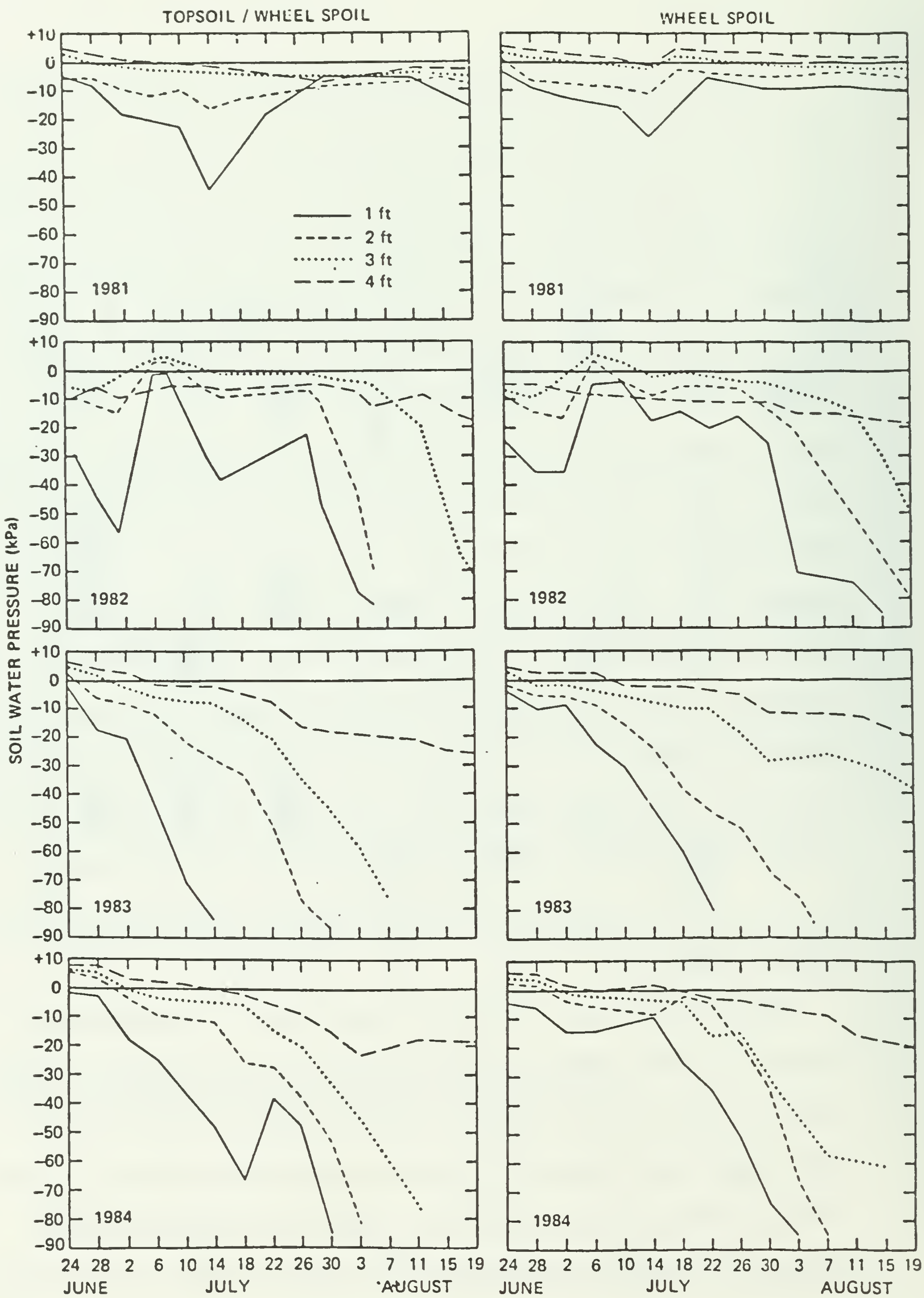

Figure 2. Soil moisture tension levels for the unirrigated mine soils for 1981-1984 at Norris Mine.

negative yield responses occurred could be due to the delayed pollination dates which normally occur on the wheel spoil treatment. The wheel spoil plots pollinated approximately one week later than the topsoil and in 1980 and 1983 had the benefit of pollinating under cooler temperatures and a 4.2 cm rain in 1980, and a 3.8 cm rain in 1983. The topsoil plots had pollinated under a considerably higher stress situation. In both 1980 and 1983 silks on the unirrigated treatments were late to emerge resulting in a high percentage of barren stalks (Table 4). This table also reflects that while the topsoil plots generally had a higher rate of plant survivability it also was more subject to aborting ears under high stress than the wheel spoil treatment. Year-to-year variation in corn yield was considerably greater for the unirrigated topsoil as compared to the unirrigated wheel spoil (Figure 3). This may be due to the fact that soil moisture levels for topsoil were considerably lower at the one and two foot levels as compared to the wheel spoil plots during the critical anthesis periods of the high stress years. No rooting depth evaluation was done during this study but it is assumed that restricted root system development on the topsoil plots might be a factor. Compaction caused by the use of scrapers to replace topsoil has created a zone directly beneath the topsoil where bulk densities of 1.7-1.9 Mg m^{-3} exist and saturated hydraulic conductivity levels are only 7.59 cm/day. Figure 3 shows that irrigation was successful in reducing the year-to-year yield variation resulting from the climatic and physical stress factors.

Soybeans showed significant positive responses to topsoil replacement with and without irrigation in 1982 but no differences existed between the topsoil and spoil in 1984. Yields of soybeans were considerably lower in 1984 due to the well below normal precipitation received during August and September. It is quite probable that the 1.9 cm/week irrigation rate used for soybeans was insufficient in 1984 to maximize yields. Tensiometer data for the unirrigated treatments (Figure 2) show that soil moisture tension levels were quite high for both topsoil and spoil by mid-August, the start of the critical pod-filling period. These results agree with those of Doss et al. (1974) who concluded that the highest soybean yield response was obtained when irrigation was applied after flowering and that the pod-fill stage was the most critical period for adequate moisture to maximize yields.

The overall years analysis showed that topsoil increased grain yields under irrigation. Mean irrigated topsoil corn yields and mean irrigated topsoil soybean yields were significantly higher than their respective irrigated wheel spoil yields. Without the benefit of irrigation corn yields for topsoil replaced and no topsoil replaced were not different for the four year mean yields. Unirrigated soybeans still showed a preference for topsoil, however, with significantly higher topsoil yields than on the wheel spoil.

Soybeans on both the irrigated and unirrigated topsoil treatments produced two year mean yields equal to the yields on the unirrigated undisturbed Sable soil. Four year mean corn yields were comparable to the Sable soil on only the irrigated treatments. Corn grown on the unirrigated topsoil produced comparable yields to the undisturbed only in 1979 and 1981, years of favorable weather, while the unirrigated wheel spoil produced comparable yields only in 1983.

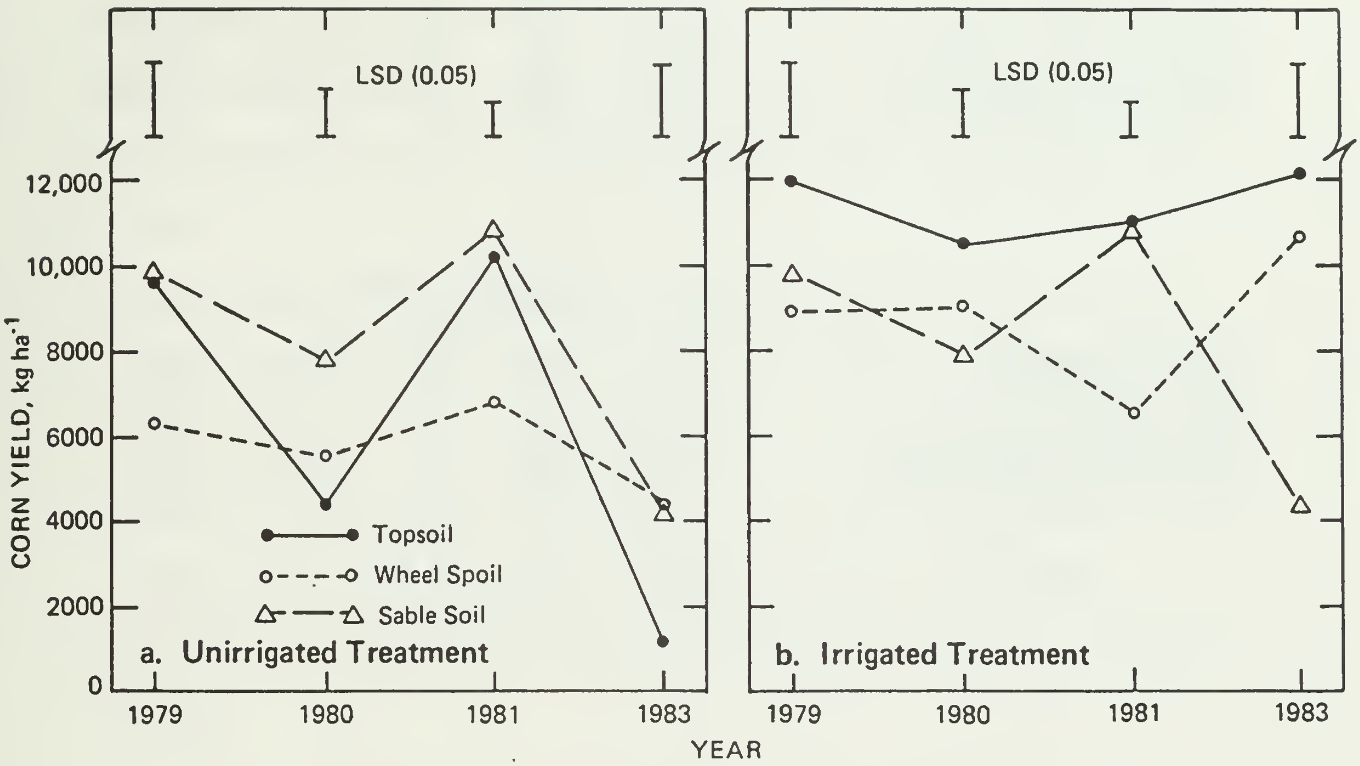

Figure 3. Average corn yields for the irrigated and unirrigated mine soils and for the unirrigated undisturbed Sable soil.

Table 4. Survival rate and % barren plants for corn grown at Norris Mine.

Treatment	1979	1980	1981	1983	Mean
	------- % Plant Survival --------				
Irrigated Topsoil	75.8	80.6	51.9	86.6	73.5
Unirrigated Topsoil	67.1	84.6	54.7	88.2	74.5
Irrigated Wheel Spoil	69.6	78.3	51.8	73.7	70.9
Unirrigated Wheel Spoil	64.2	80.9	51.7	77.2	70.5
Undisturbed Sable Soil	70.2	83.6	73.7	83.2	77.7
LSD 0.05	9.2	NS	5.5	5.1	5.1
	-------- % Barren Plants --------				
Irrigated Topsoil	0.1	5.4	-5.5	5.8	1.6
Unirrigated Topsoil	0.2	51.9	-4.6	70.4	33.5
Irrigated Wheel Spoil	3.0	3.1	3.3	3.5	3.3
Unirrigated Wheel Spoil	1.3	38.5	1.9	27.4	20.9
Undisturbed Sable Soil	1.0	18.2	9.2	34.1	15.6
LSD 0.05	NS	6.5	3.9	10.3	7.0

Conclusions

Data from corn and soybeans grown at Norris Mine support the following general conclusions.

1. Corn and soybeans grown on recently constructed mine soils which have favorable chemical and textural properties can produce yields comparable to those of rowcrops grown on undisturbed natural soils under favorable weather conditions. Temperature and moisture stress adversely affect crops on mine soils more than those on the undisturbed control.
2. Irrigated mine soil crop yields were equal to or better than those on the unirrigated, undisturbed Sable soils in all years, indicating that good quality water from surface mine lakes can be a valuable agricultural resource and that irrigation can substitute for topsoil replacement.
3. Topsoil replacement on mine soils produced a significant positive soybean yield response, when averaged over years, both with and without irrigation.
4. When averaged over years, topsoil replacement on mine soils produced a significant positive corn yield response under irrigation, but no corn yield response without irrigation.

5. Where not irrigated, topsoil replacement on mine soils produced a significant positive corn yield response in those years having favorable weather, but produced a negative response in years having severe temperature and moisture stress.
6. Yield responses of both corn and soybeans to irrigation were directly related to the amount of temperature and moisture stress in that growing season.
7. Irrigation produced a significant positive corn yield response, averaged over years, on mine soils both with and without topsoil replaced.
8. Irrigation produced a significant positive soybean yield response, when averaged over years, on mine soils without topsoil, but not where topsoil had been replaced.

Acknowledgments

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Penetrometer Resistance and Bulk Density as Parameters for Predicting Root System Performance in Mine Soils[1]

P. J. Thompson, I. J. Jansen and C. L. Hooks[2]

ABSTRACT

Material handling methods used in the construction of soils after surface mining often result in a soil with physical and structural characteristics that restrict root development. A method to quickly and easily predict root system performance and compare mine soils on the basis of their suitability for root growth is needed. This study was conducted to determine the effectiveness of penetrometer resistance (as measured by a constant rate cone penetrometer) and bulk density as parameters for predicting root system performance. Both penetrometer resistance and bulk density data fit well into a multiple linear regression model that could be used to predict root length density in the lower portion of the root zone (67 - 110 cm depth). Results suggest that in the mine soils studied, both bulk density (R^2 = 0.81) and penetrometer resistance (R^2 = 0.73) are useful predictors of root system performance.

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Additional Index Words: Surface mine reclamation, penetrometer resistance, bulk density, root length density, soil compaction.

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INTRODUCTION

Many material handling methods used in the construction of soils after surface mining result in soils having physical and structural characteristics that restrict root growth (McSweeney and Jansen, 1982). This restriction of the root system generally results in an increased sensitivity of the crop to weather stress. State and federal legislation has become more stringent in its regulation of prime farmland reclamation. Because of this, a method to quickly and easily predict root system performance is needed for early detection of areas more likely to be sensitive to drought stress.

Soil compaction is defined as the pressing of soil together to make it more dense (Gill, 1961). When soil is compressed, bulk density increases, pore volume decreases, pore size distribution shifts toward smaller pore size, and pore space continuity decreases (Vomocil, 1957). A compacted soil generally has poor aeration, low nutrient and water availability, slow permeability, and mechanical impedance to root growth (Raney et al., 1955). All of these factors can limit root system development.

Soil compaction impedes the movement of water and air through the soil by reducing the number of large pores. The impeded aeration that results can inhibit root growth (Hillel, 1982). Evidence suggests that although some minimum oxygen level is essential (Gingrich and Russel, 1956; Gill and Miller, 1956; Flocker et al., 1959; Tackett and Pearson, 1964), root restriction in compacted soils can result from mechanical impedance regardless of the aeration.

Some studies have supported the concept of a critical bulk density beyond which roots cannot penetrate as the physical parameter that will best characterize root growth into compacted soils (Veihmeyer and

Hendrickson, 1948; Zimmerman and Kardos, 1961). Although Merideth and Patrick (1961) found a linear relationship between bulk density and the root penetration of sudangrass, their study does not support the concept of critical bulk density.

Other researchers suggest that it is not bulk density that is the most important limiting factor reducing root growth, but soil strength (Taylor and Gardner, 1963; and Taylor and Burnett, 1964). Phillips and Kirkham (1962) argue that soil strength is a better measure of root penetration than bulk density because soil strength, as measured by a penetrometer, more accurately reflects the resistance encountered by the root when entering the soil.

Small pore size is sometimes, but not always, associated with high soil strength (Barley and Greacan, 1967). Merideth and Patrick (1961) interpreted the results of their study to mean that the main effect of compaction in restricting root entry is the reduction of large pores. Other researchers have found that it is not the reduction of large pores per se, but the rigidity of the pore system that determines root penetration. In a rigid pore system (one in which particles are fixed in their positions), plant roots were unable to pass through existing voids narrower than the diameter of the root tip. But in a non-rigid system, roots were able to grow into all pore sizes (Taylor and Burnett, 1964; Aubertin and Kardos, 1965; Greacan et al., 1969). These researchers conclude that it is the high soil strength and not the reduction of pore size below some critical diameter that reduced root penetration. Roots penetrate soils lacking in large pores by deforming the soil. Soils resist penetration and root growth can be prevented if soil strength is sufficiently high (Barley et al., 1965).

The objective of this study is to evaluate the effectiveness of penetrometer resistance (as measured by a constant rate recording cone penetrometer) and bulk density as parameters for predicting root system performance.

MATERIALS AND METHODS

The study was conducted on three mine soils (Typic Udorthents) constructed after surface mining in Southern Illinois. Two were located at the Captain Mine, Perry County and the other at the River King Mine, Randolf County (Figure 1).

One set of research plots located at the Captain Mine, the Captain Mix Plots (Figure 2), were constructed with a mining wheel-conveyor-spreader system. These plots consist of 6 treatments representing various blends of soil materials. The soil here is generally quite loose and porous.

The other set of plots located at the Captain Mine, the Captain Wedge Plots (Figure 3), consist of shovel spoil covered by a layer of hauled rooting media (mostly composed of B horizon material) varying in thickness from 0 - 122 cm. The rooting material was hauled and placed using rubber tired scrapers. The subsoil at these plots is quite compacted and massive. Superimposed are randomly located strips that have topsoil replaced.

The River King Plots (Figure 4) consist of mining wheel spoil graded with bulldozers. The two treatments are mining wheel spoil with topsoil replaced and mining wheel spoil only. The material handling method used resulted in a soil with high variability in the degree of compaction.

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). The 1 sq. inch cone was driven into the soil at a rate of 2.9 cm/sec. Measurements were taken on June 6,7 and 8, 1984. The data were collected in the spring when soils are generally quite uniformly moist to minimize the effects of variable soil moisture on penetration resistance. Soil moisture data, determined by the gravimetric method, were also collected simultaneously to verify this uniformity (Table 1).

Locations for penetrometer measurements are shown in Figures 2, 3 and 4. At each sample site, six penetrometer measurements were taken, three on either side of a FR MO17 X FR B73 hybrid corn plant. This plant was located approximately five feet in from the edge of the plots and was flagged for further reference. Individual penetrometer measurements were located about 20 cm apart. The 110 cm penetrometer profiles were separated into five 22 cm segments.

The segments represented the following depth increments:

Segment 2 - 23 - 44 cm

Segment 3 - 45 - 66 cm

Segment 4 - 67 - 88 cm

Segment 5 - 89 - 110 cm

(Depth segments will be referred to, hereafter, by segment number).

A mean penetrometer resistance value was obtained for each segment and then averaged over the six profiles at each site (Table 2). Segment one was not included for analysis because it was within reach of tillage equipment.

Half of the original sites used for penetrometer analysis were used for root analysis. These 14 sites are indicated in Figures 2, 3, and 4. Sites for root analysis were chosen after analyzing the penetrometer data and were selected to represent a wide range in soil strength values.

Root cores were taken July 18 and 19, 1984 with the assumption that root maturity had been reached. Cores were taken using a 7.6 cm diameter coring tool.

Three root cores were taken from each site, one from below the flagged plant and one from below the corn plants located to either side of the flagged plant and in the same row. Cores were taken by cutting off the top of the plant and driving the coring tool into the soil directly below it. A fourth core located within 30 cm of the flagged plant, was taken at the same time for bulk density analysis. Bulk density data are given in Table 2.

Both root cores and bulk density cores were 110 cm long. They were cut into five 22 cm segments (corresponding to the penetrometer depth segments) and wrapped in plastic bags.

Root cores were kept at approximately 10°C until soil and roots could be separated. Soil material was washed from the roots using a hydropneumatic root elutriation system designed after one developed by Smucker et al. (1982). After washing, roots were stored in jars with a 15% alcohol solution (Bohm, 1979) and were kept in a dark place at room temperature.

Total root length was determined using Tennant's (1975) modified Newman line intersect technique. Root length density was obtained by dividing root length by the volume of soil in the 22 cm segment. An averge root length density value was obtained for each segment (Table 2).

Regression analysis was used to determine the following relationships between: (1) penetrometer resistance and root length density, (2) bulk density and root length density; and (3) penetrometer resistance and bulk density.

RESULTS AND DISCUSSION

There appears to be no relationship between root length density and penetrometer resistance or between root length density and bulk density in segment 2 (Table 3). However, the within segment relationship generally improves with depth. Perhaps this is partly because of the wet-dry cycles creating more dessication cracks nearer the surface than at greater depths. The presence of these dessication cracks could provide a route for root growth even when the area between the cracks has a soil strength or bulk density high enough to inhibit root growth. In addition, roots need only travel through high strength materials a short distance to reach the near surface layers. They must travel through these materials considerably farther to reach the lower segments.

It seems reasonable that root growth into any one segment would be affected not only by the physical characteristics of that segment, but of the segments above, as well. Because of this, a model was developed that would predict the average root length density in segments 4 and 5 by using the average penetrometer resistance of segments 2 through 4 or the average bulk density of segments 2 through 4 as the predictor variable. A model including segment 5 into the average for the predictor variable was also fitted, but including segment 5 did not improve the fit. Figures 5 and 6 show, graphically, the results from this model.

This type of model is simple and can generate two-dimensional graphs that can be easily examined. However, one or more segments may have greater influence over root growth than any of the others. Averaging over segments 2 through 4 would dampen the effect of individual segments.

A more complex multiple regression model was developed to separate the effects of segments 2, 3 and 4 into three predictor variables. These variables were entered into the model sequentially. The sequential model is order dependent, each effect being adjusted for the preceding effects in the model. The model and corresponding statistics are given in Table 4.

This type of multiple linear regression model is a better fitting model for predicting root length density in segments 4 and 5 than is the simple regression model. Segment 5 was added to the model after synthesizing missing values, but adding segment 5 did not signifi-cantly improve the R^2 for either parameter.

Although many studies suggest that it is soil strength and not bulk density that is the most important factor limiting root growth, the results here suggest that bulk density may be more important. Perhaps this is because a penetrometer cone is not as flexible as a root tip and therefore does not measure exactly the same strength the root encounters. However, soil strength, as measured by a recording cone penetrometer, should not be disregarded as a means of predicting root system performance in mine soils. Penetrometer resistance data can be collected more quickly and easily than can bulk density data. The ability to collect much more data by using the penetrometer rather than measuring bulk density could increase the total number of observations obtained. Given the high variability in mine soils, increasing the number of observations could improve the evaluation of reclaimed soils.

Since both of these physical properties, soil strength and bulk density, increase upon compaction, they would be expected to be correlated in a compacted soil, all other factors being constant. Penetrometer resistance and bulk density are correlated in all segments except segment 2 (Table 5). The reason for lack of correlation in segment 2 is unclear. Variation in moisture content was investigated, but there was no better correlation between soil moisture and penetrometer resistance or bulk density in segment 2 than in other segments.

A model using both penetrometer resistance and bulk density for segments 2 through 4 as the independent variables and the root length density of segments 4 and 5 as the dependent variable was examined using a stepwise procedure. In this model, all variables not meeting the 0.05 level of significance are dropped out of the model. Penetrometer resistance for segments 2 and 5 dropped out, along with the bulk density of segment 5. The final model is as follows: RLD 4&5 = PR3 + PR4 + Db2 + Db3 + Db4, where RLD = root length density, PR = penetro-meter resistance , and Db = bulk density. This model has an $R^2 = 0.90$. Although this model is the best fitting model investigated, the time and effort needed to collect and analyze the data for a complex model like this one is a distinct disadvantage. Investing the available data collection time in taking penetrometer data only, along with supporting soil moisture data, would enable a larger number of sites to be investigated and would probably provide a better prediction of suitability for root system development than would collecting both penetrometer data and bulk density for fewer sites.

CONCLUSIONS

The data analyzed in this study support the following general conclusions.

1) Both penetrometer resistance and bulk density are good predictors of root system performance in newly constructed soils. They are especially useful in predicting root extension into the deeper regions of the root zone.

2) The relationship between root length density and either of two physical parameters, penetrometer resistance or bulk density, generally improves with depth.

3) The best models investigated were multiple linear regression models that use physical data from sub-tillage layers to predict root development in the lower zone.

4) Penetrometer resistance and bulk density are highly correlated in the lower root zone, but poorly correlated nearer the soil surface.

5) Bulk density is a slightly better predictor (R^2=0.81) of effective rooting depth than is penetrometer resistance (R^2=0.73).

6) A complex model using both penetrometer resistance and bulk density as independent variables was the best fitting model examined.

7) The cone penetrometer looks promising as a tool for predicting root system performance and for evaluating mine soils on the basis of their suitability for row crop production. Because penetrometer resistance data can be collected and analyzed more quickly, easily, and economically than bulk density data can, it might be more useful in that more samples can be taken.

ACKNOWLEDGMENTS

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LIST OF TABLES

Table 1. Percent soil moisture values for the final 14 sites used in regression analysis. (Gravimetric Method)

		% Soil Moisture		
Location	Plot Number	15-30	46-61	76-91
Captain Mix	1	16.7	19.3	19.9
	2	19.5	17.4	19.2
	3	16.1	19.9	17.9
Captain Wedge	6	17.7	15.6	15.8
	7	17.0	16.1	16.6
River King	east 2	18.8	15.6	16.4
	3	18.5	17.6	16.6
	4	13.8	15.6	15.9
	5	18.4	17.1	14.6
	7	16.3	15.4	15.5
	west 2	19.9	17.6	18.5
	3	18.4	18.7	16.9
	7	18.6	15.5	16.5
	8	16.6	15.8	15.6

Table 2. Average penetrometer resistance, bulk density, and average root length density data for the final 14 sites used in regression analysis.

Location	Plot No.	Ave. Penetrometer Resistance (KPa) 23-44cm	45-66cm	67-88cm	89-110cm	Bulk Density (g/cm3) 23-44cm	45-66cm	67-88cm	89-110cm	Ave. Root Length Density (cm/cm3) 23-44cm	45-66cm	67-88cm	89-110cm
Captain Mix	1	1464	1049	787	647	1.74	1.58	1.45	1.51	.70580	.54837	.39640	.49273
		(11.5)	(19.0)	(15.6)	(31.2)					(8.4)	(25.9)	(70.9)	(59.3)
	2	1204	865	536	529	1.58	1.54	1.48	1.43	.73010	.62513	.70267	.64783
		(9.5)	(13.3)	(18.2)	(34.4)					(20.9)	(22.8)	(17.1)	(45.6)
	3	1131	1628	1412	802	1.40	1.62	1.68	1.56	.74813	.60787	.41833	.24207
		(8.6)	(11.5)	(12.0)	(20.6)					(22.0)	(19.0)	(26.4)	(76.0)
Captain Wedge	6	3709	3166	3203	2791	1.59	1.78	1.73	----	.63220	.16607	.00000	.00000
		(19.8)	(12.1)	(20.9)	(14.8)					(42.2)	(87.0)	( )	( )
	7	1905	2410	2969	----	1.70	1.79	1.73	1.62	.86953	.21153	.00000	.00000
		(10.6)	(14.9)	(25.9)	( )					(17.8)	(56.5)	( )	( )
River King	east												
	2	1348	1773	2076	1691	1.56	1.74	1.76	1.70	1.72727	.74500	.50060	.13160
		(17.7)	(14.1)	(21.0)	(31.8)					(6.7)	(24.3)	(27.4)	(131.5)
	3	2021	2096	1884	1717	1.49	1.56	1.74	1.93	.72383	.58830	.32430	.04777
		(17.2)	(22.6)	(17.8)	(15.8)					(23.4)	(3.6)	(23.0)	(94.2)
	4	2647	2205	1923	1496	1.44	1.78	1.78	1.74	.57733	.53893	.38857	.03213
		(12.7)	(14.2)	(11.6)	(21.6)					(26.9)	(29.0)	(54.8)	(173.2)
	5	1651	2595	3064	2671	1.63	1.91	1.79	1.78	1.14917	.50530	.11597	.00313
		(5.4)	(14.1)	(7.3)	(16.4)					(47.8)	(25.8)	(161.0)	(173.2)
	7	2225	1346	887	771	1.72	1.73	1.60	1.51	.96587	.41677	.37837	.18490
		(15.9)	(16.9)	(13.7)	(12.0)					(2.3)	(12.1)	(48.2)	(113.9)
	west												
	2	2241	2651	2483	2399	1.57	1.65	1.62	1.71	.83117	.68153	.39797	.27497
		(14.0)	(7.3)	(27.0)	(13.7)					(49.8)	(5.2)	(48.3)	(70.3)
	3	2000	2227	2158	1995	1.69	1.68	1.68	1.63	.71207	.45903	.11753	.00000
		(18.1)	(26.3)	(29.6)	(32.6)					(8.1)	(61.9)	(92.3)	( )
	7	1895	1434	1494	1149	1.62	1.81	1.73	1.62	.59460	.40110	.24257	.14337
		(30.8)	(14.0)	(16.2)	(15.7)					(13.7)	(74.3)	(45.3)	(110.9)
	8	1982	1690	2023	1931	1.55	1.75	1.82	1.77	.86485	.57930	.11755	.03050
		(22.0)	(18.0)	(16.2)	(6.9)					(30.3)	(46.0)	(41.6)	(86.6)

Numbers in ( ) are coefficients of variation

Table 3. Results of regression analysis: dependent variable is root length density (cm/cm^3).

Predictor Variable	Segment #	Prob>F	R^2
Penetrometer Resistance	2	0.2021	0.13
	3	0.1463	0.17
	4	0.0018	0.57
	5	0.0167	0.45
Bulk Density	2	0.7707	0.00
	3	0.1044	0.20
	4	0.0342	0.32
	5	0.0053	0.56

Table 4. Multiple linear regression models using average penetrometer resistance and bulk density as preditor variables.

Model 1: RLD (seg.4+5) = 1.15 - 2.56(PR(seg.2)) + 5.58(PR(seg.3)) - 6.68(PR(seg.4))

Source of Variation	df	Sum of Squares	Prob.>F
PR(2)/a	1	0.5672	0.0079
PR(3)/PR(2), a	1	0.4291	0.0165
PR(4)/PR(3), PR(2), a	1	0.3766	0.0226

Residual error = 0.0519 (df = 10)
R^2 = 0.73
C.V. = 50.6

Model 2: RLD (seg.4+5) = 9.25 - 2.11(Db(seg.2)) + 0.52(Db(seg.3)) - 3.77(Db(seg.4))

Source of Variation	df	Sum of Squares	Prob.>F
Db(2)/a	1	0.0189	0.4890
Db(3)/Db(2), a	1	0.8872	0.0006
Db(4)/Db(3), Db(2), a	1	0.6193	0.0021

Residual error = 0.0367 (df = 10)
R^2 = 0.81
C.V. = 42.6

RLD = root length density, PR = penetrometer resistance, Db = bulk density.

Table 5. Correlation between average penetrometer resistance and bulk density for each segment.

Segment #	R value	Prob.>R under Ho:RHo = 0
2	0.01	0.9640
3	0.49	0.0759
4	0.68	0.0070
5	0.75	0.0048

Because of missing data, segments have two fewer observations.

LIST OF FIGURES

Figure 1.
P.J. Thompson,
I.J. Jansen, and
C.L. Hooks

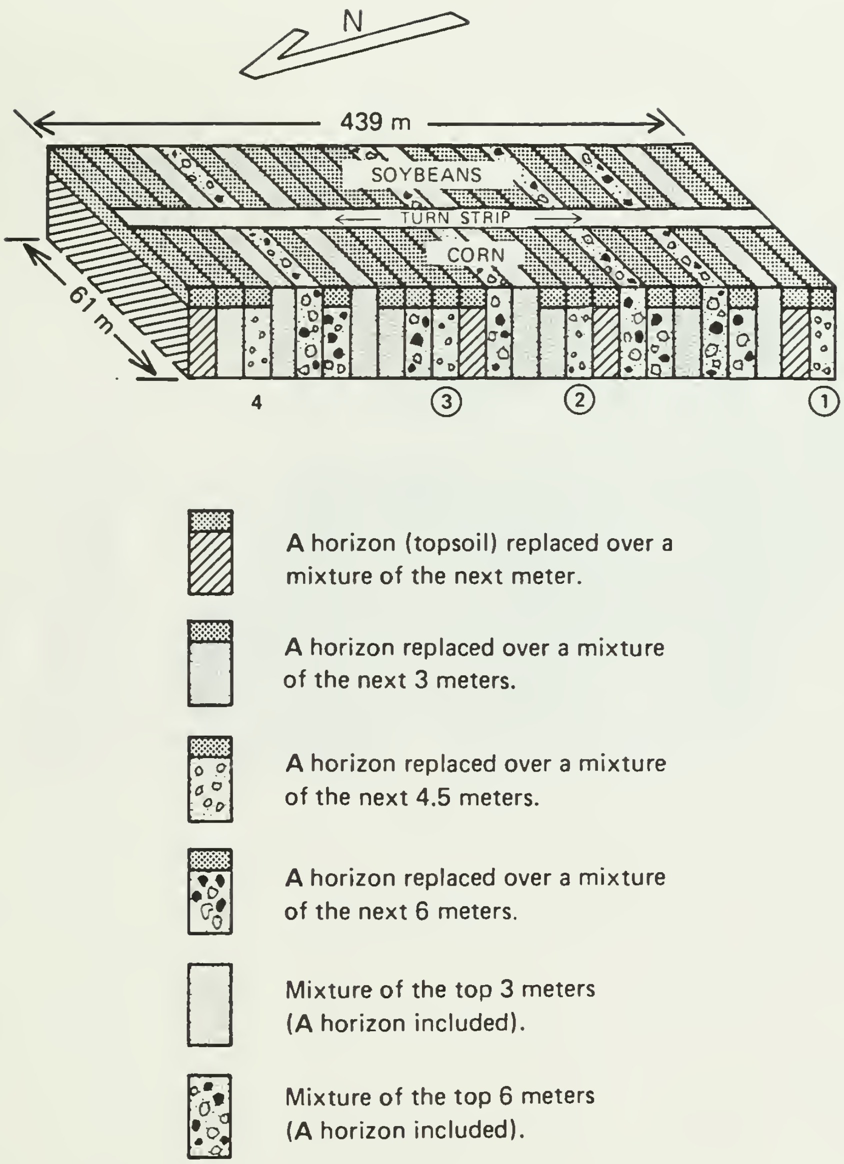
N
439 m
SOYBEANS
TURN STRIP
CORN
61 m
4
③
②
①
A horizon (topsoil) replaced over a mixture of the next meter.
A horizon replaced over a mixture of the next 3 meters.
A horizon replaced over a mixture of the next 4.5 meters.
A horizon replaced over a mixture of the next 6 meters.
Mixture of the top 3 meters (A horizon included).
Mixture of the top 6 meters (A horizon included).

Fig 2

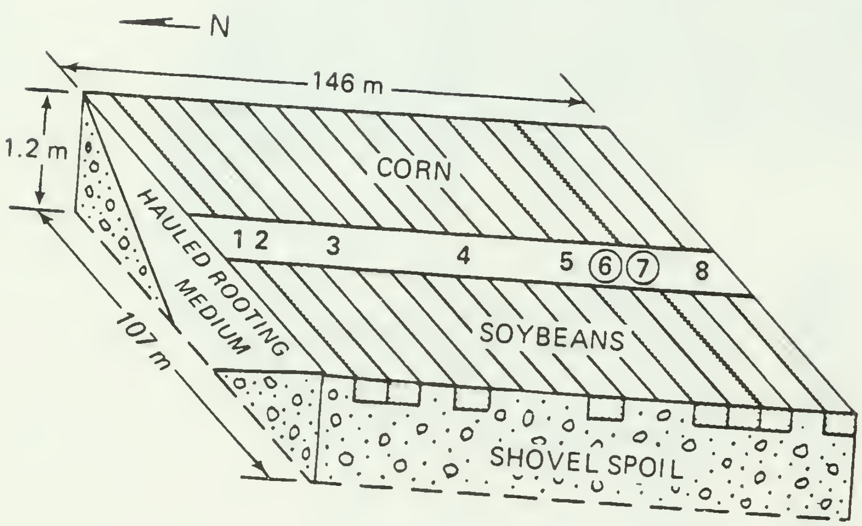

Figure 3,
P.J. Thompson,
I.J. J[illegible],
and C.L. Hooks

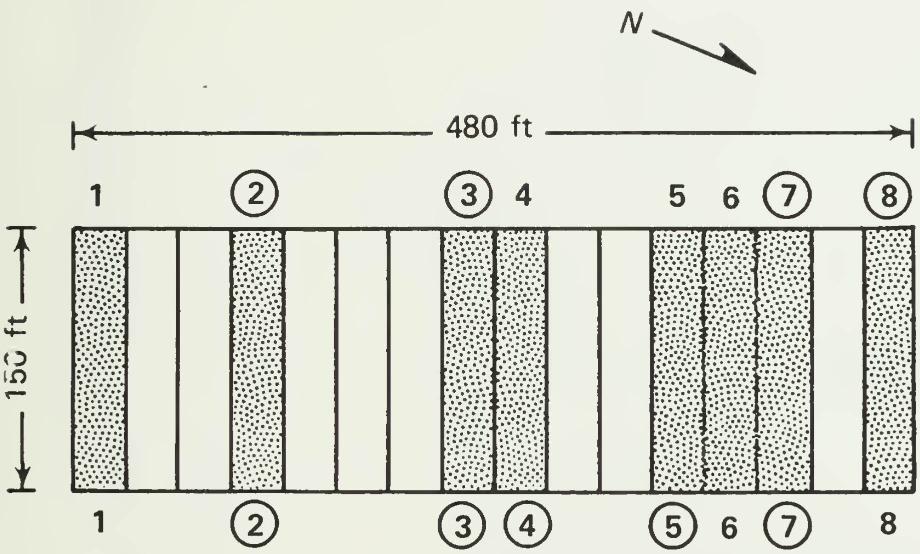

Figure 4.
P.J. Thompson,
[illegible]

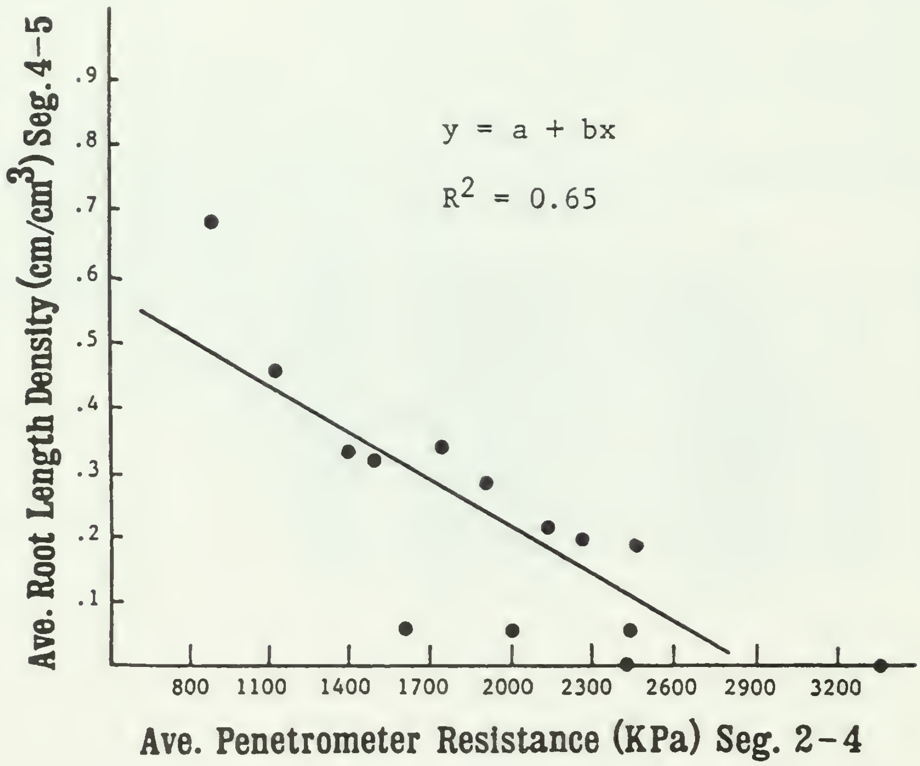

Figure 5
P. J. Thompson,
I. J. [illegible],
and R. [illegible] Hooks

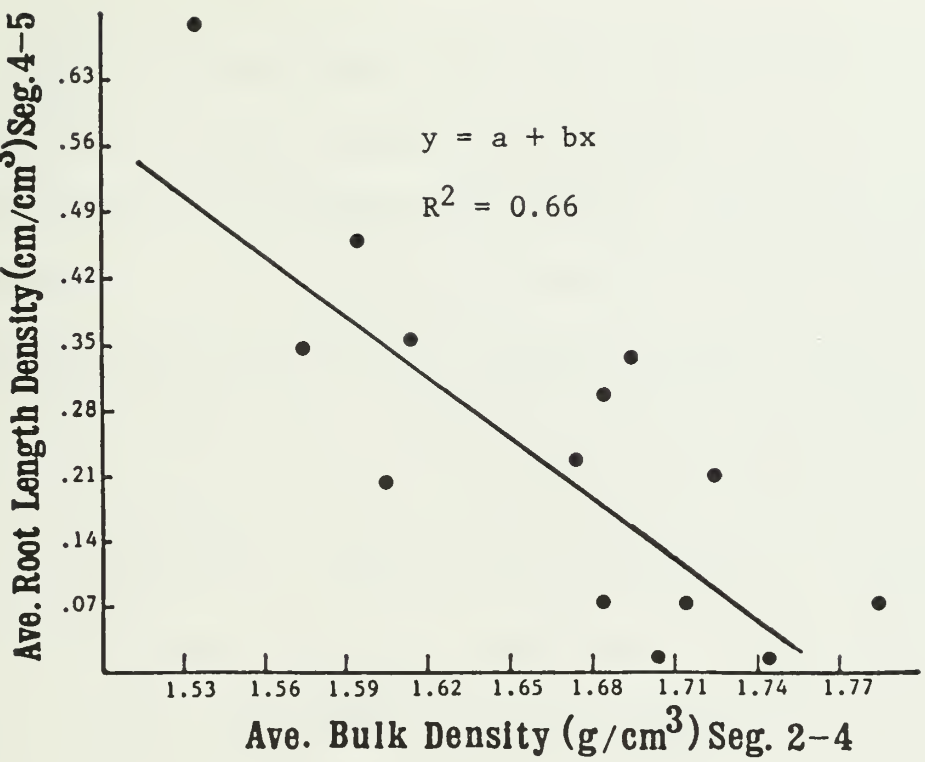

Figure 6.
P. J. Thompson,
I. J. Jansen
and C. L. Hooks

ROW CROP PRODUCTIVITY OF EIGHT CONSTRUCTED MINESOILS

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Abstract

McSweeney, K., Jansen, I.J., Boast, C.W. and Dunker, R.E., 1986. Row crop productivity of eight constructed minesoils. Reclamation and Revegetation Research, 0: 000-000.

Keywords: minesoils; soil structure; soil compaction; reclamation; plant rooting.

Research plots were established at a mine site in southern Illinois to evaluate suitability of various soil construction designs and methods for production of row crops. One set of plots was constructed by using scrapers, and the other set of plots was constructed using a mining wheel-conveyor-spreader system. Each site had a variety of soil treatments, differing in presence or absence of topsoil and in the mixture or depth of materials used to construct the subsoil. The best 4-yr average yields (2216 kg ha^{-1} soybean; 7126 kg ha^{-1} corn) were on the soil consisting of A horizon material replaced over a mixture of the next 1 m of soil material and constructed with the mining wheel-conveyor-spreader system. The same soil design, when built with scrapers, however, produced only 655 kg ha^{-1} soybean and 1727 kg ha^{-1} corn, the poorest 4-yr average yields of all soils evaluated. Yield variation was principally related to differences in the

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Reclamation and Revegetation Research (In Press)

subsoil physical characteristics of the minesoils. The scraper system produces a more compact subsoil than the mining wheel-conveyor-spreader system.

Introduction

The design and construction of productive minesoils on surface mined land requires selection of both suitable materials and appropriate material handling techniques (Indorante et al., 1981). Minesoils can be constructed with selected chemical, textural, and microbiological attributes by amending or substituting horizons of the original soil with suitable unconsolidated materials from below the solum (McCormack, 1974; Jansen and Dancer, 1981; Hargis and Redente, 1984). Material selection, however, is usually limited to unconsolidated overburden materials available on the mine site. Many of the prime agricultural soils in southern Illinois that will be disturbed by surface mining have strongly-to-very-strongly acid and/or natric infertile subsoil horizons (Miles et al., 1970). These soils are underlain by unconsolidated glacial and aeolian materials that could potentially be used for reclamation to amend some of the adverse properties of the natural subsoil (Dancer and Jansen, 1981). In greenhouse studies using materials from mine sites in southern Illinois, topsoil materials have generally produced better plant growth than materials from soil B or C horizons, but B-C mixtures were commonly equal to or better than B horizon materials alone (Dancer and Jansen, 1981; McSweeney et al., 1981; Stucky and Lindsey, 1982).

Construction of minesoils with specified structural attributes is more complex because material handling disturbs the original structure of the soil material. Newly constructed soils commonly exhibit a compact physical condition within the profile which is attributable to the soil construction operation rather than soil forming processes (McSweeney and Jansen, 1984). Row crop yield reduction during drought stress years in Illinois minesoils constructed using scrapers has been attributed to restricted root development in compacted subsoil layers (Meyer, 1981). Greenhouse studies (Stucky and Lindsey, 1982) have correlated yield reduction with increased compaction for soybeans grown on constructed soil profiles compacted to several different bulk densities. The objective of this study was to evaluate a selection of soil construction methods and designs for row crop production.

Materials and methods

Two sets of experimental plots were constructed at the Captain Mine, Perry County, Illinois. They were designed to evaluate various combinations of substratum and A and B horizon materials for corn (Zea mays L.) and soybean [Glycine max (L.) Merr.] production.

The soil design of one set of plots, hereafter referred to as the wedge plots (Fig. 1), consists of a wedge of hauled rooting medium (subsoil) placed over graded shovel spoil. The materials were hauled and placed by rubber-tired scrapers. The rooting medium is selected material consisting mostly of B horizons, but also includes some C horizon material. In addition, half of the plots include an upper layer (0.3 m) of topsoil (A horizon). In this investigation, evaluation of row crop performance is limited to portions of the plot where the constructed soil is at least 1.2 m deep (Fig. 1). In plots where topsoil is present, the soil design corresponds in soil material composition to the A/1m treatment in the other set of experimental plots (Fig. 2).

The second set of plots, hereafter referred to as the mix plots, consists of six soil treatments (Fig. 2). The treatments differ in presence or absence of a separately replaced topsoil layer and in material composition of the subsoil. The two treatments without replaced topsoil, the top 3m mix and top 6m mix include A horizon material blended throughout the soil. The blending of varying increments of soil and unconsolidated substratum materials (Fig. 3) was achieved using a mining wheel (Chironis, 1978). The soil material was transported by a conveyor belt and placed on the reclamation site with minimal grading. Materials very similar to those used for soil construction of the experimental plots have been described and evaluated by McSweeney et al. (1981), Snarski et al. (1981), and McSweeney and Jansen (1984, 1985).

Conventional farming equipment and procedures were used for tillage and planting. Harvesting and yield determination procedures followed those outlined by Jansen et al. (1985).

An undisturbed tract of Cisne soil (fine, montmorillonitic, mesic, Mollic Albaqualfs) located nearby was used as an unmined reference area during the 1981-83 growing season. A tract of Stoy soil (fine-silty, mixed, mesic, Aquic Hapludalfs) was used as a reference area in 1984 due to the Cisne tract being unavailable for row cropping. Both the Cisne and Stoy area are representative of the majority of agricultural soils in the area.

Statistical comparisons between soil treatments within and among the mix plots, wedge plots, and undisturbed plots were made using the within treatment variances and individual t tests at the 0.05 level of probability.

Results and discussion

The weather during the four growing seasons spans a broad range of the variation experienced in this part of southern Illinois. The 1981 and 1982 growing seasons were favorable for plant growth, and in contrast 1983 and 1984 were drought years and thus unfavorable for plant growth.

Yield data (Table I) reviewed by individual year and by 4-yr average demonstrate the clear superiority of plant performance on the mix plots compared to the wedge plots. This difference is largely attributed to the marked contrast in physical condition of the rooting environment of the subsoil in the two plots, which is a result of different reclamation methods.

The subsoil physical condition of the wedge plots can be best described as compact and massive. Root growth inhibition by a physical barrier in the soil profile reduces the volume of soil exploited by the plant and can result in growth retardation and yield suppression (Scott and Erickson, 1964; Taylor and Burnett, 1964; Tinker, 1980; Wiersum, 1980). Root exploitation of constructed subsoils particularly for water is essential for successful row crop production in Illinois especially during drought stress years, unless the soil receives supplemental irrigation (Dunker et al., 1982). Total crop failure on the wedge plots during the drought years, 1983 and 1984 and poor performance in 1981 and 1982 is strongly associated with very limited root exploitation of the subsoil. The plots were constructed using scrapers, and pits excavated in these plots and other plots in southern Illinois constructed in a similar manner have shown these high strength compact subsoils to contain very few roots (Meyer, 1981). Roots were largely confined to desiccation cracks in the upper 0.2 m of the subsoil, resulting in a total soil depth of about 0.6 m for root exploitation.

The mix plots, constructed using a mining wheel-conveyor-spreader system have subsoils consisting of pockets of compacted material within a framework of loosely compressed aggregates of varying sizes (McSweeney and Jansen, 1984, 1987). This artificial soil structure, termed fritted, is a product of the material handling method (McSweeney and Jansen, 1984). The fritted structure favors formation of extensive subsoil root systems extending >1.2 m below the ground surface (McSweeney and Jansen, 1984, 1985). This favorable subsurface rooting environment is considered to be central to the successful crop performance on these soils.

The extent to which the subsurface rooting environment affects crop productivity is best illustrated by yield comparison among the A/1m, A/RM/SS and undisturbed soil treatments (Table I). These soils consist of essentially the same collection of soil materials; A horizon overlying B horizon. The soils differ in degree to which the physical condition of the soil especially the B horizon has been disrupted, and differ appreciably in their productivity.

Crop performance on the mix plots was comparable with yields achieved on undisturbed soils (Table I) during drought stress years and soybean yield was actually superior to that achieved on the undisturbed soil in 1981 and 1984, and the same was the case for corn yield in 1984. Four-year average yields for the mix plots were comparable or higher than yields on the undisturbed soils (Table I), indicating that minesoils appropriately constructed can be at least as productive as their undisturbed neighbors.

One of the principal reasons for constructing the mix plots was to evaluate suitability of unconsolidated substratum and solum material for use as mine subsoils. Previous greenhouse studies (Dancer and Jansen, 1981; McSweeney et al., 1981; Stucky and Lindsay, 1982) had indicated that certain B/C mixtures were more productive than B horizons alone. The 4-yr field evaluation of the various mixtures (Table I), however, demonstrated that the A/1m treatment, which corresponds to a reconstruction of pre-minesoil, produced the highest overall yields for both crops.

The reason for the superior productivity of the A/1m treatment is not clear. Simply mixing a 1-m thick layer (after removing the A horizon) could achieve some textural and chemical improvement by disrupting the zone of maximal soil development and blending that material with less strongly weathered material from the lower B horizon. It is also probable that this treatment has a larger portion of small fritted aggregates than the other subsoil treatments, because the dense till components of the subsoil are less disrupted during transport than loessial constituents (McSweeney and Jansen, 1984, 1987).

The two treatments, 3m mix and 6m mix, in which A horizon material was incorporated into the soil blend rather than replaced separately, were not as productive overall as the other mix plot treatments (Table I) with the exception of the 6m mix for soybeans. However, yields on these non-topsoil treatments were as high or higher than those on the undisturbed control and substantially higher than those on soils constructed with scrapers.

Yield response to topsoil replacement on reclaimed land has ranged from positive to negative and varies with the crop, the season, and the site (Jansen et al., 1985). In most instances there has been some positive yield response to topsoil replacement, but the topsoil factor has generally been much less critical than creating a desirable subsoil physical condition by controlling compaction during soil construction.

Tillage management is much more critical for constructed soils that do not have topsoil replaced than for those that do. The topsoil has favorable tilth, and numerous options are available for successful seedbed preparation and stand establishment. Tillage management on minesoils that do not have replaced topsoil is very delicate; the soils should only be tilled to a very shallow depth, if at all in the spring. Timing of planting operations is very critical on these soils in that there might only be 1 day or less between the time that the soil becomes dry enough for tillage to a depth of 5-8 cm and the time that the crust is hard and very difficult to work with. More work is needed to determine the degree to which soils without topsoil can be made more productive by improved tillage management.

Conclusions

1. Yield on the A/1m mix plot treatment was comparable to undisturbed soils composed of similar materials for growing seasons considered favorable for plant growth and better for drought stress growing years. This demonstrates that minesoils can be constructed that have comparable productivity to their undisturbed neighbors.

2. Yield was better on mix plot treatments that included a separately replaced A horizon; the opposite was the case on the wedge plots. This issue requires further investigation.

3. All minesoils constructed by the wheel-conveyor-spreader system had 4-yr average yields that were at least as high as those on natural soils.

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List of figures

List of tables

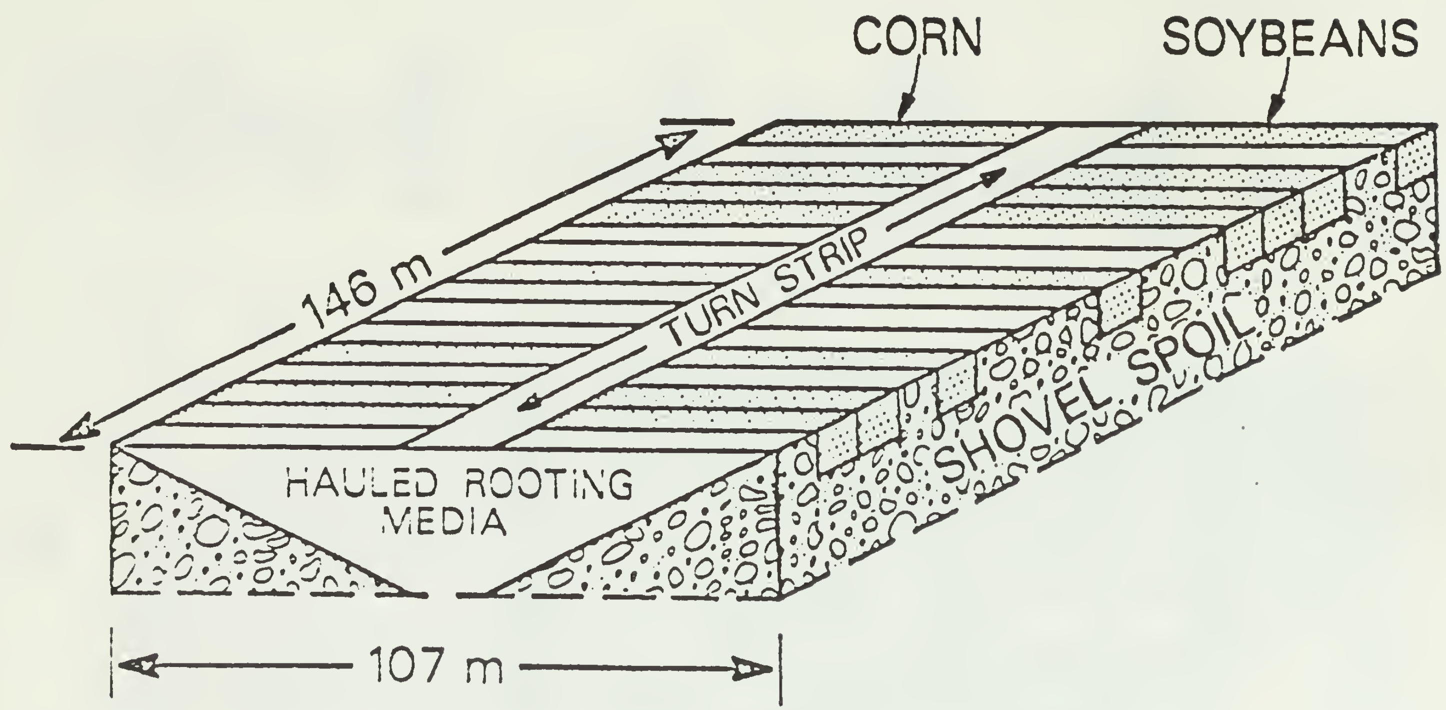

Fig. 1. Diagrammatic representation of wedge plot layout, Captain Mine. Shaded plots have replaced A horizon material. Corn and soybeans are shown in their 1982 and 1984 configuration.

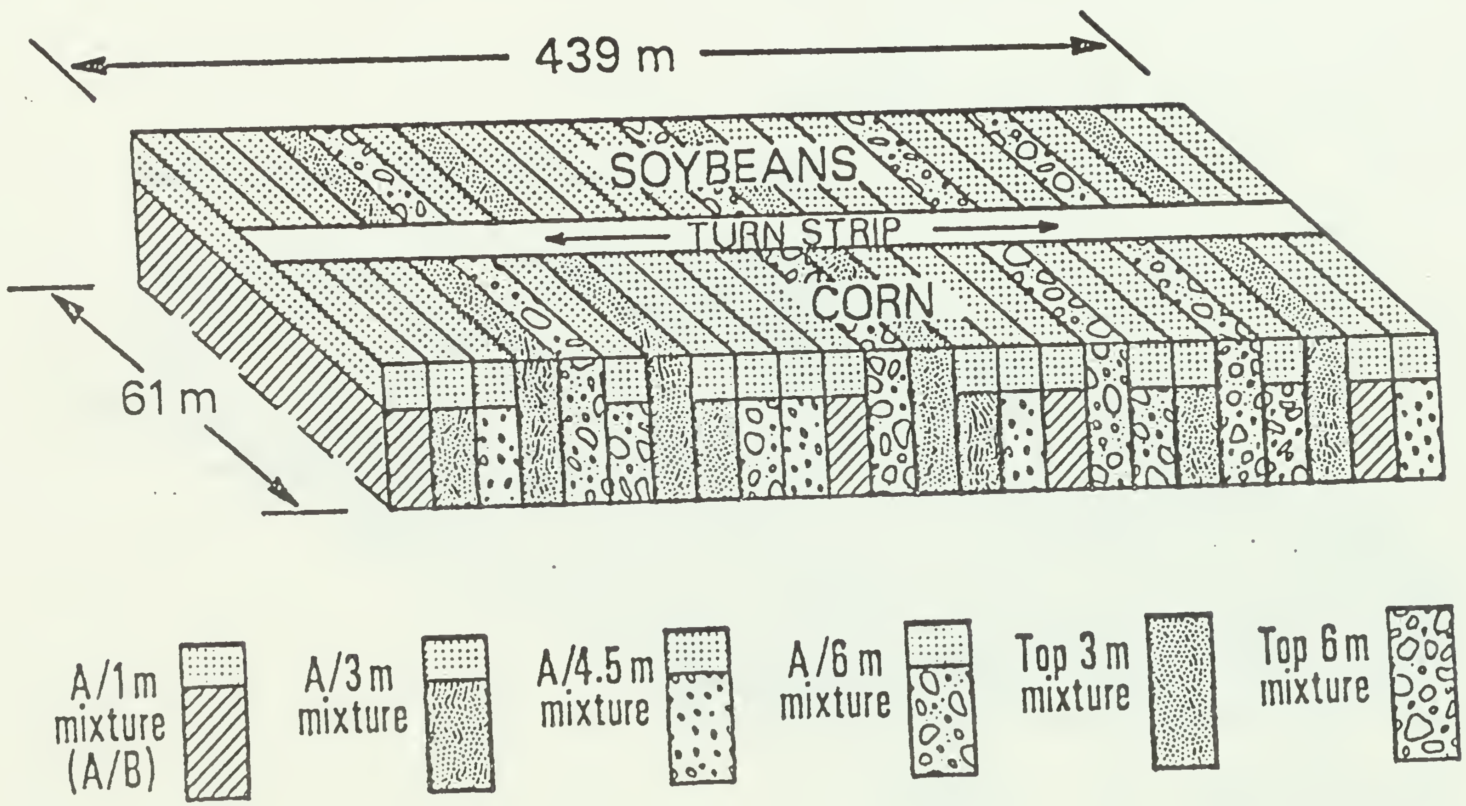

Fig. 2. Diagrammatic representation of mix plot layout, Captain Mine. Top 3m and top 6m mixtures do not have a separately replaced A horizon. Corn and soybeans are shown in their 1981 and 1983 configuration.

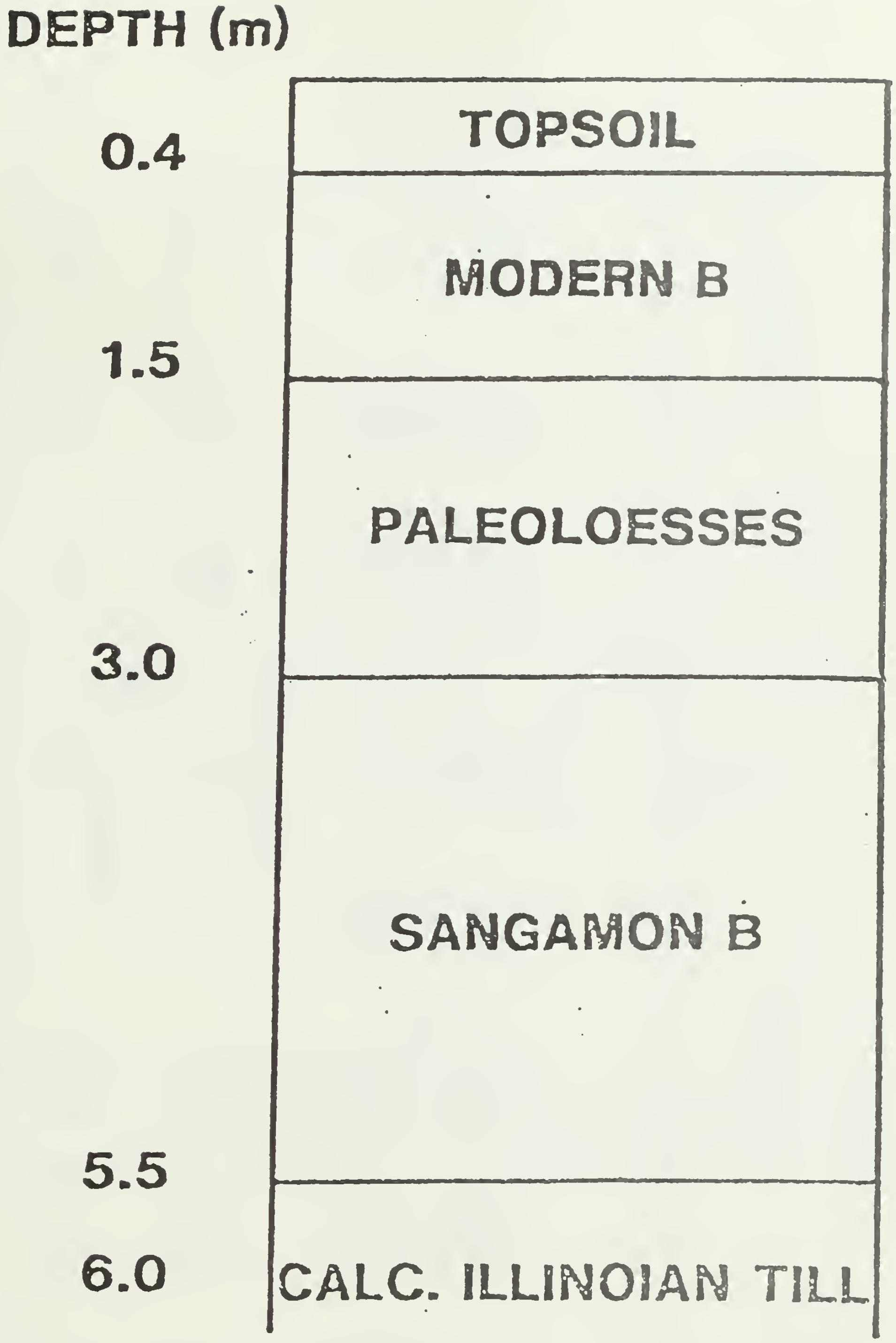

Fig. 3. Idealized profile of high wall showing materials used in construction of mix plot treatments.

TABLE I

Row crop yields at Captain Mine, 1981-84.

Treatment[1]	Corn yield[2] 1981	Corn yield[2] 1982	Corn yield[2] 1983	Corn yield[2] 1984	Corn yield[2] 4-yr. avg.	Soybean yield[2] 1981	Soybean yield[2] 1982	Soybean yield[2] 1983	Soybean yield[2] 1984	Soybean yield[2] 4-yr. avg.
					kg ha^{-1}					
					Mix Plots					
A/1m	7094a	9040ab	4520a	7848a	7126a	2350a	3290a	1142a	2082ab	2216a
A/3m	5211c	9543ab	3265b	7091ab	6278bc	1947bc	2552b	940ab	2082ab	1880b
A/4.5m	6592ab	7596d	4332a	7220a	6435b	1746cd	2686b	806ab	2149a	1847b
A/6m	5776bc	8161cd	33327b	6780ab	6011c	1813bcd	2753b	873ab	2144a	1897b
3m mix	3516de	9103ab	2511b	6152b	5411de	1679d	2619b	739b	1813ab	1713c
6m mix	5085c	8789bc	2951b	6215b	5650d	2082b	2887ab	1007ab	1813b	1947b
					Wedge Plots					
RM/SS	4018d	4897e	0	0	2229f	1209e	1612c	0	0	702d
A/RM/SS	3076e	3830f	0	0	1727g	1007f	1612c	0	0	655d
					Undisturbed Plots					
	7722a	10045a	3641ab	0	5352c	1477de	3223a	1007ab	873c	1645c

1 A = separately replaced topsoil; RM = hauled root media; SS = shovel spoil.

2 Values followed by different letters are significantly different at the 0.05 level of probability.

CORN HYBRID RESPONSES TO RECONSTRUCTED MINE SOILS IN WESTERN ILLINOIS

BY

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B.S., University of Illinois, 1972

THESIS

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Urbana, Illinois

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Illinois has the largest reserves of bituminous coal of any state in the nation. Thirteen percent of these reserves are strippable and much of the coal lies beneath Illinois' most productive farmland (Smith and Stall, 1975). Federal law (Public Law 95-87), 1977, requires that within a reasonable time such surface mined prime farmland be reclaimed and restored to productivity for row crops equivalent to that present before mining. Section 1816.116 (a) (3) (iii) of the Surface Coal Mining Land Conservation and Reclamation Act (Illinois Public Act 81-1Ø15) states that for areas to be used as cropland, success in revegetation of cropland shall be determined on the basis of crop production from the mined area as compared to approved reference area or other technical guidance procedures. Production shall not be considered equal if it is less than 9Ø% of the production of the approved standard with 9Ø per cent statistical confidence. Section 1823.15 (b) (1) of the same act requires that the final graded prime farmland areas within the permit area shall be planted with crops commonly grown, such as corn, soybeans, hay, sorghum, wheat, oats, barley or other crops found on surrounding prime farmland.

Obtaining optimum row crop productivity on reconstructed mine soils requires the understanding of complex integrated soil, water, climatic, and genetic relationships. Crop varieties, plant populations, herbicide and fertilizer rates are management factors which are generally recognized as affecting crop yields. The effects of these management factors are compounded when rowcrops are grown on newly constructed mine soils, which may have wide ranging physical and chemical properties making it difficult to project productivity success. Because these mine soils are fundamentally different from natural soils and have unique problems contributing to stress susceptibility of present commercial hybrids, the potential to minimize effects caused by physical or chemical properties of the mine soils should exist through hybrid selection. Corn yields of current commercial hybrids display considerable year to year variation when grown on mined land. There have been significant yield differences among soil treatments in most years for an individual hybrid but the ranking of treatments has not been consistent from year to year.

The objective of this research was to evaluate response of a wide range of genotypes grown on mined land as compared to on an adjacent undisturbed soil. Yield, pollination dates, and other agronomic variables were measured on mined and unmined land. The use of a diverse range of genetic material should also result in a more precise evaluation of each mined land treatment.

REVIEW OF LITERATURE

Reclamation and reconstruction of soils on surface-mined land often involves extensive traffic by large earth moving equipment, thus creating several compaction zones which result in poor physical soil properties. Considerable attention must be given to the chemical and physical properties of these reconstructed soils if their productive potential is to be reached. Depending upon the properties of their parent materials, mine soils may have objectionably high or low pH, a very low cation exchange capacity (CEC) requiring extensive fertilization and a high fragment content (Pedersen et al., 1978). Low CEC's are generally not a problem in Illinois, however. Bulk densities are usually high and infiltration rates and hydraulic conductivities low (Pedersen et al., 1980). Indorante et al. (1981), in a comparison of mined and unmined land in southern Illinois reported that the reconstructed mine soils studied had higher bulk densities and they lacked any notable soil structure. In western Illinois, Fehrenbacher et al. (1982), has shown that corn root penetration for the hybrid Mo17 x B73 was significantly deeper in the undisturbed Clarksdale silt loam (Udollic Ochraqualf, fine, montmorillonitic, mesic) than any of the four reconstructed mine soils studied. These physical properties which restrict root growth inhibit the plants ability to take up water and nutrients (Russell, 1977). Hence, row crops grown on post-mined soils should be more susceptible to stress during the growing season as compared to row crops on adjacent undisturbed land. That has commonly been observed, but irrigation can be used to reduce or eliminate this stress factor and help promote satisfactory row crop yield response on surface-mined land (Dunker et al. 1982). In that study it was suggested that corn grown on these newly constructed soils appear to be more sensitive to weather variability than corn grown on undisturbed natural soils.

Research by Peabody Coal Co. indicated three year average corn yields of 7,580 kg/ha on 20-year-old spoil recently graded with 38 cm of Muscatine silt loam topsoil replaced; 4,760 kg/ha on graded spoil without topsoil; and 7,900 kg/ha on undisturbed Muscatine silt loam soil (Grandt, 1978). This mine spoil had been in alfalfa and bromegrass before topsoil was added and plots established in 1974. Although these soil treatments do not meet the federal requirements of B horizon replacement nor the coarse fragment criteria of the Illinois legislation 60 to 96% of the undisturbed land productivity was obtained. In a national survey (Nielsen and Miller, 1980) corn yields on reclaimed surface mined land were reported to be highly variable depending on the original soil, fertility, initial planting of legumes and grasses, soil replacement, weather variability, and age of spoil. Corn yields from Illinois, Ohio and Pennsylvania ranged from 4% less to 90% less than adjacent undisturbed soils. Henning and Colvin (1977) reported that corn grown on an Iowa coal project demonstration mine the first year after reclamation yielded 67 to 31% less than corn on similar soils which were undisturbed. Jansen et al. (1985b) studied the response of corn and soybean yields to topsoil replacement at two mine sites in southern Illinois. Yields of 8,000 kg/ha of corn and 2,400 kg/ha of soybeans were achieved on reclaimed lands in the best growing seasons, but yields were very poor in years of moisture and temperature stress. Severe compaction caused by methods of soil reconstruction was identified as the major cause of poor crop performance during years of temperature and moisture stress. Soybeans responded favorably to topsoil at both locations. Corn yields were higher on the topsoil replaced treatment than on spoil only at one location but no yield differences resulted between the two treatments at the other site.

Soil replacement and thickness of soil materials was studied at the Captain mine in southern Illinois and at the Norris mine in western Illinois (Jansen et al., 1985a). The Captain wedge, which was designed to evaluate scraper placed root media thickness (0 to 120 cm) with and without topsoil replaced, resulted in crop failures in 2 of the 5 years studied due to shallow rooting of corn and weather stress. Yields of both corn and soybeans increased with increasing thickness to about the 60-80 cm depth. No response was observed after this depth since corn roots were not exploiting depths deeper than 8Ø cm. The Norris topsoil wedge with topsoil thicknesses ranging from Ø to 6Ø cm resulted in a significant positive yield response for corn but not for soybeans. Year by year results showed positive relationships to topsoil thickness in years of favorable weather, but negative responses resulted in years of moisture and temperature stress.

Thompson (1969) studied corn yields and trends for a period from 193Ø to 1967. After adjusting for changes made in technology and management practices he reported that weather variables accounted for most of the variation over the time trends. Below average temperatures in July and August and above average rainfall in July were found to be associated with the highest yields. Rust and Odell (1957), in a study on the productivity of Illinois soils over a 1Ø year period, found that yield variation was associated more with weather than any of the other factors such as amounts of nitrogen, phosphorous, and potassium added, cropping systems followed, and time. Research by Runge and Odell (1958) indicated that corn yields were influenced greatly by precipitation and temperature values during anthesis and concluded that above normal precipitation is most beneficial approximately one month before and during the pollination period. Moisture stress at any stage of development up to maturity adversely affects corn yields, but stress during silking and pollination results in the greatest reduction (Robins and

Domingo, 1953; Denmead and Shaw, 1960; and Claassen and Shaw, 1970). Previous row crop research on the University of Illinois reclamation plots has shown that silking date in corn commonly varies between mine soils even though management factors (planting date, population, fertility, herbicides) are held constant over soil treatments. Hence the coincidence of high weather stress periods with pollination date by treatment needs to be considered as a confounding factor in interpretating yield results for a soil treatment.

Genotype variation in response to environmental stress factors such as drought and heat stress has been observed in many field crops (Blum, 1974; Boyer, 1970; Dedio, 1975; Samson et al., 1978). Hyne and Brunson (1940) observed that corn hybrids showed less yield reduction under adverse drought and temperature stress than their inbred parents. Because the response of plants to drought and temperature stress involves genotype-environment interactions one needs to obtain, identify, and measure responses of various genotypes to be able to distinguish genotypes that respond well in both favorable and unfavorable environments. Mitui et al. (1981) reported that plant growth and development is influenced by temperature, soil-water availability, plant-water status, and atmospheric water demand. Plant water status depends on soil moisture conditions, atmosphere water demand, and genotypic characteristics.

Attempts to classify the rate of development in corn based on heat accumulation result from the need to determine the adaptability of genotypes to particular locations and to predict the date of flowering and harvest (Tollenar et al., 1979). Heat units are used to assign maturity classes of corn and evaluate energy requirements of various hybrids to initiate tassels, pollen shed, and to reach physiological maturity. The simplest and most broadly researched method is Growing Degree Units (GDU). A base temperature for growth of 10 C is subtracted from the mean air temperature to give daily GDU. Modifications of this simple method frequently impose some upper and lower limits on the daily temperature. For corn, these limits commonly are 30 C for the maximum temperature and 10 C for the minimum temperature. Gilmore and Rogers (1958) studied the development of 10 hybrids and 10 inbred lines of corn using 15 different methods of calculating thermal units. Thermal units calculated using temperature measurements taken at 3 hour intervals did not estimate silking significantly better than those calculated using daily maximum and minimum temperatures. Differences among hybrids in the rate of development based on accumulated thermal units to silking were noted. Other researchers also have observed differences in the rate of development among hybrids (Shaw and Thom, 1951; Stauber et al., 1968). A study by Cavalieri and Smith (1985) report that heat units required for 50% of the plants to silk has not changed consistently in hybrids which have been released over years. Results from this investigation showed that heat units from a wide range of genotypes to silk ranged from 1356 to 1493 in 1982, a year of good weather, and from 1551 to 1705 in 1983, a year of high weather stress. The genotype by year interaction was not significant. There are no reported studies concerning heat requirements to silking for corn grown on reclaimed soils. But if thermal unit accumulation methods correlate to silking of corn when grown on mine soils as it does when grown on natural undisturbed soils it will be of considerable value in making management decisions on maturity groups and decisions which must be tied into stage of crop development. The Growing Degree method is advantageous to using calendar day maturity ratings when genotypes are grown under several varying environmental and soil conditions. In some cases, using the calendar day method the same hybrid may be listed under two different maturity classes when grown in two different regions. Daughtry et al. (1984) reported that thermal models were significantly less biased and more accurate than the calendar days model for predicting dates of silking in both Indiana and Iowa.

MATERIALS AND METHODS

Experimental Plot Construction

The research plots used in this study are located at the Consolidation Coal Company's Norris Mine in Fulton County, west central Illinois (Figure 1). The plots were constructed in the fall of 1978 under favorable conditions and had been under forage management until 1983 when corn was planted in a preliminary study. The predominate premine soils are in the Ipava-Sable soil association which are highly productive dark colored soils developed in 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 the graded resultant material is referred to as wheel spoil. Two main mine-soil treatments were constructed and used for this study.

The two treatments consisted of; 1) 45 cm of topsoil replaced over graded wheel spoil, and 2) wheel spoil only.

Figure 1. Location of Norris Mine.

The wheel spoil consists of a mixture of leached loess, calcareous loess, calcareous glacial till, and some small shale fragments. The topsoil replaced plots meet the requirements of the 1975 amended Illinois law (Illinois Public Act 78-1295) which requires the segregation and replacement of the A horizon and a rooting zone to a depth of 122 cm including the A horizon and must meet certain textural and chemical limits. The Norris Mine was under permit requirements which required that soil reconstruction should use this procedure. This treatment, however, does not meet the federal law (Public Law 95-87) requirement that the B horizon material be replaced unless other strata can be shown to be equally favorable or better than the B horizon of the natural soil. The wheel spoil without topsoil does not meet the requirements of either state or federal law. An undisturbed tract of Sable silty clay loan (fine-silty, mixed, mesic, Typic Haplaquoll) located nearby was used as an unmined treatment. Table 1 shows representative chemical and textural properties of the topsoil, wheel spoil, and Sable soil at the time of construction.

Plot Management

Corn hybrid plots were completely random within each of the three replicated soil treatment blocks and planted with a John Deere Maxi Merge planter. The only modification was the

Table 1. Chemical and textural properties of topsoil, wheel spoil, and Sable soil at Norris Mine.

Material	Depth	pH	Bray P_1	Bray P_2	Exchangeable bases Ca	Mg	Na	K	Organic C	Particle size distribution Coarse >2.0	Sand 2.0-0.05	Silt .05-.002	Clay <.002
	10^{-3} M		- kg ha^{-1} -		cmole(+) kg^{-1} soil				---------- g kg^{-1} ----------				
Topsoil	0-50	5.1	184	72	12.8	4.9	0.2	0.5	14.4	0	20	662	318
W Spoil	51-78	7.0	10	107	10.9	4.7	0.2	0.4	1.5	10	331	391	268
W Spoil	79-120	7.2	10	115	10.1	4.4	0.2	0.4	1.1	18	248	462	272
Sable:*													
Ap	0-31	5.5	41	54	16.9	5.9	0.2	0.3	28.2	<10	12	665	323
A3	31-43	5.5	9	9	17.2	6.1	0.1	0.3	19.3	<10	10	657	333
B21	43-71	5.5	10	15	17.0	7.0	0.2	0.5	7.7	<10	10	630	360
B22	71-86	6.0	36	76	13.9	7.1	0.2	0.4	3.3	<10	90	660	331
B23	86-107	6.7	10	81	14.3	6.8	0.2	0.3	2.6	<10	80	692	300
B3	107-140	7.5	7	172	12.3	7.3	0.2	0.3	1.3	<10	130	756	231
C1	140-274	8.0	4	155	12.8	6.9	0.2	0.2	0.9	<10	120	828	160
C2	274-338	8.0	6	124	12.5	7.1	0.2	0.2	1.3	<10	40	845	151
IIC3	338-404	7.8	15	178	11.1	6.7	0.1	0.1	1.3	<10	57	752	191
IIC4	404-445	7.6	4	11	9.1	5.6	0.1	0.1	0.9	40	176	652	172
IIIAb	445-483	7.5	3	6	10.4	6.1	0.1	0.1	0.8	140	216	550	229
IIIB21t	483-544	7.4	2	3	15.8	6.8	0.2	0.2	0.7	190	284	361	355
IIIB22b	544-594	7.5	2	141	14.6	6.8	0.2	0.2	0.7	280	363	370	267
IIIC	594-633	8.1	1	148	28.1	3.6	0.2	0.2	0.4	380	337	440	223

* Determinations by R. R. Snarski, J. B. Fehrenbacher, and I. J. Jansen (1981).

cone seeder attachments which allowed for small seed lot plantings of a certain desired length. Management practices were the same as would be followed by a typical central Illinois farming operation. Fertilizer rates, herbicide rates, and management practices used in this study are described in Table 2.

Grain yield samples were hand harvested when black layer formation indicated physiological maturity. Grain yield estimates were based upon the amount of shelled grain after adjusting for variation in the moisture content of grain to 15.5%.

Forty genotypes were planted in 1984 and in 1985 with 29 hybrids being used both years (Table 3). The germplasm represents a wide range of characteristics and are a mixture of commercially released hybrids and experimental lines supplied by plant breeders interested in their response when grown on reconstructed mine soils.

Agronomic and Climatic Measurements

Dates on which 50% of the plants in the hybrid had shed pollen and silked were recorded and converted to days from planting for each plot. Daily maximum and minimum temperatures were recorded from the Peoria station of the National Climatic Data Center. Heat unit accumulation (HU) was recorded from the date of planting, 1 June 1984, and 20

Table 2. Management of hybrid plots at Norris Mine.

	1984	1985
Soil Trt Block	16.9 x 61.5 m	16.9 x 61.5 m
Hybrid Plot size	2 rows x 5.4 m	2 rows x 5.4 m
Fertilizer	268 kg N/ha 134 kg P/ha 134 kg K/ha	268 kg N/ha 134 kg P/ha 134 kg K/ha
Planting date	1 June	20 May
Planting rate	64,220 seeds/ha	64,220 seeds/ha
Row spacing	76 cm	76 cm
Herbicide (l/ha)	2.3 l Atrazine 2.6 l Metolachlor	2.3 l Atrazine 2.6 l Metolachlor
Insecticide	Chlorpyrifos	Carbofuran
Tillage	Fall chisel 2 spring discings	Fall chisel 2 spring discing

Table 3. Hybrids selected for 1984 and 1985 Norris Mine studies.

	Trt ID			Trt ID	
Genotype	1984	1985	Genotype	1984	1985
CB59G X LH38	1	12	B73 X H99	26	26
LH74 X LH123	2	16	FRB73 X MS71	27	--
LH119 X LH123	3	14	FR632 X FR619	28	27
LH132 X LH123	4	19	FR27 X FRMo17	29	--
B73 X LH123	5	--	FRB73 X FRMo17	30	38
B73 X LH24	6	18	FRB73 X FRVa26	31	--
LHE136 X LH24	7	25	An 81-10	32	--
LH132 X LH51	8	11	GRE 82-4	33	31
N7A X Mo17	9	--	GRE 82-10	34	30
B73 X LH38	10	15	An 83-7	35	34
B73 X LH50	11	17	An 83-10	36	--
LH117 X MS71	12	23	An 83-17	37	28
LH119 X LH51	13	21	W117 X Co109	38	--
LH74 X LH51	14	20	Mo17 X A634	39	--
CB59G X LH51	15	22	W153R X A632	40	--
Dekalb 505	16	9	B73 X LH51	--	1
Dekalb 587	17	10	LH132 X LH50	--	13
Dekalb 656	18	8	LHE136 X LH123	--	24
Funks G4522	19	--	An 83-18	--	29
Funks G4589	20	2	GRE 82-7	--	32
NK PX9527	21	4	GRE 83-3	--	33
NK PX9581	22	3	An 82-12	--	35
Pioneer 3358	23	7	An 82-2	--	36
Pioneer 3389	24	5	Pioneer 3377	--	37
Pioneer 3541	25	6			

May 1985 using the Growing Degree Days method reported by Tollenar et al. (1979). The formula for computing heat units by this method is as follows:

$$\text{Daily HU} = [(\text{Max} + \text{Min})/2] - 10\ \text{C}.$$

$$\text{If Min} < 10\ \text{C, Min} = 10\ \text{C};$$

$$\text{If Max} > 30\ \text{C, Max} = 30\ \text{C};$$

where Daily HU is daily heat unit accumulation and Max and Min are the maximum and minimum temperature for the 24 hour interval.

Rainfall at the research plots was recorded daily to the nearest 0.25 mm. Using the minimum and maximum temperature data and rainfall data estimated weekly crop water use was calculated based on daily temperatures, hours of sunlight, and crop growth using the Blaney-Criddle method (1950, 1962).

Tensiometers were installed in each of the replications of each soil treatment to record soil moisture tension levels at the 30, 60, 90, and 120 cm depths, and were read on Mondays and Thursdays of each week. Mercury manometer type tensiometers were used which have a special scale graduated directly in millibars of soil suction with a range of 0 - 850 millibars. Soil suction can be read to an accuracy of 0.10 millibar with these instruments. At each station distances were measured from the soil surface to the 0 mark on the manometer scale and from the top of the mercury in the bottle to the Ø scale and used for conversion of millibars of suction into soil water pressure using the formula:

$$\text{Pressure cm } H_2O = (12.55 \times 0.081)(\text{manometer reading}) + Z\,Hg + Z\,cup$$

where 12.55 = density of Hg - density of water

Ø.Ø81 = conversion of scale markings to centimeters

Z Hg = distance from soil surface to Ø on scale.

Z cup = distance from center of porous cup to Ø on scale.

Additional agronomic variables were measured only in 1985. Plant height was measured 2Ø days after the 5Ø% pollen shed date to compare vegetative growth differences between the two mine soils and the undisturbed Sable. During the harvest sampling plants per plot, ear number and ear weight was recorded. An estimation was then made on % barren stalks, ear size, and shelling percentage on a dry weight basis for the hybrids on each soil treatment.

Soil cores to a 2Ø centimeter depth were taken in the three soil blocks within each hybrid replicate randomly placed. Sampling was done in this manner to allow for correlations with other agronomic data.

Statistical Analysis

The experimental plots used for the study were located in three separate soil blocks due to the impossibility of randomly placing undisturbed plots in the reclaimed areas. Soils form the main treatment factor while hybrids are a split effect with the hybrid plots completely randomized in three replications within each soil treatment. The following stepwise procedure was followed for the analysis of yield and pollination data from this study:

1). Homogeneity of variances were tested for the soil treatment areas.

2). If variances were homogeneous, an analysis of variance was used to test for significant differences between soil treatment and hybrid effects.

3). If variances were heterogeneous, a Students t test was to be used to determine differences.

Variances were found to be homogeneous for the soil treatments in both 1984 and 1985. The variance for the 1984 experiment was found to be homogeneous with the 1985 experiment allowing a combined years analysis to be used in interpreting responses.

RESULTS AND DISCUSSION

Soil Tests

Results from the soil tests conducted in November of 1984 are presented in Table 4. The mean and median values are from 12 samples taken from each soil treatment. A single sample is composed of a composite of 5 cores taken to a depth of 20 centimeters.

Table 4. Soil test results for surface samples (20 cm depth) from Norris hybrid plots.

Soil Trt		pH	P1	P2	Olsen	K
			-------- kg/ha			------------
Wheel Spoil:						
	mean	7.6	30	160	41	205
	median	7.6	24	175	40	210
Topsoil:						
	mean	5.0	46	67	46	378
	median	5.0	48	68	49	408
Sable Soil:						
	mean	5.6	128	201	98	403
	median	5.5	129	204	97	403

<u>Wheel spoil:</u> Wheel spoil pHw values ranged from 7.6 to 7.7 with a median value of 7.6. This value is normal when considering the nature of the materials of which it is composed. The bucket wheel excavator mixes the unconsolidated materials above the coal seam which is composed primarily of calcareous loess and glacial till. The presence of free carbonates in the wheel spoil is undoubtedly a disadvantage for obtaining maximum yields and indications are it will take considerable time before pH values decrease.

Two phosphorous tests (Bray P1 and Olsen) were used to measure readily available phosphorous. The Bray P1 test correlates well with crop yield response to phosphorous levels on most acid and neutral soils in Illinois, but does not work well for calcareous materials (Knudsen, 1980). The high pH of the wheel spoil may be causing the phosphorous to be tied up in insoluble forms such as calcium phosphates. The Olsen bicarbonate test for P is generally preferred for these calcareous materials because it prevents precipitation of P during extraction. The Bray P2 procedure was used to indicate if considerable amounts of reserve P (phosphorous in less soluble forms) were present. Test results show high P2 values indicating a high level of low soluble P in the wheel spoil material. Most of that reserve will be released in the future by natural weathering, especially as the wheel spoil is leached of carbonates. This leaching process and release of P could be accelerated if the wheel spoil comes in contact with more acid materials or mixed with acidic materials. Guidelines put forth by the University of North Dakota advise that at an Olsen test of 34 kg/ha the phosphorous is dissolving at a rate fast enough to supply crop requirements. A maintenance application of $P_2Ø_5$ is therefore recommended.

Potassium tests recommend that buildup plus maintenance rates (134 kg/ha) are required over the next four years to obtain optimum values. It is assumed that there may be a substantial amount of presently unavailable potassium in the wheel spoil in the form of feldspathic minerals which will gradually become available through weathering.

Topsoil/wheel spoil and Sable soil: Discussion of these soils are combined as their surface layer characteristics are similar. The pHw values of both soils are low and show the need for applications of lime. Thirteen Mg/ha of lime with a CCE (calcium carbonate equivalent) of 90% should be applied over a 2 to 3 year period on the topsoil/wheel spoil and nine Mg/ha applied on the Sable soil. Phosphorous amounts are at a very desirable level for the topsoil/wheel spoil while values are excessively high for the Sable soil, assumed to be due to intensive fertilization. Maintenance applications are recommended for the topsoil/wheel spoil and no $P_2Ø_5$ additions for the Sable soil is required. Potassium levels for both the topsoil replaced treatment and the undisturbed Sable are adequate and only maintenance applications required.

Fertility levels for the topsoil and Sable appear comparable in pH, available phosphorous and potassium.

Consequently, any yield differences between these two soil treatments are undoubtedly due to physical properties and water availability.

Special tests: Because of the relatively high pH values of the wheel spoil treatment the available amounts of zinc, manganese, and iron were evaluated. In general, as pH increased, availability of these nutrients decreases.

Zinc: The concentration of water soluble zinc in soil solution decreases with increasing pH. Zinc deficiency, usually occurs on naturally high pH or calcareous soils. The level of zinc occurring in soils is related to the original parent materials and the degree that weathering has taken place. Soils originating from basic igneous rocks are high in zinc, while soils developed in more silicious materials are generally low. Because the wheel spoil is such a heterogeneous mixture of materials, it is hard to predict the amounts of zinc which should be present. The soil test results show a very wide range of values from Ø.98 kg/ha to 26.9 kg/ha with the median value of 2.1Ø. Using the guidelines found in "Secondary and Micronutrient Soil Test Interpretation" (Peck, 198Ø) the 2.1Ø kg/ha falls into the medium availability range while values below 1.1 kg/ha are considered deficient. Values above 2.2 kg/ha would not likely respond to zinc application. Several samples fell into the medium and deficient range suggesting that corn might respond to a zinc application (5 kg/ha) on the wheel spoil treatment.

Iron: Fe nutrition of plants is most frequently disturbed in plants growing on high pH and calcareous soils. Iron uptake is particularly depressed by high pH, high phosphate and calcium concentration. Soils with high concentrations of Ca^{++} compete with Fe^{++} for the same binding sites of chelating compounds and the availability of iron is reduced. Test results show high values of Fe (27.8 to 144.4 kg/ha) and Fe deficiency should not be a problem. Since test results for iron are high it is likely that lime induced chlorosis on the field plots would not occur.

Manganese: Mn availability is similar to availability of Fe and Zn. Mn availability is higher in acid soils due to the higher solubility of Mn compounds under low pH conditions. Mn values from the phosphoric acid test were all above the 22 kg/ha level and considered low enough to warrant supplemental fertilization. However, under high pH soil conditions Mn availability can be inadequate to meet plant demands. Manganese deficiency symptoms such as intervienal chlorosis of the corn leaves would indicate that manganese additions are necessary. Results from the soil tests for Zn, Mn, and Fe are given in Table 5.

Table 5. Soil test results for zinc, manganese and iron on wheel spoil treatment.

	$H_3PØ_4$ extract	DPTA extract		
	Mn	Mn	Zn	Fe
	Kg/ha	------- Kg/ha	---------	
Mean	34.2	17.7	6.62	5Ø.1
Median	34.5	17.5	2.11	35.Ø

Determination of CEC: An estimation of cation exchange capacity using the summation method with values from the Ca, Mg, K, and SMP buffer lime requirement tests is presented in Table 6. Sodium values were not determined and considering the inherent properties of the parent soils, it is assumed that Na on the exchange sites would be insignificant of the total values. Results from the determinations made by Snarski et al. (1981) show that sodium values for the Sable soil and underlying glacial till to be less than Ø.2 cmole(+) kg^{-1} soil.

Table 6. Cation exchange capacity calculation for mined and unmined soils at Norris Mine.

	Element	Soil test,Kg/ha	meq/100 gms
Wheel Spoil:	Ca	4300	9.6
	Mg	1559	5.8
	K	210	0.2
	H	-	0.0
			CEC = 15.6
Topsoil:	Ca	4063	9.1
	Mg	1193	4.4
	K	408	0.5
	H (SMP LR)	7840	7.0
			CEC = 25.4
Sable soil:	Ca	6094	13.6
	Mg	1456	5.4
	K	403	0.5
	H (SMP LR)	6496	5.8
			CEC = 25.3

Correlation of soil test values to 1984 yields shows that fertility levels of P and K have a significant linear relationship to yield values (Table 7). The correlation coefficients estimate the degree of closeness of the linear relationship between yield and the fertility parameter and can not be used as a predictor to estimate changes in yield due to increases or decreases in the soil test level. When Rho (R) is 0.50 or less, only a minor portion of the variation in yield can be attributed to its linear regression on fertility level. At R = 0.70 about one half the variance of yield is associated with a fertility parameter. Statistical significance of a correlation coefficient merely shows that there is a linear relation and is a function of sample size. In a sample size of 200, a R value of 0.20 would be significant at the 1% level but 96% of the variation of yield is not explainable through its relation to fertility levels. The correlation matrix of Table 7 shows a high association to yield variation for all phosphorous tests with all correlation coefficients (R) greater than 0.50. The P1 and Olsen tests are highly intercorrelated as would be expected since both tests measure readily available phosphorous. These correlations were made using the median values of each soil treatment area and correlating with individual yield results of all hybrids within that soil.

Table 7. Correlation matrix of soil test values to 1984 corn yields at Norris Mine.

Correlation Coefficients/Prob>R under Ho: Rho=Ø/ N=36Ø

	Yield	pH	P1	P2	K	Olsen
Yield						
pH	-Ø.1765					
	Ø.ØØØ8					
P1	Ø.6837	-Ø.3133				
	Ø.ØØØ1	Ø.ØØØ1				
P2	Ø.5Ø87	Ø.4918	Ø.6423			
	Ø.ØØØ1	Ø.ØØØ1	Ø.ØØØ1			
K	Ø.4254	-Ø.88Ø1	Ø.6758	-Ø.1Ø8Ø		
	Ø.ØØØ1	Ø.ØØØ1	Ø.ØØØ1	Ø.Ø4Ø6		
Olsen	Ø.7Ø33	-Ø.2471	Ø.9885	Ø.7Ø4Ø	Ø.6117	
	Ø.ØØØ1	Ø.ØØØ1	Ø.ØØØ1	Ø.ØØØ1	Ø.ØØØ1	

Hybrid Responses

Yield results of each individual hybrids for each soil is presented in Table 8. Individual years will be discussed followed by results of a combined years analysis.

1984: Grain yields of the 40 corn genotypes were highly variable within soil treatments and among hybrids. The undisturbed Sable soil produced significantly higher corn yields than the topsoil replaced treatment in 39 hybrids and higher than the wheel spoil only plots in 38 hybrids. No significant yield differences occurred between the two mine soil treatments for any of the 40 hybrids although there was a wide range in values. The least significant difference (LSD, $P<0.05$) for the comparison of two soil treatments within the same hybrid was 2,586 kg/ha reflecting the high degree of variability associated with this experiment. The hybrid Mo17 X A634 had the highest yield on the topsoil treatment and was the only genotype to produce comparable yields to the undisturbed Sable. It did rank poorly on the Sable soil compared to the other hybrids and yield on the wheel spoil plots was low (Table 9). Yield response of all the hybrids to the mined land soils was low and is assumed to be primarily the result of moisture stress. Mean yields of all hybrids over the individual soil treatments for 1984 were 9,511 kg/ha for the Sable soil, 5,060 kg/ha for the topsoil/

Table 8. Yield results of hybrids on mined and unmined land.

Genotype	Soil Trt	1984 Yield, kg/ha	1985 Yield, kg/ha	Mean
GB59G X LH38	PL	9210 a	8984 a	9097 a
	TS	4740 b	6548 a	5644 b
	SP	4319 b	6448 a	5384 b
LH74 X LH123	PL	10396 a	14176 a	12286 a
	TS	6033 b	9448 b	7740 b
	SP	5826 b	6303 c	6065 c
LH119 X LH123	PL	9091 a	12336 a	10714 a
	TS	5744 b	7220 b	6482 b
	SP	4646 b	8274 b	6460 b
LH132 X LH123	PL	10371 a	11809 a	11090 a
	TS	5192 b	7358 b	6275 b
	SP	5242 b	8004 b	6623 b
B73 X LH123	PL	12525 a		
	TS	4935 b		
	SP	4005 b		
B73 X LH24	PL	11570 a	10710 a	11140 a
	TS	4765 b	9517 a	7141 b
	SP	5663 b	9474 a	7569 b
LHE136 X LH24	PL	10152 a	9856 a	10004 a
	TS	5882 b	7891 a	6887 b
	SP	7490 b	7521 a	7506 b
LH132 X LH51	PL	9674 a	9247 a	9461 a
	TS	6630 b	7873 a	7252 b
	SP	4558 b	7433 a	5996 b
N7A X MO17	PL	9084 a		
	TS	4219 b		
	SP	5217 b		
B73 X LH38	PL	8557 a	10767 a	9662 a
	TS	3993 b	7841 b	5917 b
	SP	5669 b	7772 b	6721 b
B73 X LH50	PL	9078 a	11413 a	10246 a
	TS	4709 b	6604 b	5657 c
	SP	6987 b	8048 b	7518 b
LH117 X MS71	PL	8708 a	10842 a	9775 a
	TS	5299 b	9047 ab	7173 b
	SP	4796 b	7822 b	6309 b

Genotype	Soil Trt	1984 Yield, kg/ha	1985 Yield, kg/ha	Mean
LH119 X LH51	PL	10447 a	10346 a	10397 a
	TS	5393 b	8369 a	7381 b
	SP	5324 b	7703 a	6513 b
LH74 X LH51	PL	10283 a	9831 a	10057 a
	TS	5085 b	7157 b	6121 b
	SP	6240 b	8218 a	7230 b
CB59L X LH51	PL	8482 a	11156 a	9819 a
	TS	4834 b	6717 b	5776 b
	SP	5192 b	6604 b	5898 b
Dekalb 505	PL	10045 a	10283 a	10164 a
	TS	6071 b	8745 a	7408 b
	SP	4288 b	8199 a	6244 b
Dekalb 587	PL	9436 a	8582 a	9009 a
	TS	5204 b	6190 a	5697 c
	SP	7050 b	7816 a	7433 b
Dekalb 656	PL	9938 a	11068 a	10503 a
	TS	5983 b	7866 b	6925 b
	SP	6391 b	7578 b	6985 b
Funks G4522	PL	10352 a		
	TS	3911 b		
	SP	5675 b		
Funks G4589	PL	10899 a	8777 a	9838 a
	TS	6058 b	6052 b	6055 b
	SP	4740 b	4231 b	4486 c
Northrup King PX9527	PL	8858 a	9988 a	9423 a
	TS	5192 b	8682 a	6937 b
	SP	5085 b	7621 a	6353 b
Northrup King PX9581	PL	11369 a	10202 a	10786 a
	TS	5236 b	5481 b	5359 b
	SP	3817 b	5066 b	4442 b
Pioneer 3358	PL	8406 a	9084 a	8745 a
	TS	4972 b	6862 ab	5917 b
	SP	4759 b	5117 b	4938 b
Pioneer 3389	PL	10384 a	7873 a	9129 a
	TS	6190 b	7402 a	6796 b
	SP	6184 b	6065 a	6125 b
Pioneer 3541	PL	7220 a	10177 a	8699 a
	TS	2273 b	6121 b	4197 c
	SP	3622 b	8400 ab	6011 b

Genotype	Soil Trt	1984 Yield, kg/ha	1985 Yield, kg/ha	Mean
B73 X H99	PL	7320 a	8281 a	7801 a
	TS	4100 b	5468 b	4784 b
	SP	4256 b	4765 b	4511 b
FRB73 X MS71	PL	9618 a		
	TS	4420 b		
	SP	5204 b		
FR632 X FR619	PL	7935 a	6209 a	7072 a
	TS	3911 b	5763 a	4837 b
	SP	5054 b	4413 a	4734 b
FR27 X FRMO17	PL	9335 a		
	TS	4740 b		
	SP	4514 b		
FRB73 X FRMO17	PL	9875 a	10760 a	10318 a
	TS	4740 b	8871 a	6806 b
	SP	4514 b	9279 a	6897 b
FRB73 X FRVa26	PL	9216 a		
	TS	5035 b		
	SP	4194 b		
An 81-10	PL	10026 a		
	TS	4457 b		
	SP	5179 b		
GRE 82-4	PL	8507 a	8456 a	8482 a
	TS	5882 b	7182 ab	6532 b
	SP	4219 b	5569 b	4894 c
GRE 82-10	PL	11074 a	10164 a	10619 a
	TS	4169 b	7465 b	5817 c
	SP	6071 b	8902 ab	7487 b
An 83-7	PL	9825 a	8419 a	9122 a
	TS	4181 b	5537 b	4859 b
	SP	3177 b	4834 b	4006 b
An 83-10	PL	10447 a		
	TS	6579 b		
	SP	5889 b		
An 83-17	PL	9825 a	12217 a	11021 a
	TS	5631 b	7942 b	6787 b
	SP	4363 b	7458 b	5911 b
W117 X Col09	PL	7239 a		
	TS	5060 a		
	SP	5248 a		

Genotype	Soil Trt	1984 Yield, kg/ha	1985 Yield, kg/ha	Mean
MO17 X A634	PL	7709 a		
	TS	6969 ab		
	SP	4740 b		
W153R X A634	PL	7923 a		
	TS	3660 b		
	SP	4175 b		
B73 X LH51	PL		11665 a	
	TS		9191 ab	
	SP		7527 b	
LH132 X LH50	PL		10158 a	
	TS		6460 b	
	SP		7345 ab	
LHE136 X LH123	PL		11407 a	
	TS		8751 ab	
	SP		6969 b	
An 83-18	PL		9856 a	
	TS		6950 b	
	SP		5983 b	
GRE 82-7	PL		7785 a	
	TS		6498 a	
	SP		8091 a	
GRE 83-3	PL		8971 a	
	TS		7038 a	
	SP		7395 a	
An 82-12	PL		10754 a	
	TS		8927 a	
	SP		4916 b	
An 82-2	PL		8331 a	
	TS		6159 ab	
	SP		4903 b	
Pioneer 3377	PL		10208 a	
	TS		10660 a	
	SP		6510 b	
	LSD(.05)	2668	2589	1349
Mean	PL	9511 a	10082 a	9797 a
	TS	5060 b	7477 ab	6269 b
	SP	5123 b	7100 b	6112 b
	LSD (.05)	1389	1197	816

Table 9. Ranking of hybrids by yield for 1984.

Genotype	Sable		Topsoil		Wheel Spoil	
	kg/ha	rank	kg/ha	rank	kg/ha	rank
NK PX9581	11369	1	5236	15	3817	38
GRE 82-10	11074	2	4169	34	6071	7
Funks G4589	10899	3	6058	6	4740	25
LH119 x LH51	10447	4	5393	13	5324	14
An 83-10	10447	5	6579	3	5889	8
LH74 x LH123	10396	6	6033	7	5826	9
Pioneer 3389	10384	7	6190	4	6184	6
LH132 x LH123	10371	8	5192	18	5242	16
Funks G4522	10352	9	3911	37	5675	11
LH74 x LH51	10283	10	5085	19	6240	5
LHE136 x LH24	10152	11	5882	10	7490	1
Dekalb 505	10045	12	6071	5	4288	32
An 81-10	10025	13	4457	30	5179	20
B73 x Mo17	9875	14	4740	27	4514	29
Dekalb 656	9838	15	5983	8	6391	4
An 83-7	9825	16	4181	33	3177	40
An 83-17	9825	17	5631	12	4363	30
LH132 x LH51	9674	18	6630	2	4558	28
FRB73 x MS71	9618	19	4420	31	5204	18
Dekalb 587	9436	20	5204	16	7050	2
FR27 x FRMo17	9335	21	4740	23	4514	10
FRB73 x FRVa26	9216	22	5035	21	4194	35
CB59G x LH38	9210	23	4740	28	4319	31
LH119 x LH123	9091	24	5744	11	4646	27
N7A x Mo17	9084	25	4219	32	5217	17
B73 x LH50	9078	26	4709	29	6987	3
NK PX9527	8858	27	5192	17	5085	21
LH117 x MS71	8708	28	5299	14	4796	23
B73 x LH38	8557	29	3993	36	5669	12
GRE 82-4	8507	30	5882	9	4219	34
CG59L x LH51	8482	31	4832	25	5192	19
Pioneer 3358	8406	32	4972	22	4759	24
B73 x LH123	8256	33	4935	24	4005	37
FR632 x FR619	7935	34	3911	38	5054	22
W153R x A634	7923	35	3660	39	4175	36
Mo17 x A634	7709	36	6969	1	4740	26
B73 x LH24	7338	37	4765	26	5663	13
B73 x H99	7320	38	4100	35	4256	33
W117 x Co109	7239	39	5060	20	5248	15
Pioneer 3541	7220	40	2273	40	3622	39

wheel spoil, and 5,123 kg/ha for the wheel spoil only treatment. Results from an irrigation experiment done on an area adjacent to this study produced irrigated corn yields of 11,550 kg/ha on a topsoil/wheel spoil treatment.

Weather in 1984 was characterized by having near normal to below normal temperatures and below normal rainfall from June through November (Table 10). Visible stress was observed in all soil treatments at the time of pollination, but the most severe wilting symptoms were observed on the topsoil/wheel spoil treatment. Analysis of tensiometer data resulted in significantly higher soil moisture tension levels at the 90 cm depth in the topsoil treatment during the pollination period as compared to the wheel spoil plots. These differences could be due to either increased demand for water by vegetative growth differences, low hydraulic conductivity in this zone to the below normal rainfall during this period, but is probably a combination of both. Lah (1980) measured saturated hydraulic conductivity (K) on soil cores from adjacent plots to be 28.3 cm/day for the topsoil material and 12.84 cm/day for the wheel spoil. Very low K values of 7.59 cm/day were measured from the topsoil interface with the wheel spoil in that treatment. These low conductivity levels are the result of compaction caused from grading and the use of scrapers in replacing topsoil. Indorante (1980) in a study of various mine soils observed higher bulk densities for this zone compared to those of nearby spoil without topsoil. Factors affecting soil water

Table 10. Precipitation and temperatures for 1984 and 1985 growing seasons at Norris Mine.

Month	Pptn	Departure of normal	Avg max temp	Avg min temp	Mean temp	Mean departure
	----- cm ------		------------- C ----------------			
			1984			
May	12.3	+2.5	20.9	8.8	14.9	-1.5
June	7.3	-2.4	29.1	17.9	23.5	+1.7
July	8.3	-1.5	28.6	16.9	22.9	-1.0
Aug.	2.0	-6.6	30.2	17.4	23.8	+1.0
Sept.	7.7	-1.3	25.3	11.4	18.8	-0.2
			1985			
May	7.9	-1.8	24.6	11.2	17.9	+1.5
June	3.9	-6.0	25.9	14.8	20.4	-1.3
July	6.3	-3.8	29.0	17.3	23.1	-0.8
Aug.	14.6	+4.4	26.5	15.9	21.2	-1.6
Sept.	8.7	-0.5	24.8	13.4	19.2	+0.9

storage include soil texture , organic matter content, depth to impervious or slowly permeable layers, density and structure (Unger et al., 1981). The rooting material of these mine soils have some degree of limitation for most of these factors. Figure 2 shows graphically the 1984 soil moisture tension levels (negative water pressure) during the June through August period. The topsoil/wheel spoil treatment broke tension (<-90 KPa water pressure) on 30 July at the 30 cm depth and 3 July at the 60 cm depth. The Sable soil and the wheel spoil did not break tension on the instruments at the 60 cm depth until 7 July.

Estimated water use for 1984 plotted with weekly precipitation (Figure 3) explains the rapid depletion of plant available soil moisture as presented in tensiometer graphs. Precipitation was in excess of estimated weekly water use only in the early part of the season when demands were relatively low. As soil moisture was depleted in the upper soil profile plants were forced to exploit water from deeper zones. The ability of a genotype to produce prolific root systems at these depths will determine how productive it will be under stress. Adequate uptake of water and nutrients is vital and is determined by the ability of root systems to recover water and nutrients from the soil profile. No measurements of root development were obtained during this study no inferences can be made to the abilities of a particular hybrid's ability to promote root growth and penetration in these materials. Researchers have previously

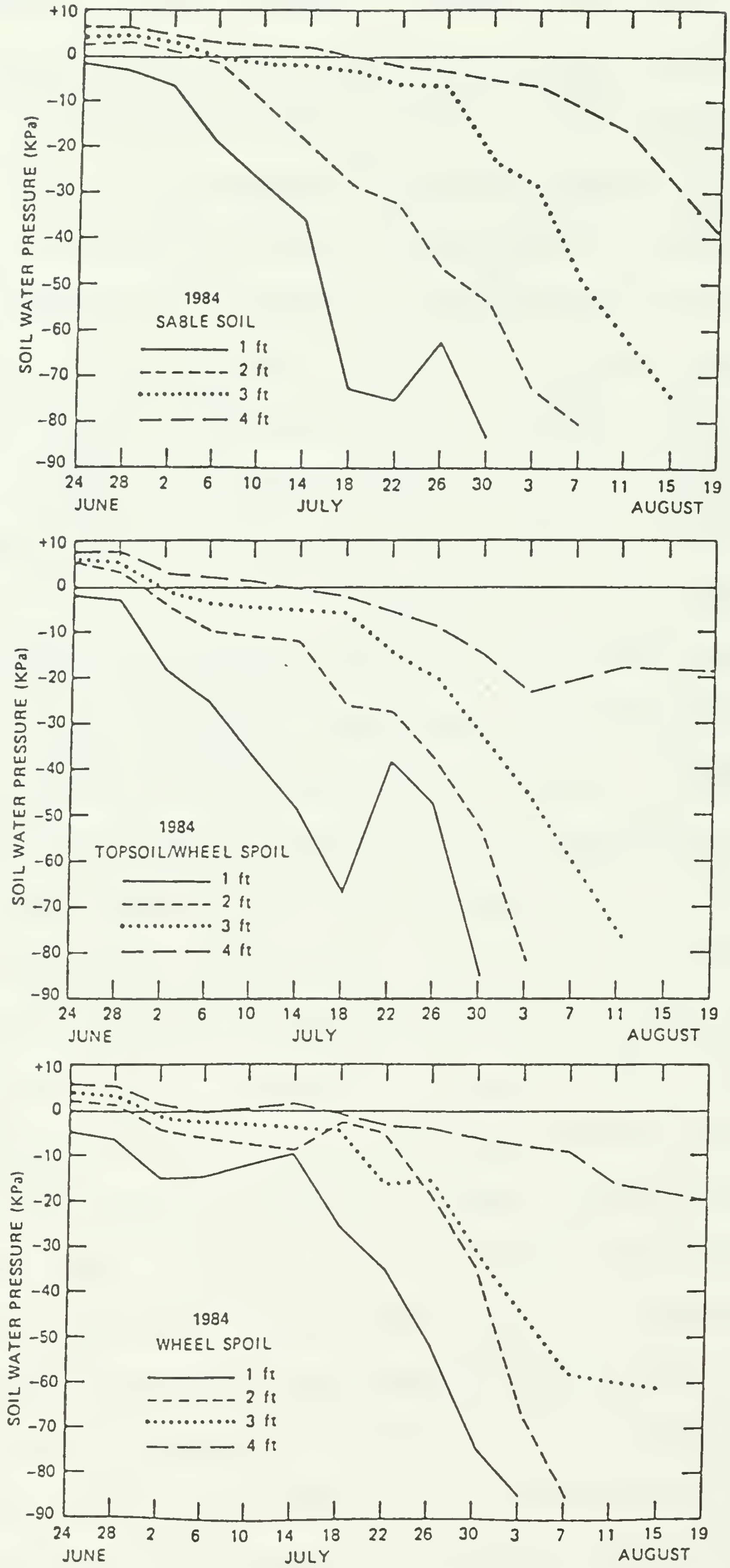

Figure 2. Soil moisture tension levels for the 1984 growing season.

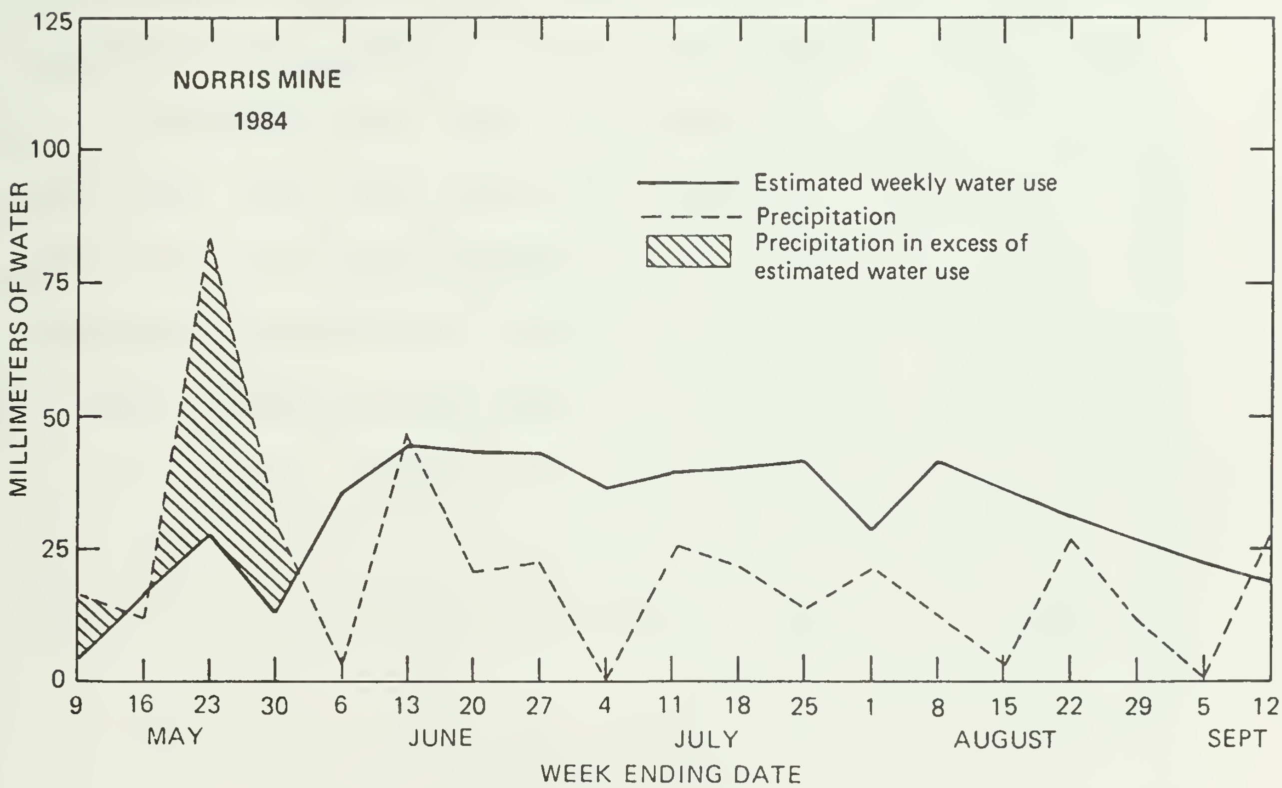

Figure 3. Precipitation and estimated weekly water use for the 1984 growing season.

documented rooting differences for selected corn hybrids between mine soil treatments. Fehrenbacher et al. (1982) reported that corn root penetration for the hybrid Mo17 X B73 was significantly deeper in the undisturbed Clarksdale soil than in any of four reconstructed mine soils studied. Replacement of the A horizon in this study resulted in significantly higher root densities in the upper profile but had little effect on the total root penetration depth. Meyer (1983) found no significant root penetration differences between a topsoil replaced mine soil and a wheel spoil mine soil in southern Illinois. He concluded that the confinement of the root systems due to adverse physical and structural properties of the subsoils resulted in a great weather sensitivity of corn grown in the reconstructed soils. Meyer found significant differences in several chemical parameters (P1, P2, K, pH) at the 0-15 cm and 45-60 cm depths between the topsoil and wheel spoil, but concluded that the chemical environment had considerably less effect than the soil physical condition on corn yield performance over a four year period.

1985: In contrast to 1984 when the undisturbed Sable outyielded both mine soils in 38 of 40 hybrids, 1985 mined land yields were comparable to the Sable soil for 26 of 38 genotypes. Grain yields of the topsoil/wheel spoil and the wheel spoil only treatments were similar in all but one hybrid. Mean yields of the soil treatments over all hybrids were 10,082 kg/ha for the Sable soil, 7,477 kg/ha for the topsoil/wheel spoil, and 7,100 kg/ha for wheel spoil only (Table 8). Twelve hybrids produced yields which were not affected by soil treatments. Variability within this study was again high in 1985. The least significant difference (LSD, P>0.05) of 2,668 kg/ha for the comparison of two soil treatments within a hybrid would be a large value for a hybrid study conducted on uniform undisturbed soil. It is suggested that added replications are necessary in experimental designs for hybrid evaluations on mined soils in order to detect smaller differences between treatments.

The ranking of hybrids by yield for 1985 (Table 11) shows that hybrids which were the highest yielders on the Sable soil were not necessarily the higher yielders on the mined land treatments. The LH74 x LH123 hybrid which was the highest yielding genotype on the Sable soil ranked number 3 on the topsoil treatment but was number 27 on the wheel spoil plots. The hybrids which produced the top ten yields on the Sable had 5 of the top ten yields on topsoil and only 1 of the top ten wheel spoil yields. Those hybrids which ranked in the middle of the Sable group were in general the better yielders on the mined land treatments.

Measurement of agronomic variables in 1985 such as plant height, barren stalks, ear size and shelling percentage showed significant differences among soil treatments for all these parameters (Table 12). The Sable soil produced corn plants of greater height, fewer barren stalks, larger ears, and a higher percentage of grain per total ear weight than

Table 11. Ranking of hybrids by yield for 1985.

Genotype	Sable		Topsoil		Wheel Spoil	
	kg/ha	rank	kg/ha	rank	kg/ha	rank
LH74 x LH123	14176	1	9448	3	6303	27
LH119 x LH123	12336	2	7220	20	8274	7
An 83-17	12217	3	7942	10	7458	19
LH132 x LH123	11809	4	7358	19	8004	12
B73 x LH51	11665	5	9191	4	7527	18
B73 x LH50	11413	6	6604	27	8048	11
LHE136 x LH123	11407	7	8751	8	6969	23
CB59L x LH51	11156	8	6717	26	6604	24
Dekalb 656	11068	9	7866	15	7578	14
LH117 x MS71	10842	10	9047	5	7822	15
B73 x LH38	10767	11	7841	12	7772	17
B73 x Mo17	10760	12	8871	7	9279	2
An 82-12	10754	13	8927	6	4916	33
B73 x LH24	10710	14	9517	2	9474	1
LH119 x LH51	10346	15	8369	13	7703	6
Dekalb 505	10283	16	8745	9	8199	9
Pioneer 3377	10208	17	10660	1	6510	26
NK PX9581	10202	18	5481	38	5066	31
Pioneer 3541	10177	19	6121	33	8400	5
GRE 82-10	10164	20	7465	17	8902	3
LH132 x LH50	10158	21	6460	29	7345	22
NK PX9527	9988	22	8682	14	7621	4
An 83-18	9856	23	6950	24	5983	29
LHE136 x LH24	9856	24	7891	16	7521	13
LH74 x LH51	9831	25	7157	22	8218	8
LH132 x LH51	9247	26	7873	11	7433	20
Pioneer 3358	9084	27	6862	25	5117	32
CB59G x LH38	8984	28	6548	30	6448	25
GRE 83-3	8971	29	7038	23	7395	21
Funks G4589	8777	30	6052	34	4231	38
Dekalb 587	8582	31	6190	31	7816	16
GRE 82-4	8456	32	7182	21	5569	30
An 83-7	8419	33	5537	36	4834	35
An 82-2	8331	34	6159	32	4903	34
B73 x H99	8281	35	5468	37	4765	36
Pioneer 3389	7873	36	7402	18	6065	28
GRE 82-7	7785	37	6498	28	8091	10
FR632 x FR619	6209	38	5763	35	4413	37

Table 12. Means of measured plant characteristics of 1985 corn hybrids.

Soil Trt	Plant Ht. cm	% Barren Stalks	Avg Ear Size gms	Shelling %	Harvest Pop
Sable soil	244.4	7.7	226	80.7	23.7
Topsoil	217.6	18.6	196	78.7	24.6
Wheel Spoil	211.1	13.3	193	77.2	21.4
LSD (0.05)	6.2	5.2	16	1.2	0.9

either the topsoil or wheel spoil treatment. Plant height and average ear size for the 38 corn hybrids was not affected by the mine soils, but the hybrids on the topsoil treatment had a higher percentage of barren plants and a higher shelling percentage. These variables are all significantly correlated to grain yield with correlation coefficients of Ø.56, Ø.52, Ø.53 and Ø.64 for plant height, % barren stalks, shelling percentage and ear size, respectively. Results indicated significant differences occurred among genotypes within a soil treatment, but the hybrid x soil treatment interaction was non-significant for all measured variables. Plant population at harvest, which reflects plant survivability, was not different for the topsoil and Sable soil but both had significantly higher plant survival rates than the wheel spoil soil treatment.

Weather in 1985 was more favorable for plant growth than it was in 1984 (Table 1Ø). Temperatures were warmer than normal in May promoting rapid early season growth and cooler than normal temperatures in the critical months of June, July and August. Temperatures in July and August are associated with the highest yields if they are coupled with adequate or above normal rainfall during July (Thompson, 1969). The estimated water use curve and precipitation for 1985 (Figure 4) shows that demand for water during July was exceeding the amount received in the form of rainfall. Moderate rainfall amounts occurred during the pollination periods of 25 July to 4 August and visible stress was

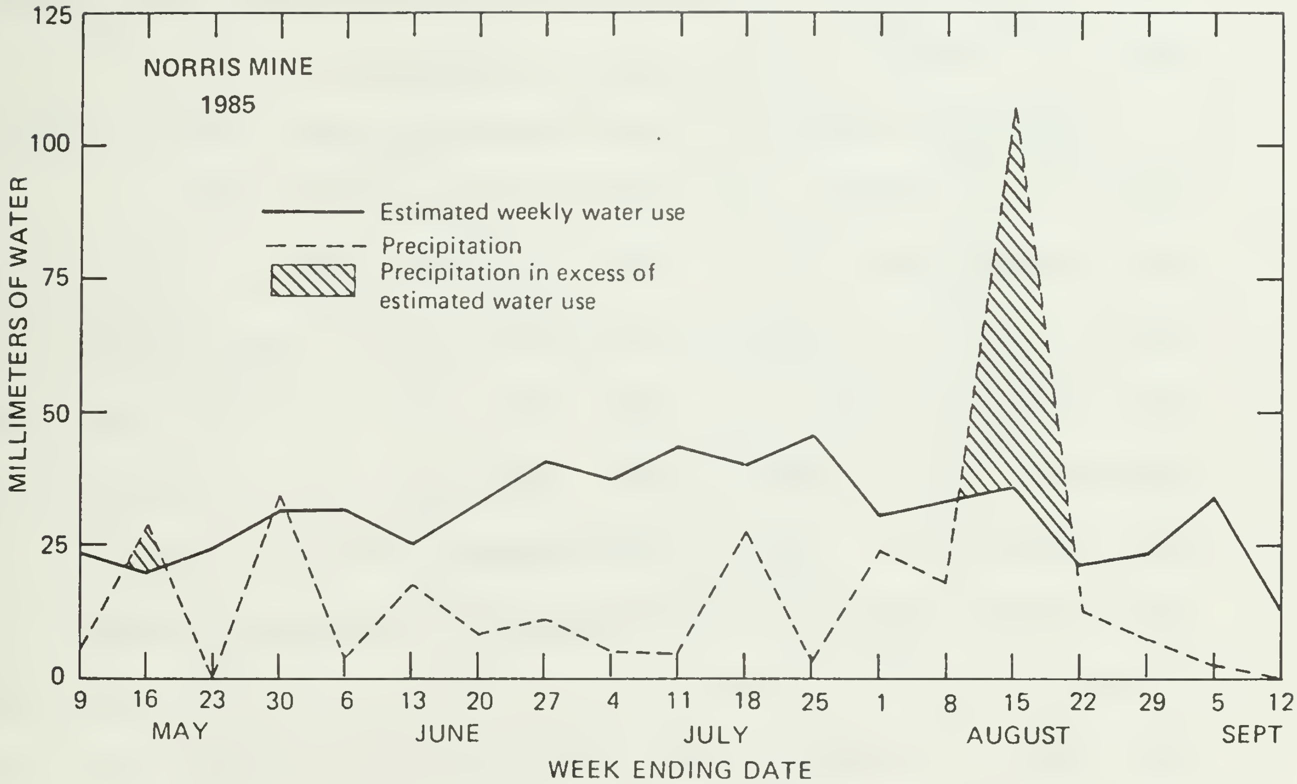

Figure 4. Precipitation and estimated weekly water use for the 1985 growing season.

observed on most genotypes growing on the mined land treatments. Rainfall occurring August 8-15 totaled 110 cm, and was quite beneficial during the subsequent grain filling period. Tensiometer data presented graphically in Figure 5 shows that soil moisture tension levels were beyond the range of recording instruments at the 30 cm and 60 cm depths by the time of pollination. Soil moisture levels at the 90 cm and 120 cm depths were adequate and remained relatively stable for the remainder of the growing season.

1984-85: Results of the combined years analysis show the performance of the genotypes to be superior on the undisturbed Sable soil, while the yield means of the two mine soils to be not significantly different. Mean yields of all genotypes combined was 9,797 kg/ha for the Sable soil, 6,269 kg/ha for topsoil/wheel spoil and 6,112 kg/ha for wheel spoil only (Table 8). Topsoil replacement resulted in a significant positive yield response in only one hybrid while a negative yield response occurred in two of the genotypes evaluated. The hybrid B73 X LH24 produced comparable yields on all three soil treatments and was among the top five yielding hybrids on both the topsoil and the wheel spoil plots. Performance of this hybrid on the Sable was below the mean and ranked 23 out of 29 (Table 13). The hybrid LH74 x LH 123 was the highest two year average yielder on both the Sable and topsoil while ranking number 16 on the wheel spoil treatment. LHE136 x LH24 was the highest grain producer over the two year period on wheel spoil and yields were above the

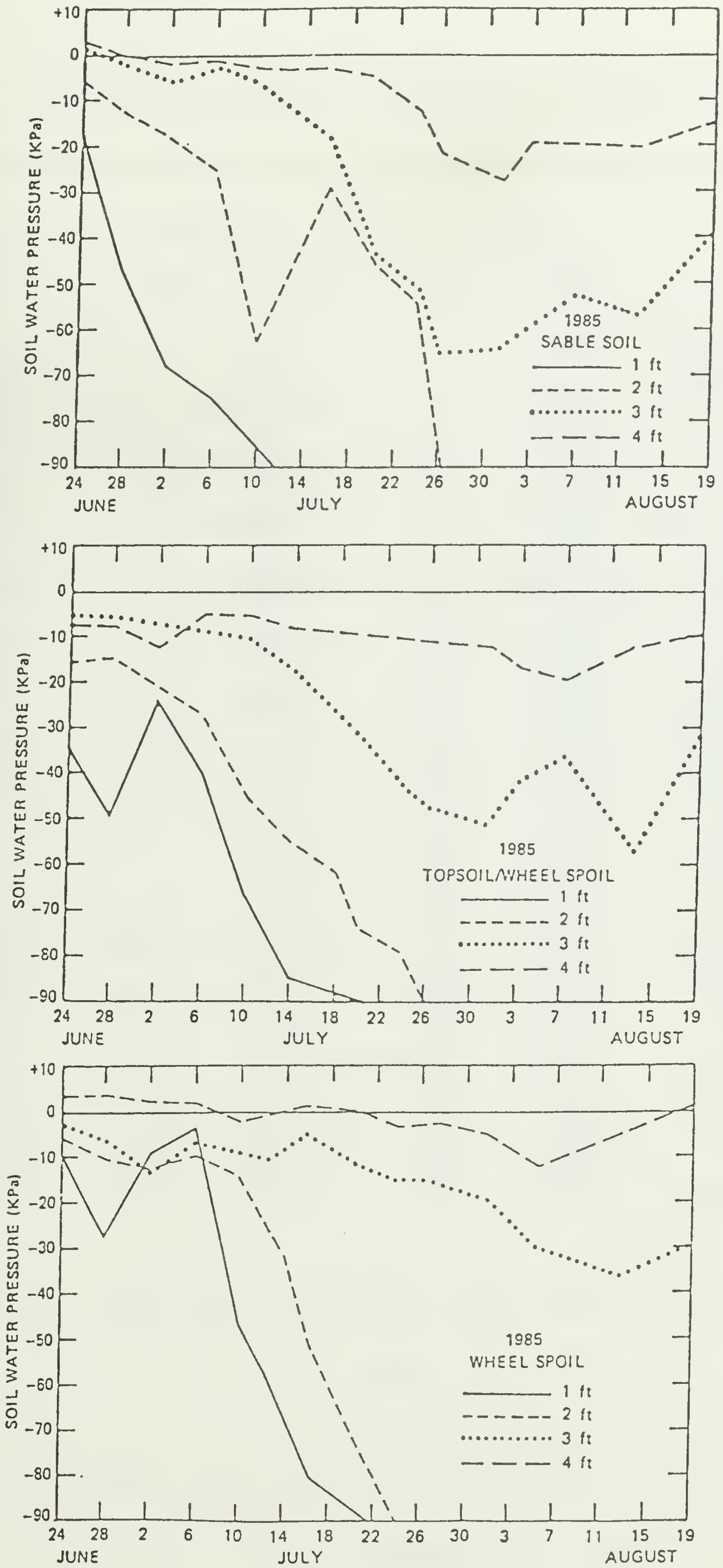

Figure 5. Soil moisture tension levels for the 1985 growing season.

Table 13. Ranking of hybrids by yield for 1984-85 combined.

Genotype	Sable		Topsoil		Wheel Spoil	
	kg/ha	rank	kg/ha	rank	kg/ha	rank
LH74 x LH123	12286	1	7740	1	6065	16
LH132 x LH123	11090	2	6275	15	6623	11
ANS 83-17	11021	3	6787	8	5911	20
NK PX9581	10786	4	5359	25	4442	26
LH119 x 132	10714	5	6482	13	6460	12
GRE 82-10	10619	6	5817	20	7487	4
Dekalb 656	10503	7	6925	9	6985	7
LH119 x LH51	10397	8	7381	11	6513	9
B73 x Mo17	10318	9	6806	6	6897	17
B73 x LH50	10246	10	5657	23	7518	3
Dekalb 505	10164	11	7408	2	6244	14
LH74 x LH51	10057	12	6121	16	7230	6
LHE136 x LH24	10004	13	6887	10	7690	1
Funks G4589	9838	14	6055	17	4486	28
CB59L x LH51	9817	15	5776	21	5898	21
LH117 x MS71	9775	16	7173	4	6309	13
B73 x LH38	9662	17	5917	19	6721	10
LH132 x LH51	9461	18	7252	3	5996	19
NK PX9527	9423	19	6937	14	6353	8
Pioneer 3389	9129	20	6796	7	6125	15
ANS 83-7	9122	21	4859	26	4006	29
CB59G x LH38	9097	22	5644	24	5384	22
B73 x LH24	9027	23	6887	5	7506	2
Dekalb 587	9009	24	5697	22	7433	5
Pioneer 3358	8745	25	5917	18	4938	23
Pioneer 3541	8699	26	4197	29	6011	18
GRE 82-4	8482	27	6532	12	4894	24
B73 x H99	7801	28	4784	28	4511	27
FR632 x FR619	7072	29	4837	27	4734	25

treatment means on both the topsoil and Sable soil. The higher yielding hybrids on the mine soils were generally ranked near the middle in the Sable group suggesting that the hybrids selected for high productivity on the natural soils are more affected by stress when grown on mined land. The low yields and failure of almost all of the genotypes to perform on the mined land as well as they did on the Sable soil reflect this by the increased sensitivity to the weather variables experienced during this study. The 1984-85 results of the adjacent irrigation experiment show 2 year corn yield averages for the hybrid B73 x Mo17 to be 10,485 kg/ha for irrigated topsoil/wheel spoil and 7,659 kg/ha for unirrigated. These plots were constructed at the same time, under the same conditions, and using the same equipment replacing the same materials. The results of the irrigation study show that these soils can be highly productive under irrigation or years of favorable weather.

The combined years analysis reveal significant differences in mean yields between 1984 and 1985 for all soil treatments although the rates of increase were variable between the mined and unmined soil treatments. Mean corn yields for 1985 increased 875 kg/ha (9%) on the Sable soil, 1,951 kg/ha (38%) on the wheel spoil and 2,147 kg/ha (42%) on the topsoil/wheel spoil. The year by soil treatment interaction was nonsignificant while the hybrid by year interaction and the soil treatment by hybrid interaction were significant at the 0.01 and 0.05 level of probability,

Table 14. Analysis of variance table for corn yields at Norris Mine 1984-85.

SOURCE	DF	ANOVA SS	MEAN SQUARE	F VALUE
YR	1	8Ø721.439	8Ø721.439	27.48**
STRT	2	399879.929	199939.96Ø	68.Ø6**
YR*STRT	2	16Ø15.788	8ØØ7.89Ø	2.73
REP(YR*STRT)	12	3525Ø.932	2937.58Ø	
HYB	28	86531.282	3Ø9Ø.4ØØ	5.25**
YR*HYB	28	43949.299	1569.62Ø	2.67**
STRT*HYB	56	46459.268	829.63Ø	1.41*
YR*STRT*HYB	56	25215.229	45Ø.27Ø	Ø.76
REP(YR*STRT*HYB)	336	19788Ø.17Ø	6Ø6.99Ø	
TOTAL	521	9319Ø3.339		

*,** Significant at the Ø.Ø5 and Ø.Ø1 probability levels respectively.

respectively (Table 14).

Pollination Response

Results from this study (Table 15) show significant differences in pollination dates between soil treatments among and within hybrids in both 1984 and 1985. Mean pollination dates for the 40 hybrids in 1984 were 60, 64, and 66 days after planting for the Sable, topsoil, and wheel spoil plots, respectively. Similar significant results occurred in 1985 with pollination dates of 70, 72, and 73 days after planting for the three soil treatments. Soil treatment effects for individual hybrids for the 1984 and 1985 seasons (summarized from Table 16) are as follows:

1). Pollination dates of the topsoil and wheel spoil treatments were not different in 23 of the 40 hybrids in 1984 and 25 of 38 hybrids in 1985.

2). Pollination date of the wheel spoil treatment was significantly later than the Sable soil in all hybrids in 1984 and later in 32 of 1985 hybrids.

3). Pollination date of the topsoil treatment was significantly later than the Sable soil in 24 hybrids in 1984 and 16 genotypes in 1985.

4). Wheel spoil pollination date was significantly later than topsoil dates in 12 and 11 hybrids for 1984 and 1985 respectively.

Table 15. Analysis of variance table for days after planting to pollination for 1984-85 growing seasons.

SOURCE	DF	ANOVA SS	MEAN SQUARE	F VALUE
YR	1	7563.542	7563.542	1159.54**
STRT	2	2037.843	1018.921	156.20**
YR*STRT	2	154.854	77.427	11.87**
REP(YR*STRT)	12	78.276	6.523	
HYB	28	1060.820	37.886	14.61**
YR*HYB	28	244.957	8.748	3.37**
STRT*HYB	56	477.490	8.526	3.29**
YR*STRT*HYB	56	347.812	6.211	2.40**
REP(YR*STRT*HYB)	336	871.057	2.590	
TOTAL	521	12836.653		

** Significant at the 0.01 probability level.

Table 16. Mean days after planting to 50% pollen shed.

Genotype	Soil Trt	1984 DAP	1985 DAP
CB59G X LH38	PL	58.0 a	66.3 a
	TS	65.0 b	70.6 b
	SP	67.0 b	71.3 b
LH74 X LH123	PL	60.0 a	72.6 a
	TS	61.7 a	74.0 ab
	SP	65.0 b	75.3 b
LH119 X LH123	PL	60.7 a	70.6 a
	TS	65.0 b	70.6 a
	SP	65.7 b	75.3 b
LH132 X LH123	PL	61.3 a	70.0 a
	TS	63.3 a	71.3 ab
	SP	68.3 b	72.0 b
B73 X LH123	PL	61.3 a	
	TS	58.6 a	
	SP	69.7 b	
B73 X LH24	PL	60.7 a	70.6 a
	TS	64.0 ab	72.0 ab
	SP	65.6 b	73.4 b
LHE136 X LH24	PL	59.0 a	68.0 a
	TS	61.3 a	72.0 b
	SP	65.0 b	72.0 b
LH132 X LH51	PL	62.0 a	72.0 a
	TS	66.7 b	72.0 a
	SP	67.0 b	75.3 b
N7A X MO17	PL	60.0 a	
	TS	64.0 b	
	SP	67.0 b	
B73 X LH38	PL	60.7 a	70.6 a
	TS	66.3 b	72.0 a
	SP	65.0 b	74.0 b
B73 X LH50	PL	62.0 a	72.0 a
	TS	64.0 ab	72.0 a
	SP	66.3 b	75.3 b
LH117 X MS71	PL	61.3 a	68.0 a
	TS	65.0 b	70.6 b
	SP	65.0 b	72.0 b

Genotype	Soil Trt	1984 DAP	1985 DAP
LH119 X LH51	PL	60.7 a	72.0 a
	TS	65.0 b	72.0 a
	SP	66.0 b	73.3 a
LH74 X LH51	PL	59.0 a	69.0 a
	TS	64.0 b	72.0 b
	SP	65.0 b	74.0 c
CB59G X LH51	PL	58.0 a	66.3 a
	TS	65.0 b	70.0 b
	SP	65.0 b	72.6 c
Dekalb 505	PL	60.0 a	65.6 a
	TS	66.0 b	70.0 b
	SP	66.7 b	73.3 c
Dekalb 587	PL	56.3 a	65.6 a
	TS	64.0 c	69.0 b
	SP	60.3 b	70.3 b
Dekalb 656	PL	62.7 a	73.3 a
	TS	66.0 b	73.3 a
	SP	70.0 c	74.0 a
Funks G4522	PL	60.0 a	
	TS	64.0 b	
	SP	66.0 b	
Funks G4589	PL	63.3 a	72.0 a
	TS	64.3 b	72.0 a
	SP	68.3 b	75.3 b
Northrup King PX9527	PL	60.0 a	68.0 a
	TS	65.0 b	72.0 b
	SP	66.7 b	72.6 b
Northrup King PX9581	PL	62.7 a	72.6 a
	TS	65.0 a	73.3 ab
	SP	70.0 b	74.6 b
Pioneer 3358	PL	62.7 a	72.0 a
	TS	63.7 a	73.3 a
	SP	67.7 b	72.6 a
Pioneer 3389	PL	62.0 a	71.3 a
	TS	62.7 a	72.0 ab
	SP	66.7 b	74.0 b
Pioneer 3541	PL	56.3 a	65.6 a
	TS	67.3 c	69.0 b
	SP	62.7 b	71.3 c

Genotype	Soil Trt	1984 DAP	1985 DAP
B73 X H99	PL	60.0 a	68.6 a
	TS	66.7 b	71.3 b
	SP	65.0 b	72.6 b
FRB73 X MS71	PL	61.3 a	
	TS	66.0 b	
	SP	65.3 b	
FR632 X FR619	PL	56.3 a	63.6 a
	TS	66.0 c	69.0 b
	SP	60.3 b	71.6 c
FR27 X FRMO17	PL	60.7 a	
	TS	63.6 a	
	SP	69.3 b	
FRB73 X FRMO17	PL	62.0 a	71.3 a
	TS	66.7 b	72.0 b
	SP	76.7 c	74.0 c
FRB73 X FRVa26	PL	60.0 a	
	TS	66.0 b	
	SP	64.3 b	
An 81-10	PL	60.7 a	
	TS	64.7 b	
	SP	66.0 b	
GRE 82-4	PL	61.3 a	70.0 a
	TS	62.7 a	71.3 a
	SP	67.7 b	74.0 b
GRE 82-10	PL	60.0 a	70.0 a
	TS	64.7 b	71.3 ab
	SP	64.0 b	72.0 b
An 83-7	PL	61.7 a	69.6 a
	TS	64.0 a	71.3 ab
	SP	68.3 b	72.0 b
An 83-10	PL	60.7 a	
	TS	62.0 ab	
	SP	65.3 b	
An 83-17	PL	61.3 a	70.0 a
	TS	66.0 b	72.0 b
	SP	66.0 b	72.0 b
W117 X Co109	PL	49.3 a	
	TS	61.0 c	
	SP	55.0 b	

Genotype	Soil Trt	1984 DAP	1985 DAP
Mo17 X A634	PL	61.3 a	
	TS	62.7 ab	
	SP	66.Ø b	
W153R X A634	PL	53.Ø a	
	TS	63.3 c	
	SP	58.Ø b	
B73 X LH51	PL		72.Ø a
	TS		73.3 ab
	SP		74.Ø b
LH132 X LH5Ø	PL		72.6 a
	TS		75.3 b
	SP		76.Ø c
LHE136 X LH123	PL		7Ø.Ø a
	TS		72.Ø b
	SP		72.Ø b
An 83-18	PL		7Ø.6 a
	TS		72.Ø ab
	SP		72.6 b
GRE 82-7	PL		69.6 a
	TS		7Ø.6 ab
	SP		72.Ø b
GRE 83-3	PL		7Ø.Ø a
	TS		72.Ø b
	SP		72.6 b
An 82-12	PL		71.3 a
	TS		72.Ø a
	SP		72.6 a
An 82-2	PL		72.6 a
	TS		73.3 a
	SP		72.6 a
Pioneer 3377	PL		72.6 a
	TS		73.3 ab
	SP		74.6 b
	LSD (Ø.Ø5)	3.9	1.9
Mean	PL	6Ø.Ø a	69.6 a
	TS	64.4 b	71.8 b
	SP	65.8 c	73.3 c
	LSD (Ø.Ø5)	1.2	Ø.6

5). Topsoil pollination date was significantly later than wheel spoil in 5 hybrids in 1984 and later in none of the hybrids in 1985.

Calculation of thermal units required to reach 50% pollen shed produced the same results within years as would be expected since cumulative thermal units are a direct result of the number of calendar days after planting in an individual year. Measurements of accumulated thermal units for an individual hybrid between years, however, produced discrepancies between the growing degree units (GDU) and the calendar day method. Twenty-nine genotypes were common to both the 1984 and 1985 studies. In all 29 hybrids the number of calendar days to pollen shed was significantly greater in 1985 than in 1984 both within and among soil treatments. Growing degree units required with the three soil treatments combined revealed that six genotypes required comparable thermal unit levels to reach pollination for the two growing seasons. Within individual soil treatments thermal units to pollination for 1984 and 1985 seasons were not different in five hybrids on the Sable soil, eighteen hybrids on the topsoil treatment, and in twenty hybrids grown on the wheel spoil treatment. Of the 29 hybrids used in both years three genotypes showed no difference in GDU's for all three soil treatments. Date of planting was 12 days earlier in 1985 and the number of calendar days to reach 50% pollen shed averaged 8 days longer in 1985. This agrees with the observations of other researchers who found that silking dates are determined by environmental factors other than number of days after planting. Tsotsis (1958) has concluded that accumulated thermal units are an improvement over calendar days to predict pollen shed and flowering dates. However, he did find there were significant differences between the accumulated thermal units for a specific hybrid grown in different seasons or at different planting dates. Differences between years may be associated with several factors such as stress, range in temperature values, or differences in photoperiod. The calendar day method may be the most affected by differences in photoperiod since it is a result of date of planting. Decreasing photoperiods hasten silking and reduce the number of leaves per plant in corn (Allison and Daynard, 1979). Increasing temperatures also hasten flowering, but also increases the number of leaves per plant. For corn grown in the Midwest, changes in photoperiod are confounded with changes in temperature and are nearly impossible to separate in field experiments (Daughtry et al., 1984). The thermal unit accumulation concept assumes that photoperiod does not influence the rate of crop development. Coligado and Brown (1975) developed a model incorporating temperature, photoperiod, and genetic factors to predict tassel initiation in corn. The use of such a model to evaluate genotypic response on mined land may be more applicable than the simple GDU approach. Results from this study using the thermal unit concept demonstrate consistent responses of hybrid GDU's to flowering of corn on mined land, just as researchers have found in studies on undisturbed natural soils. Mine soils should conceptually improve with time and as improvement occurs the differences between pollination dates between mined and unmined treatments should narrow. Because delayed pollen shed is a result of some factor of stress then the alleviating of stress or increased productivity should result in comparable pollination dates between mined and unmined land.

Response to Rainfall and Temperature

Previous research has suggested that row crops grown on mined land may be more sensitive to weather stress than row crops grown on natural undisturbed soils (Dunker et al.,1982; Jansen et al., 1985a; Meyer, 1983). If corn yields are affected by mined land at different magnitudes to weather variation then covariance analysis should be useful in making treatment comparisons. The analysis of covariance is a technique that combines the features of analysis of variance and regression. Variation in corn yield that is associated with climatic variables is removed from the error variance which should result in more precise estimates and more powerful tests. Group means of the yield variable are adjusted to correspond to a common climatic value thereby producing an "equitable" comparison of groups.

Rainfall and maximum temperature three days before to three days after (one week period) pollination date was used in the analysis. This has been recognized as the stage of corn development to be most affected by moisture and temperature stress (Robins and Domingo, 1953; Denmead and Shaw, 1960; and Claassen and Shaw, 1970). It is also the time period where above average rainfall will increase grain yields of corn. Stone et al. (1978), studied the effect of one time irrigation of corn at different stages of growth and reported the highest corn yields occurred when a single irrigation was applied at silking. Consequently, genotypes which pollinate at different dates may be either adversely or favorably affected by weather variability within a year. Pollination date differences for a hybrid between soil treatments will be a confounding factor when interpretating yield results.

Results of the analysis of covariance (Table 11) show that rainfall, temperature, soil treatment, and hybrid all had a highly significant effect on yield. The Type III sum of squares gives the sum of squares adjusted for the covariate. Note that the unadjusted soil treatment sum of squares (Table 14) of 368902.598 is larger than the adjusted sum of squares of 346318.367; however, the reduction in error mean squares from 18615.510 to 773.850 allows for an increase in the F statistic from 59.45 in the analysis of variance (Table 14) to 223.76 in the analysis of covariance (Table 17). The least-squares means procedure produces a set of estimates called the adjusted treatment means. Following is a comparison of means generated using the ANOVA procedure and

Table 17. Analysis of covariance of hybrid corn yields with precipitation and temperatures.

$R^2 = 0.594$

SOURCE	DF	TYPE III SS	F VALUE	PROB > F
Rainfall	1	18806.932	24.30	0.0001
Max Temp	1	24218.793	31.30	0.0001
Soil Trt	2	346318.367	223.76	0.0001
Hybrid	28	80853.333	3.73	0.0001

Parameter	Estimate	T for HO: Parameter=0	Std Error of Estimate
Intercept	295.269	7.81	37.827
Rainfall	17.085	4.93	3.465
Max Temp	-0.344	-5.59	0.061

Partial regression coefficients for Sable soil: $R^2 = 0.333$

Parameter	Estimate	T HO:P=0	PR > T	Std Error
Intercept	21.331	0.26	0.7922	80.820
Rainfall	6.754	1.26	0.2106	5.371
Max Temp	0.233	1.70	0.0912	0.137

Partial regression coefficients for wheel spoil: $R^2 = 0.502$

Intercept	390.840	7.68	0.0001	50.876
Rainfall	18.684	2.60	0.0102	7.178
Max Temp	-0.493	-5.96	0.0001	0.086

Partial regression coefficients for topsoil: $R^2 = 0.397$

Intercept	227.113	2.54	0.0121	89.322
Rainfall	32.696	4.23	0.0001	7.732
Max Temp	-0.262	-1.84	0.0679	0.142

the adjusted treatment means for the analysis of covariance with rainfall and temperature.

	Unadjusted Means	Least-squares Means
Sable soil	154.46 a	155.57 a
Wheel Spoil	97.69 b	99.05 b
Topsoil	98.45 b	98.30 b

The comparisons of the adjusted least-squares means did not result in different significance groupings for soil treatments from that of the analysis of variance. Since significant effects of rainfall and temperature were detected in the analysis of covariance procedure, however, it was of interest to generate partial regression coefficients for the weather variable effects on each soil treatment (Table 11). Results indicate that the relationship between rainfall and yield was better for wheel spoil (Prob> T = .0102) and topsoil (Prob> T = .0001) than it was for the Sable soil (Prob> T = .2106). The maximum temperature at pollination was also associated at higher significance levels for the mined land treatments. While identifying that we are making assumptions on partial regression coefficients it is interesting to look at the magnitude of the weather coefficients generated for each soil treatment. Partial regression coefficients for rainfall are considerably higher for the topsoil and the wheel spoil treatment than for the

Sable soil suggesting that yield is more affected by the levels of rainfall on the mined land treatments. Coefficient values for maximum temperature show negative effects for increasing temperatures on mined land and a positive influence on the undisturbed soil. Runge and Odell (1958) in a study of weather effects on corn yield concluded that above normal temperatures at pollination can be quite beneficial to yield of corn if the crop is not under stress. The study also concluded that high temperatures can be quite detrimental to yields if moisture stress is occurring. In previous discussion on hybrid responses it was noted that mine land treatments were more visibly stressed than hybrids growing on the Sable soil and is believed to be the cause of negative and positive temperature effects.

SUMMARY AND CONCLUSIONS

1). The potential to minimize the effects of stress on corn grown on newly constructed mine soils exists through hybrid selection of adapted genotypes. Results show that some hybrids are capable of producing yields on mined land comparable to undisturbed soil within a particular year. Hybrids with the highest yield potential on unmined soils were highly variable when grown on mined land and did not necessarily produce the highest yields on the disturbed plots.

2). Weather variables are more significantly associated with yield variation on the mine soils than the Sable soil. This is reflected in the fact that 25 of the 38 hybrids produced mined land yields comparable to the natural soil in 1985 while no hybrid yields equaled the Sable soil in 1984.

3). Significant differences in pollination dates among soil treatments for a hybrid were observed in both 1984 and 1985. Hybrids grown on the Sable soil were the first to pollinate, followed by hybrids on the topsoil treatment while hybrids on the wheel spoil treatment were the last to shed pollen. The differences in pollination dates for a hybrid between soil treatments were greater in

1984, a year of relatively higher moisture and temperature stress than 1985.

4). The thermal unit accumulation concept appears to be a useful technique to predict pollination dates on mine soils as well as undisturbed treatments and is an improvement over using a simple calendar day method. The growing degree method should reduce year to year variation caused by planting date and may also be a useful parameter in evaluating the rate of plant development between mined and unmined land.

5). Results of this two year study show the Sable to be superior to the topsoil and wheel spoil treatments for growing corn, at least under conditions experienced during this investigation. Yield differences may be associated with many factors influenced by the physical or chemical properties of each soil. Chemical tests show that differences exist at the present time in levels of pH and nutrients which will need to be equalized through fertilization and liming. No yield response to topsoil replacement for any hybrid occurred in 1984 and only one hybrid produced a significant positive response and two responding negatively to topsoil replacement in 1985. It is suggested that added replications are needed to be able to make precise comparisons between the more variable mine soil treatments.

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