Prime Farmland Reclamation Workshop

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Soil Physical Properties

SOILS AND SOIL PHYSICAL PROPERTIES

I.J. Jansen

I. General concepts.

A. Soil - - The term soil is used, in this course, in the pedologic sense rather than in the engineering or geologic sense. In the pedologic sense, soil is the mantle of material at the earth's surface which supports or is capable of supporting plant growth. Soil serves as a plant root environment and generally contains living matter.

1. Vertically, soil extends from the land surface down to the lower limit of the zone affected by soil developing processes. Thickness ranges from a few centimeters to a few meters, but is commonly one or two meters. The Pedologist's soil differs from the Engineer's soil in that the former has a lower limit as per above, whereas the latter generally encompasses most or all unconsolidated'material.

2. Horizontally, Soil forms a continuum on the earth's surface, broken only by such non-soil areas as deep water or bare rock.

3. This soil continuum is commonly subdivided into "c which are individual bodies of soil whose limits are arbitrarily defined. The soil continuum is arbitrarily segmented into soils for convenience in perceiving and communicating geographic patterns in soil character.

B. Soil constituents:

```
                    Soil
          /---------------|----------------\
      solids                          pore  space
 / --------|-------- -\              / -------|----------\
organic          mineral          air                  water
            /-----I-------\
        texture      mineralogy
```

C. Soil Morphology - - observable properties.

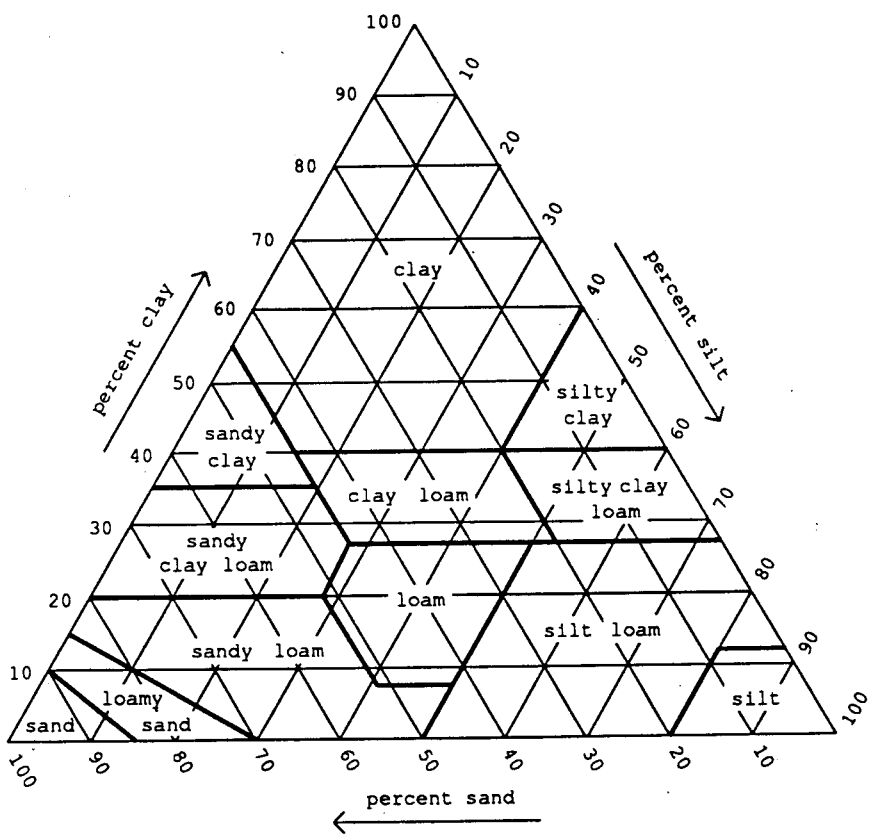
1. texture
2. structure
3. color

D. Soil Texture: Particle size distribution.

Fine earth fraction				Coarse fragments		
	.002mm	.05mm	2mm	3"	10"	
clay	silt	sand	gravel	cobbles	stones, boulders	

1. For a discussion of principles and methods for measurement of particle size distribution see: G.W. Gee and J.W. Bauder, Particle Size Analysis. Chapter 15, pp. 383-411 in: Methods of Soil Analysis, Part 1- physical and mineralogical methods, second edition, AGRONOMY #9, American Society of Agronomy, Madison, Wisconsin, 1986.

2. Soil texture class -- texture triangle. A set of named texture classes with limits defined in terms of an inclusion range for each of the three fine earth fraction separates.



3. What texture is desirable? Why?

   a. Clays & organic matter, active constituents, Sands & silts inert.

4. Appearance

a. Sand -- looks & feels grainy, individual mineral grains visible with the naked eye.

b. Silts -- powdery when dry -- smooth, but non plastic when wet. Individual mineral grains visible with a light microscope.

c. Clay -- plastic or sticky when'wet -- submicroscopic.

5. The term clay is used in two ways:

a. Mineral -- size & shape.

b. Particle size class.

6. Clay from the layman -- meaningless

a. Color, etc. often basis for impression.

7. Functions of clay:

a. CEC

b. Binder to stabilize structure.

8. Ideal clay content ranges.

a. 15% too low, except that high organic matter levels can substitute for clay to some degree. 40% is too high, effects can be off-set somewhat by high organic matter and structure.

b. Perhaps 20% to 35% ?

9. Sand - - sand content is not important unless it is too high. < 30% certainly acceptable'; Some soils with as much as 50% sand can be highly productive, particularly if there isrelatively high organic matter.

10. The texture modifiers in soil phase names:

a. Refers to surface texture only.

1) Sabel silty clay loam - - has silty clay loam surface

2) Clarence silt loam - - silt loam surface, but has clay or silty clay subsoil.

3) Port Byron silt loam vs. Edina silt loam

E. Soil Structure - - arrangement of the individual mineral grains. Structured soils have the individual mineral grains bound together into secondary units (peds, or aggregates). Soil structure is a genetic property. Clay and organic matter serve as binding agents to stabilize structure.

1. Soil peds - - "ped" is standard parlance for individual structural units (aggregates).

2. Structure grade:

a. structureless - - is actually absence of structure rather than being a structure grade; no identifiable peds.

1) massive - - all mineral grains bound together into one mass.

2) single grain - - no binding of mineral grains, each is separate.

b. weak - - identifiable tendency to break into peds, but easily disrupted.

c. moderate - - readily breaks into peds which persist through modest disturbances.

d. strong - - very stable structure, peds persist through considerable disturbances.

3. Structure types:

a. granular

b. crumb

c. blocky
1) subangular
2) angular

d. platy

e. prismatic

f. columnar

g. fritted? - - not official. Has been used for artificial structure in some mine soils. See: K. McSweeney and I.J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. Soil. Science Society of America Journal. 48:607-612.

4. Structure size: - - modifiers ranging from very fine to very coarse, size ranges are specific to structure type.

F. Soil color - - soil color is described in reference to the Munsell color system. See: Munsell Soil Color Charts, Munsell Color Company, INC., Baltimore, Maryland 21218.

1. Color patterns - - Some soil horizons have one uniform color throughout. Others have distinct matrix and mottle colors which must be described separately. Distinct color differences between ped interiors and ped exteriors are also common, and each color is identified accordingly. Peds in some soils are coated with a thin clay, silt, or organic film, in which instance the exterior color is that of the coating, and described as such.

G. Soil horizonation.

1. A soil horizon is a layer that is distinguished from the layers above and below it.

2. A soil profile is the sequence of horizons making up the whole soil.

3. Horizon nomenclature - - each master horizon bears A capital letter: O, A, E, B, C, or R, or some combination of the same. Lower case letters are used as suffixes to identify specific kinds of master or subordinate horizons. Any subhorizons which are of the same general kind and bear the same letter code are distinguished by adding a number as an additional suffix, numbered sequentially from the top horizon bearing a common letter code on down until the letter code changes to reflect a different kind of horizon. Whereas the capital and lower case letter elements of the horizon designation are specifically defined, the number is added only where needed to distinguish layers bearing the same letter code, and has no specific implications.

a. Examples: Ap, Btl, Bt2, BC, C

4. Master horizons:

a. O horizons - - layers dominated by organic material.

b. A horizons - - mineral layers formed at the surface or below an 0 horizon that are characterized by -accumulation of humified organic material; with or without significant eluviation (depletion through genetic translocation to other horizons) of silicate clay, iron, and/or aluminum.

c. E Horizons - - mineral layers distinguished primarily by- eluviation of silicate clay, iron, aluminum, organic material, or some combination of these.

d. B Horizons - - horizons that formed below an A, E, or 0 horizon and are dominated by: 1) obliteration of rock structure, 2) development of genetic soil structure, 3) illuviation (concentration through translocation from other horizons) of various soil constituents, 4) removal of carbonates, 5) residual concentration of sesquioxides, 6) sesquioxide-coatings on mineral grains which significantly change color, 7) clay formation or oxide release, or any combination of these.

e. C Horizons - - unconsolidated material, commonly occuring below one or more of the above, which does not show the effects of genetic soil development and lacks the properties of the above horizons.

f. R layers - - hard rock.

g. Transition Horizons - - are named by using a combination of the letters designating the horizons that they are in between (the letter for the horizon it is most like, or whose properties predominate, is used first).

l) A B - - a gradational transition horizon which has properties more like an A horizon than like a B. BA would be used where B horizon properties predominated.

2) B/A - - a mixture, has distinct areas with B character and A character, respectively, that are to intimately intermixed to separate into two horizons. The B being first indicates that in this instance the B-like material predominates.

3) Etc.

5. Subordinate distinctions within master horizons.

a - - Highly decomposed organic material.
b - - Buried genetic horizon.
c - - Concretions or hard nonconccretionary nodules.
e - - Organic material of intermediate decomposition
f - - Frozen soil.
g - - Strong gleying.
h - - Illuvial accumulation of organic matter.
i- - Slightly decomposed organic material.
k- - Accumulation of carbonates.
m - - Cementation or induration.
n - - Accumulation of sodium.
o - - Residual accumulation of sesquioxides.
p - - Plowing or other disturbance.
q - - Accumulation of silica.
r - - Weathered or soft bedrock.

s - - Illuvial accumulation of sesquioxides & O.M.
t - - Accumulation of silicate clay.
V - - Plinthite.
w - - Development of color or structure.
x - - Fragipan character.
y - - Accumulation of gypsum.
z - - Accumulation of salts more soluble than gypsum

H. Other terms for soil layers:

1. Solum - - true soil, includes any 0, A, E, or B horizons, excludes any C horizons or R layers.

2. Topsoil - - a popular term used very inconsistently. It is often used for all A horizons collectively, but it is also often intended to mean the whole solum. It might even refer to a surficial layer that is mostly C horizon material in some instances. Don't jump to any conclusions as to what is meant unless you can determine from the context, or where the term has been specifically defined in the text.

3. Subsurface - - a popular term that is sometimes used to refer to the E horizons.

4. Subsoil - - another popular term. It is most commonly used to refer to all B horizons collectively, but it will also often include some or all E horizons, and might even include some C horizons.

5. Substratum - - layers below the solum, includes any C horizons and R layers, particularly those that are close enough to potentially affect the behavior of the soil.

I Soil Density.

1. Particle density (Dp).

a. $$Dp = \frac{\text{mass}}{\text{particle volume}}$$

1) Strictly a function of mineralogy and organic matter content. Soil structure and compaction do not affect particle density.

2) Particle density for many mineral soils runs around 2.65g/cc, the density of quartz. Variability in Dp is very low for soils of common mineralogy and low organic matter levels, so that large numbers of measurements are usually not needed.

3) For a discussion of principles and methods for Dp measurement see: G.R. Blake and K.H. Hartge,

Particle Density. Chapter 14, pp. 377-382 in: Methods of Soil Analysis, Part l-physical and mineralogical methods, second edition, AGRONOMY #9, American Society of Agronomy, Madison, Wisconsin, 1986.

2. Bulk density (Db).

a. $Db = \frac{\text{mass}}{\text{total volume}}$

1) Mass is oven dry weight.

2) The volume parameter for calculating Db includes pore volume, whereas such is excluded from the volume parameter for calculating Dp.

3) Bulk density is changeable. It is affected by soil structure and particle arrangement as well as by mineralogy.

4) Bulk density can be decreased by any tillage operation 'which increases pore volume. It can be increased by reducing pore volume through compaction.

b. Factors affecting Db.

1) Particle density - - generally not a major factor among mineral soils.

2) Particle shape & arrangement.
   a) Spherical vs. plate shaped
   b) dispersed vs. flocculated.

3) Effect of water.
   a) SS vs. SLS

4) Range in particle size distribution.
   a) Narrow range ----- low potential density.
   b) Wide range ----- high potential density. Well "graded" aggregate or base material.
   c) Marble illustration.

5) Effect of soil structure.

c. Why do clays commonly have a lower bulk density than sands?

1) Narrow range in particle size.

   a) Many sands have enough fines to partially fill the voids between sand grains.

2) Clay particles tend to be separated by water.

a) dispersed clays are SLS soils, sands are SS.

3) Clayey soils commonly maintain stable structure.

4) Clay particles are plate shaped and when not dispersed are prone to random card-stack arrangement.

3. Summary and Critique of bulk density measurement methods.

a. For a discussion of principles and methods for Db measurement see: G.R. Blake and K.H. Hartge, Bulk Density. Chapter 13, pp. 363-375 in: Methods of Soil Analysis, Part l- physical and mineralogical methods, second edition, AGRONOMY #9, American Society of Agronomy, Madison, Wisconsin, 1986. See also my critique in the next section.

b. No ideal method which is best for all circumstances exists. Need to select a method which is appropriate for the soil to be tested.

c. Primary or direct methods - - those which will yield a density value without reference to some other method.

1) Core methods - - volume determined by cutting a known volume of "undisturbed" soil. Suitable only where it is possible to get a clean-edged core without significantly compressing it. It should not be used for stony, gravely, or easily compressible materials.

a) Uhland sampler - - device for taking a known bulk volume core, about 3" in diameter and 3" in length, from an exposed surface.

b) Hydraulic probe - - segmented long core method - - truck or tractor mounted machine for taking a long core of known diameter, which must then be cut into segments of known length. A more thorough description of this method is given below.

2) Excavation methods - - better suited than the core method to stony materials, etc. These methods determine volume by measuring the volume of the hole from which the sample was removed.

a) Sand cone

b) Rubber balloon

3)Clod method - - a clod of unknown volume is selected, then volume is determined by sealing its outer surface with paraffin or saran and then determining the amount of water displaced as the sealed clod is immersed.

d. Secondary or reference methods - - can be interpreted only by reference to some primary method.

a) Radiation method, gamma probe.

e. Considerations in the selection of a bulk density method.

The radiation (gamma probe) method is appropriate where numerous bulk density measurements are required, particularly if one needs density profiles to one or two meter depths. Before this method can be used, however, a primary method must be employed to calibrate the gamma probe for local soils. Hence one still faces the burden of choosing an appropriate primary method.

The clod method is widely used and has become almost the standard for most Db measurements in Pedology. It is an appropriate method for most natural soils, but I consider it inappropriate for most mine soils. The reason for my concern is that it forces you to select a relatively small clod for measurement from a soil mass containing potential clods which commonly very widely in density. The higher density clods are more likely to remain intact, and hence more likely to be chosen for the clod than is the matrix in which it is set. In some instances the matrix might be so loose as to make removal of an intact clod impossible, while chunks of more dense material might readily be salvaged for measurement. The result is an inherent bias toward high values. Even a conscious effort to select a representative clod leaves one with the dilemma of figuring out how to determine what is representative. That is somewhat less of a problem with most natural soils, because they are less inclined to have extreme density contrasts within a given layer than are mine soils.

Other methods minimize that problem by avoiding the necessity to select and retain intact any undisturbed soil mass for measurement. Other methods also tend to measure a larger soil volume, so that some averaging effect acts to avoid extreme values. The clod method would be the most appropriate one where the objective is to measure the extremes or range of Db present among clod-sized masses.

The segmented long core method has the advantage of being a primary method which yields a bulk density profile, rather than just one value per site. It will provide some indication of the range in Db represented, as well as of depth trends. I favor the segmented long core method for sites where it will work. Excavation methods will be the only feasible way to measure Db of many stoney, gravelly, incoherent, and/or highly compressible materials.

4. The segmented long-core method.

a. The approach is to take an undisturbed, continuous 'core of known diameter, from the soil surface down to the desired depth. The core is then cut into segments of known length, all of which are dried and weighed so that Db can be calculated separately for each segment.

b. A truck or tractor mounted hydraulic coring machine, such as a Giddings machine, is used to take the cores.

c. Suggest that a tube be selected which will cut a 2.5" to 3" core. Use a cutting bit that is sharp and free of nicks, carefully measure and record the inside diameter of the cutting edge. Use a slotted tube so that any compression of the core could be detected by watching the core through the slot as the tube is inserted.

d. Take the cores under moist conditions. Observe the top of each core through the slot in the tube as the tube is forced into the soil. Stop immediately if the top of a core begins to sink, revealing compression within or below the core. Discard any cores where significant compression has taken place before you stopped the probe. Don't continue by discarding compressed cores and keeping only good cores when you are experiencing compression on a significant number before reaching the desired depth. Such would likely bias the data toward the high side, as high density sites would be somewhat less likely to compress. When experiencing significant compression, either select another method, or wait and try again when the soil is somewhat dryer.

e. Pull the core and extrude it from the tube and into a tray, carefully. Avoid flexing, cracking, compressing, etc. Don't use the core if you fail, and don't continue if many fail. Work out your technique.

f. Cut the core into segments of predetermined length, perhaps 10, 15, or 20 cm. Be careful to get the true length, a clean cut, etc. Record the length, either a

common length for all segments, or an individual length for each segment.

g. Bag each segment individually, being careful to include any crumbs with the segment to which they belong.

1) Suggest 2# brown paper bags lined with plastic liners (quart-sized freezer bags). Close plastic liner to retain moisture in the sample. Write sample ID on the paper bag. Group into larger paper bags to organize by profile or sets of profiles.

h. Weigh several empty paper bags and plastic liners to establish a tare weight. Precision of the tare weight is not critical, because the samples are quite large.

i. Weigh moist sample in the bag and subtract the tare weight.

j. Remove the liner and transfer the soil from the plastic liner to the paper bag from which it came. Discard the liner.

k. Leave the paper bag open at the top and place it in a 105 C drying oven for 24 hr. Remove the sample to cool, then weigh it dry and subtract the appropriate tare weight (tare for paper bag only).

1. Calculate moisture content and bulk density.

1) mass = OD wt (oven dry weight).

2) bulk volume, moist = Length * πr

3) Moisture content = $\frac{\text{moist wt} - \text{OD wt}}{\text{OD wt}}$

J. Soil porosity - - pore volume.

1. % solids = Db/Dp* 100%

2. % pore volume (porosity) = (1 - Db/Dp) * 100%

3. Caution: this is only pore volume, it provides no information about pore size. Some soils with a normal to high porosity might perform poorly because all pores are very. fine, and hence macropores are lacking.

K. Soil'strength.

1. Soil strength and soil bulk density are often correlated, but are entirely different properties which have quite different implications. Bulk density is mass per unit volume. Particle density varies relatively little among most mineral soils (generally close to 2.65 g/cc), hence Db is inversely related to porosity. Soil strength refers to a soils resistance to deformation or fracture and is often expressed as resistance to penetration with a standard cone penetrometer.

2. There is a long standing argument in the literature as to whether it is lack of a network of sufficiently large pores or excessive strength that restricts plant root development. I believe that the error is in trying to separate the two factors. Given an extensive network of macropores, soil strength would not be terribly critical, because roots could follow existing channels. Given a soil with few pores adequate in size for root penetration, it appears that most roots can enlarge pores by forcing soil back in low strength soils, but are stopped in high strength soils.

3. For a description of a long-stroke, recording penetrometer to evaluate soil strength, see: C.L. Hooks and I.J. Jansen. 1986. Recording cone penetrometer developed in reclamation research. Soil Science Society of America Journal. 50:10-12.

Soil physical condition - - I have often used this phrase to refer to all physical properties which can be changed without replacing the soil material. These would be structure, bulk density, and soil strength. The three are interrelated such that it is often convenient to conceptually group them. They can be changed by crop management, tillage, etc. Other physical properties, such as texture, are not subject to manipulation and management in a given soil, and are hence excluded from the concept of soil physical condition.

II. Interpretation of soil physical properties.

A. Soil drainage class.

1. Inherent drainage, natural state only, gives no indication as to whether or not the natural condition has been changed by an artificial drainage system.

2. Drainage classes are defined in terms of depth to the natural seasonally high water table:

a. Excessive---------- >6'
b. Well ---------- >6'
c. moderately well ------- 3 - 6'
d. Somewhat poor ---------- 1 - 3', early Spring
e. Poor ---------- <l', Winter and Spring, planting delayed most years, perhaps not possible in some years.
f. Very poor - - - - - water table at or near the surface (sometimes ponded) for a substantial portion of most growing seasons. Cultivation generally not feasible without artificial drainage.

B. Functions of the surface soil:

1. Seed bed

a. soil-seed contact, tilth, crusting, texture & O.M.

2. Water infiltration, resistance to surface sealing.

a. infiltration rate.

3. Store and supply plant nutrients.

4. Water storage and supply.

5. Support traffic.

C. Functions of the subsoil:

1. Water storage and release to plants.

2. Plant nutrient supply, secondary.

a. fertility management can be done in the surface.
b. Chemistry of subsoil pertinent, but mainly because of its effects on soil physical condition and on plant root system development.

3. Differences between a highly productive soil and a' mediocre soil are often in the subsoil.

D. Soil water relations

1. Drainage

a. hydraulic conductivity
b. outlet - - underdrainage

2. Available water storage capacity.

E. Conditions for effective soil water relations:

1. Continuous network of macropores.

a. Plumbing system, conduct water into and through soil.
b. Maintain air-filled pore space for aeration.
c. Provide abundant channels for root growth.
d. Soil structure is major factor. Sandy soils commonly have the macropores, but lack other desirable features.

2. An intersecting network of micropores - - to sop up and store water for later plant uptake.

a. Particle size class important.
1) Silts desirable.
2) Clays - - pores often too small, water held too tightly.
3) Sands - - usually short on micropores, water passes on through.

3. Moderate soil strength.

a. Enable roots to enlarge some pores, otherwise too small.

4. Must have the combination of available water and an extensive, diffuse root system.

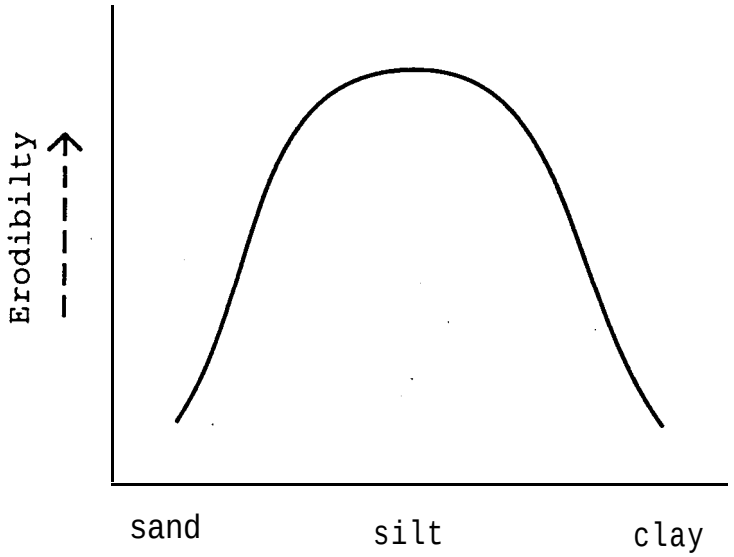
a. Rooting problems:
1) Shallow - - deeper water can not be exploited.
2) Rootsystem not diffusely distributed, confined to mats in widely separated fissures.
3) Poorly branched, flattened, contorted.

F. Erosion hazard

1. erodibility of the surface soil.

a. particle size distribution

1) (figure on next page)



b. surface organic matter levels

2. Run-off rates

a. infiltration rates
b. slope
1) gradient
2) length
3) shape
c. climatic factors

G. Soil Water Behavior. - - - Reference: R.M. Dixon and A.E. Peterson. 1971. Water infiltration control: a channel system concept. Soil Science Society of America Proceedings 35:968-973.

Intuitive approach, pedologic perspective.

1. Soil performance - - potential productivity of Midwestern crop land largely determined by water storage and behavior.

a. storage
b. conductivity
c. saturation
d. trafficability
e. root development

2. Water moves in and is stored in soil pores.

a. Water behavior determined by:

1) Pore characteristics.
2) Character of soil particle surfaces.
3) Osmotic effects;

3. Characteristics of soil pores.

a. Pore volume (porosity).

b. Pore size (size distribution).

c. Pore shape.

1) Cross section.

2) Bottle necks.

d. Pore continuity.

1) Discontinuities.

a) dead ends (drastic change in pore size).

b) bottle necks - - restrictions, narrowing.

e. Tortuosity.

4. Pore characteristics controlled by:

a. Particle size distribution.

1) Marble demonstration - - effect of particle size range on potential bulk density/porosity.

b. Soil structure.

1) aggregation
2) compaction

5. Soil development effects on pore characteristics:

a. Soil structure.

1) Wet-dry stresses.
2) Freeze-thaw stresses.
3) Root disturbance.
4) Fauanal activity.
   a) earthworms
   b) crayfish
   c) burrowing animals
5) Leaching of carbonates from calcareous loess.
6) Clay formation.
7) Clay translocation.

6. Water movement.

a. Direction.

b. Rate.

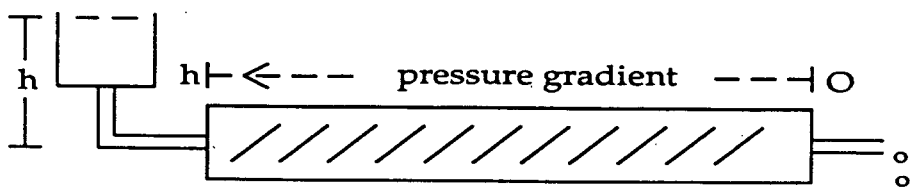
c. Flow - - response to a force gradient.

1) Gradient = rate of change in potential over distance.

Gradient = (potential difference)/distance

2) Potential - - amount of work the water is capable of doing upon moving to a pool of water in the reference state.

3) Flow rate is proportional to force/resistance.



Pressure decreases along the length of a soil column experiencing water flow.

4) Analogous to $I = V/R$ in electricity.

d. Driving forces pertaining to water movement.

1) gravity

a) pressure gradient

2) capillary - - intermolecular attractions - - adhesion & cohesion.

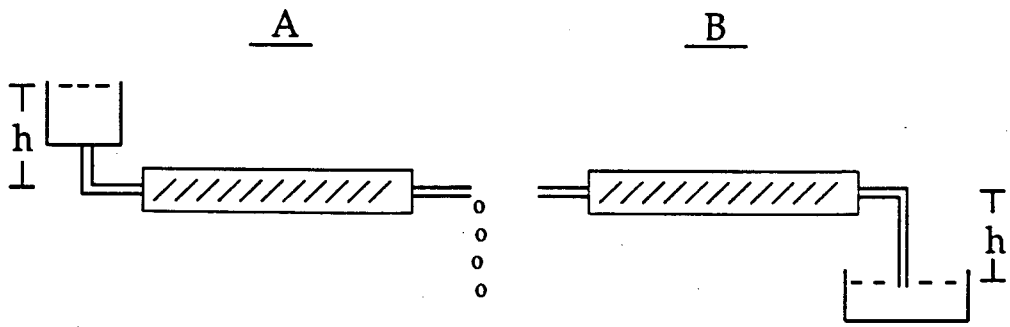
a) tension gradient (negative pressure)

3) osmotic

a) osmotic gradient

e. water potential - - expresses the balance of all driving forces.

f. Pressure vs. tension.



1) Start with both soil systems saturated, then allow flow to begin. Water at the elbow in system A is under h cm. of water pressure. Water at the elbow in system B is under h cm. of water tension. It is convenient to express h in centimeters of water, representing the length of the perched, or hanging, column of water.

g. Types of flow ****.

1) Saturated flow - - most or all pores filled with water (other than trapped air).

   a) Gravity is the principal driving force, flow generally responds to a pressure gradient.

   b) Net direction is downward. Artesian type phenomena might cause localized upward movement.

   c) Air-water interface needed for capillary tension is lacking.

   d) Effect of pore size.

      1- no effect on the driving force.

      2- greatly affects resistance.

         resistance α $1/R^4$

      3- consequently, flow rate decreases rapidly as pore size decreases.

      4- saturated flow rate, sand > loam > clay

   e) saturated flow is largely full-pore flow.

2) Unsaturated flow - - larger pores contain air, primarily film flow & some small pores yet water filled.

a) Capillary (intermolecular) forces are the principal driving forces, water flows in response to a tension gradient.

b) Gravity does act, either to enhance flow or to resist flow. Gravity may be quite significant in a relatively wet soil, but is overwhelmed by intermolecular forces in a relatively dry soil.

c) Flow can be in any direction. Water moves from low tension zones to high tension zones, until any remaining tension gradient is only sufficient to off-set the effect of gravity (potential gradient = 0). Given a uniform pore size distribution, that means that water moves from relatively moist areas to relatively dry areas.

d) Effects of pore size.

l- driving force increases as pore size decreases.

2- resistance:

a- in the wet (low tension) range, small and very large pores increase resistance.

b - in the moist (intermediate tension) range, large pores increase resistance.

e) relative flow rates:

l- wet range, sand > loam > clay

2- moist range, loam > clay > sand

3- water tends to form a rigid ice-like structure when the films are drawn thin around clays.

h. Free water surface - - point at which water is under zero relative pressure, no pressure, no tension.

1) water table.
2) perched water table
3) saturation zones

i. Water table - - a free water surface, a convenient reference level, saturated below, unsaturated above.

j. Capillary fringe - - the soil layer immediately above the water table which is wet due to capillary forces pulling or holding water up from the water table.

k. The relationship between soil water content and soil water tension.

$$\theta = \text{water content} = \frac{\text{mass of water}}{\text{mass of soil}}$$

1) For a given soil medium, there is an inverse relationship between water content and the tension at which it is-held (unsaturated soil).

a) add water to reduce tension.

b) extract water to increase tension.

2) For an unknown soil medium, θ reveals little about the tension at which that water is held.

1. The direction of water flow is determined by the soil water potential gradient, not any water content gradient.

1) Knowledge of differences in soil water content between two soils is generally not readily translatable to differences in soil water potential, because of possible differences in the pore characteristics to the two soils.

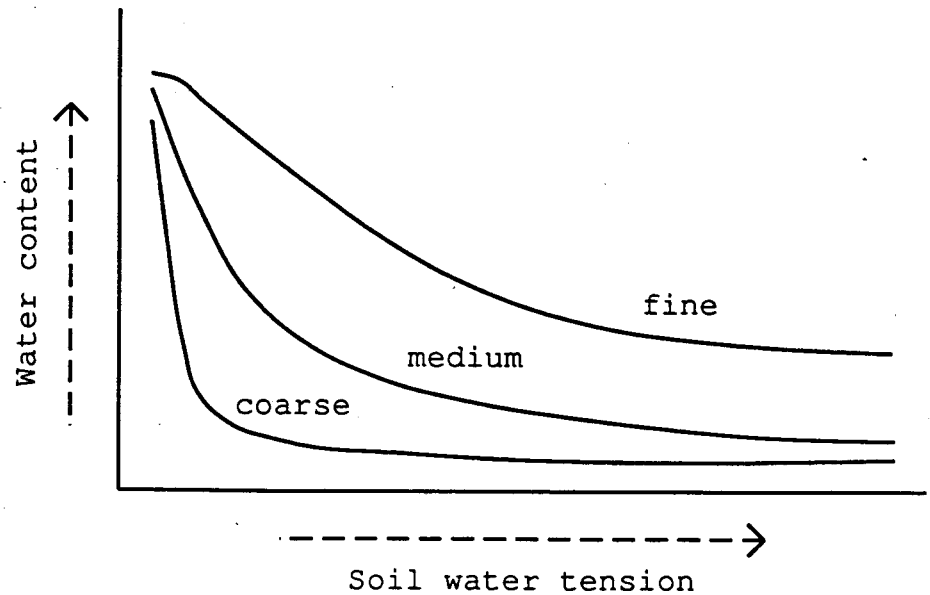
m. Soil water content is interesting, but not the whole story.

1) Soils treated in similar ways might have very different water contents.

2) Plant performance can be very different in soils having the same θ.

3) Soils having the same θ can experience flow from one to the other when they are put in contact.

n. Soil moisture characteristic curves (moisture release curves) - - express the relationship between θ and tension. Consider the three curves on the following graph to be soil moisture characteristic curves for three different soils a fine soil, a medium textured soil, and a coarse soil.



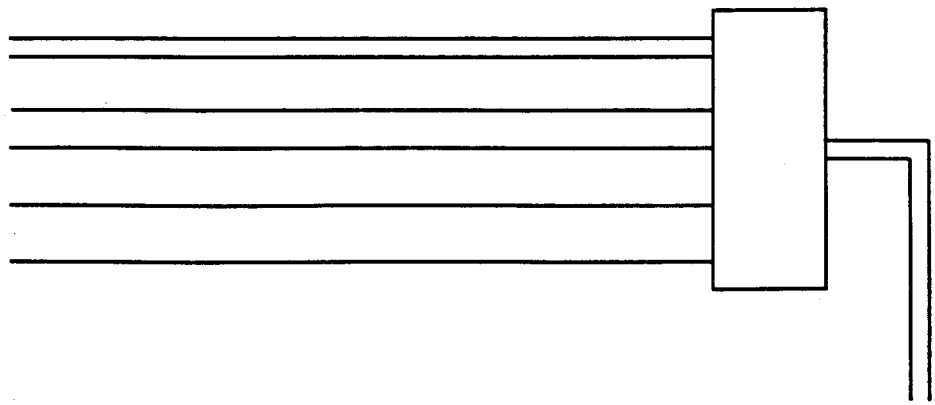
1) water is extracted as tension increases, through:

   a) progressive evacuation of increasingly larger pores

   b) progressive thinning of remaining moisture films on solid surfaces.

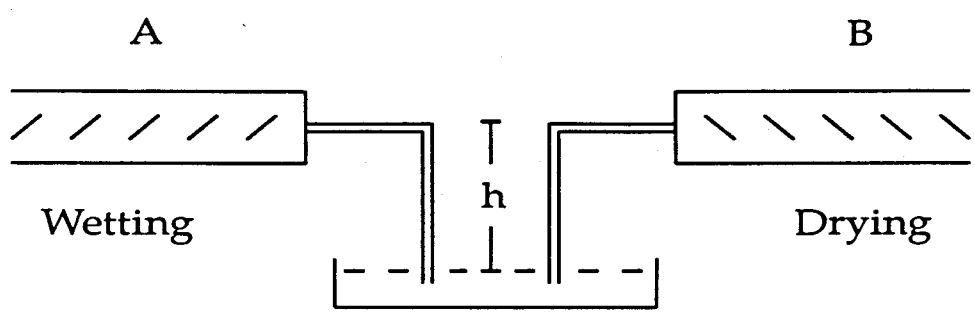
2) If slowly increasing tension were applied to the outlet tube in the following system, water would begin to be extracted only when the tension became sufficient to overcome the meniscus in the largest tube, then that tube would be completely emptied. Flow would begin again only when tension became sufficient to overcome the meniscus in the next

largest tube, whereupon it would be completely evacuated, etc. Consider this only a crude, analogy, of the way water behaves in soil systems.



o. Equilibrium soil water retention.

Assume two identical soil media, A and B, both the same distance (h cm.) above a free water surface.

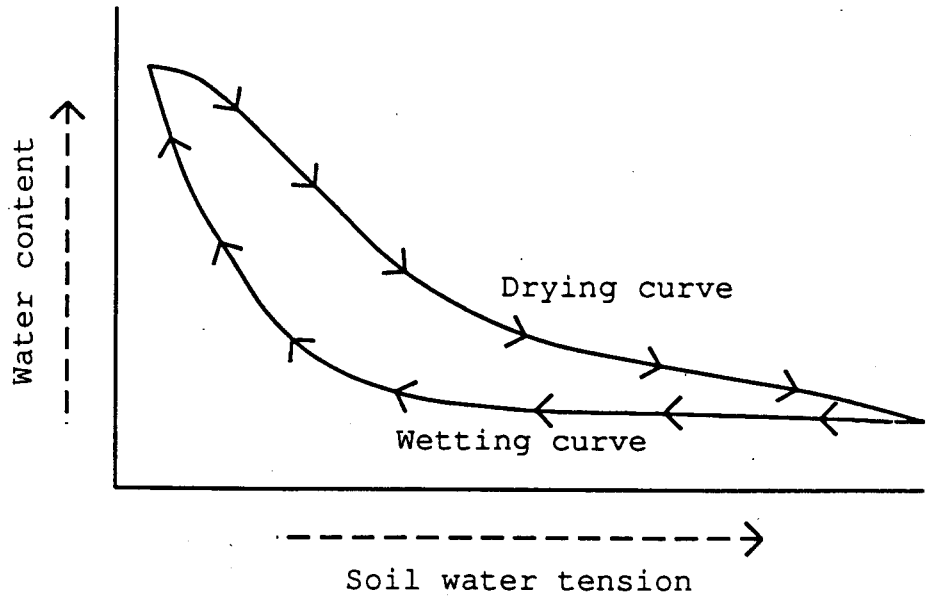


Assume that B is initially saturated and A is initially dry, but in contact with the water in the water filled tube connecting it with water in the bowl. Now open hypothetical valves in the tubes to both soil columns so that water can flow out of soil B to the bowl and from the bowl to soil A. Allow time for both systems to equilibrate. How will the two then compare?

1) In terms of soil water tension?

2) In terms of θ?

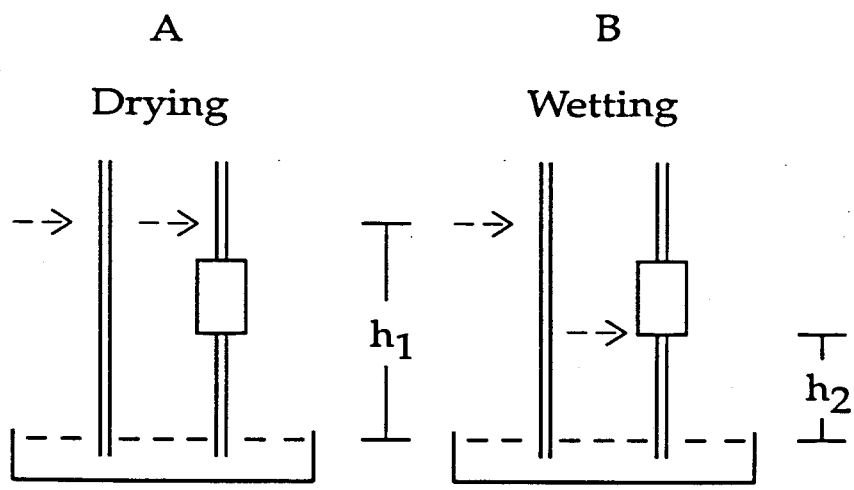
p. Hysteresis - - the discrepancy between wetting and drying curves for a given soil. The equilibrium θ at any given soil moisture tension is normally lower if tension is decreasing after having been higher than if tension is on the increase.



q. Mechanisms for hysteresis - - consider the two identical capillary systems as below. The enlarged section in the right tube of each pair represents a capillary discontinuity. Assume that in system A you start with both tubes full of water. Upon removing your fingers from the top end of each tube they would both drain to the same level, assume that level marked by the arrows, at which the the length of the remaining water column (h_1 cm) was just sufficient to balance the intermolecular forces associated with a water meniscus in a capillary tube of that diameter. The enlarged section in the right tube would not affect the level to which it would drain, providing that the meniscus did not reach that section of the tube.

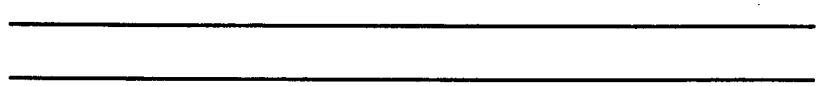
Now assume that you start system B with both tubes empty and allow them to fill from the dish below in response to capillary forces. The left tube would fill to h_1 , the same level to which both tubes drained in A. But, the right tube

would fill only to h_2, because capillary forces could not support a longer column of water than that with the meniscus in the enlarged section of the tube.



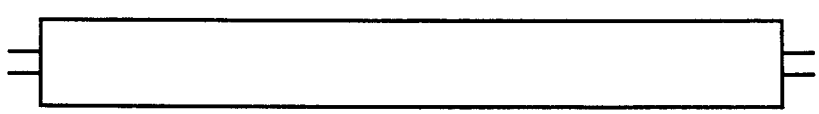
1) If soils were ideal porous media as illustrated in m.2 above, one might expect hysteresis effects to be minimal, but most soils are loaded with capillary discontinuities which produce effects similar to those illustrated above.

   a) uniform pore in contact with the reference level.



   Flow would begin only when tension increased to the level at which it would overcome capillary forces in this pore, then it would evacuate completely without further increase in tension. The pore would refill when tension again fell below that level.

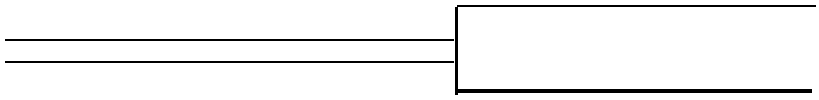
   b) Pores with bottle necks. Interped pores might commonly have constrictions at both ends due to clay coatings on ped surfaces.



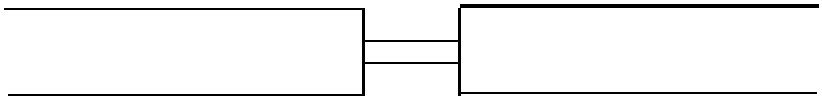
   The pore would remain full until tension became sufficient to overcome the meniscus in the constriction at the outer end of the pore, whereupon it would empty completely. The pore

would not refill until tension dropped below the level which could be supported by a meniscus in the large section of the pore.

c) Pore size discontinuities.



Fine intraped pores connecting to large interped pores.



Pore constrictions along their length.

Critical tension determined by the location of the meniscus.

r. Ideal pore arrangement in soils.

1) Continuous network of large pores to serve as a plumbing system and to provide aeration. (interped pores?)

2) Intersecting network of fine pores - - to sop up water as it moves through the macropores, to store store it for subsequent uptake by plant roots. (intraped pores?)

s. Equilibrium water content of a soil at any given soil moisture tension depends on:

1) Effective pore size distribution and pore continuity.

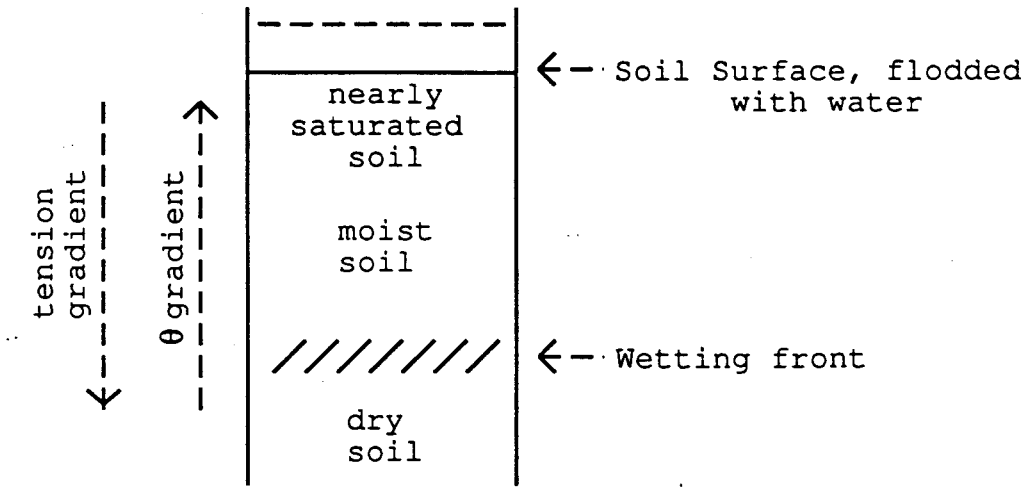
2) Composition of the soil (including the soil solution).

3) Temperature of the soil.

4) Whether the soil is wetting or drying.

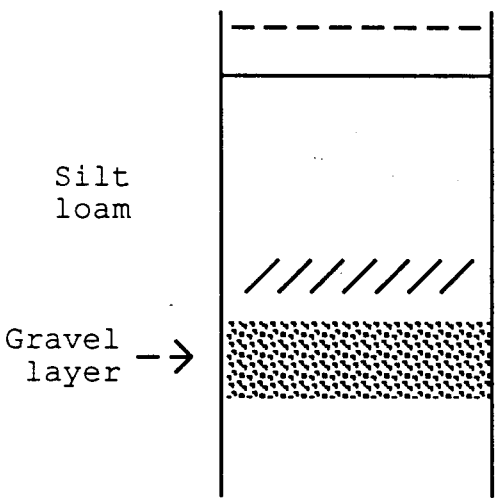
7. Water behavior in real soils.

a. A uniform silt loam - - consider what happens after a dry, uniform silt loam soil is flooded with water.



Upon flooding a dry soil, water would begin to move into the dry soil under the combined effects of capillary forces and gravity. Near the wetting front, capillary forces will predominate, water content will be low, resistance will be high, and the tension gradient will be very steep. Moving back from the wetting front, water content increases, resistance decreases, and the tension gradient decreases. As the tension gradient decreases, gravity becomes a more significant factor in determining flow. If one were to quit adding water to the surface, downward movement of water would continue until equilibrium was established.

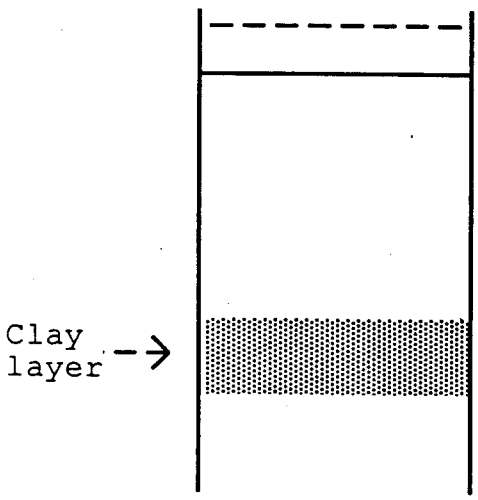
b. Stratified soils - - consider water behavior upon flooding a soil having a gravel layer.



Upon flooding the surface, the wetting front would move downward as above until it reached the gravel layer. Then it would stop, but water would continue to move downward to that point, slowly increasing water content and lowering the tension at which the water is held. When the soil above the gravel layer becomes nearly saturated and the tension falls to near zero, water will move freely across the interface and into the gravel, under the force gravity.

Movement of the wetting front down to the gravel is in response primarily to capillary forces. The capillary forces are minuscule in the gravel layer, hence forward movement of the wetting front ceases until the soil is nearly saturated, so that gravity can move water across the interface and into the gravel. The gravel layer (interface) is a barrier to unsaturated flow, but does not in any way inhibit saturated flow.

c. Clay layers - - consider the behavior of water upon flooding a soil having a clay layer.



Water will move readily into the clay layer when it is reached by the wetting front. There will actually be a temporary acceleration of the wetting front when the clay is reached, because of stronger capillary forces therein. They clay will soon begin to inhibit flow because of low conductivity/high resistance.

Clay layers tend to perch free water temporarily, because of low saturated hydraulic conductivity. Frequent saturated-moist cycles above clay layers are common (fluctuating perched water table).

8. Available soil water.

a. Method.

1) Estimate water content of soil that has been wet up such that water passes completely through the soil, and allowed to drain freely until the rate of downward movement decreases substantially. The remaining water content of the soil may be considered the upper limit of available water (field capacity).

a) Water movement never really stops (equilibrium is never really achieved), hence the "substantial decrease in rate" language.

2) Estimate the amount of water held so tightly that it cannot be extracted by plants. Consider the

water content at that point (the permanent wilting point) to be the lower limit of available water.

3) The difference between 1) and 2) is the amount of water available to plants (available water storage capacity).

b. Field capacity - - concept defined by Veihmeyer & Hendricksen. Soil Science, 32:181-193--1931, and 68:75-95--1949.

1) Field capacity - - the amount of water held in the soil after excess gravitational water has drained away and after the rate of downward movement of water has materially decreased.

2) 1/3 bar convention - - widely used. Is it conceptually sound? It is based on the following assumptions:

a) Uniform silt loam soil and no capillary discontinuities.

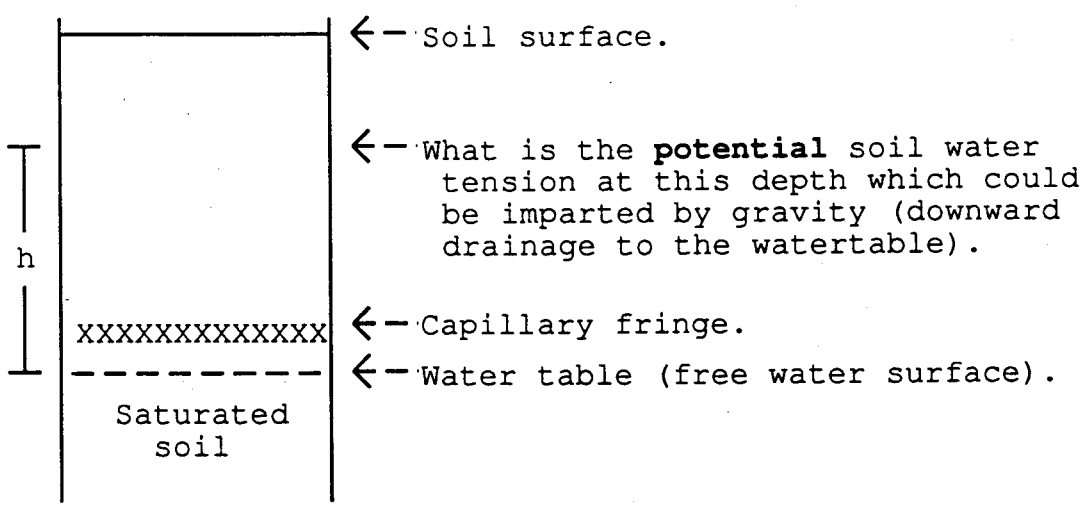
b) Deep water table (or none), or dry soil above any water table.

3) The above assumptions do not apply for many soils.

a) Pore size discontinuities.

b) Shallow water table.

4) Effects of a shallow water table on potential soil moisture tension due to gravity (downward drainage of water in response to gravity).

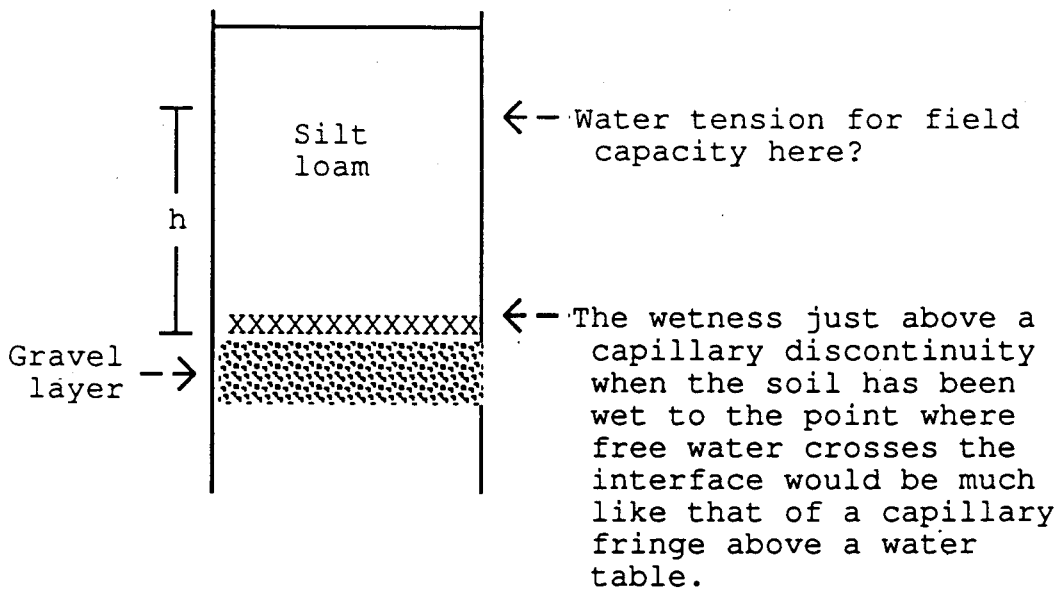


Assume that the above is a uniform silt loam soil with a water table at 110cm. Apply water to the surface to saturate the soil such that water begins to drain down to the water table in response to gravity. Stop applying water and allow the soil to drain for a few days until the rate of downward movement materially decreases. Assume that the water table now stands at 100cm depth. If h = 50cm, no more than 50cm of water tension could be imparted on the water at the depth represented by the arrow above. The actual tension might well be less than 50cm of water, due to capillary discontinuities, etc., but no greater tension could be established at that depth through drainage in response to gravity.

One third bar would be about 330cm of water tension, hence such would be clearly be inappropriate for use in estimating field capacity in such soils. There can be a significant amount of water held between 50cm and 330cm of tension. There can be no assurance that 50cm tension is precisely the correct level to use in measuring field capacity for this soil at that depth, but we can be certain that the appropriate tension level is not higher than that.

Vast acreages of Illinois soils have a high water table in Spring and early Summer (the critical period for calculating available water storage capacity). Most of our poorly drained soils have drainage tile to control the water table at 0.5m to 1.5m during that period. Where tile continue to run well into the growing season, that is clear evidence that the one third bar convention would underestimate the field capacity water content for those soils. The one third bar convention would clearly underestimate available water for all such soils.

5) Medium textured soils with gravel or sand layers.



The potential tension gradient from free drainage through a sand layer would be very much like that above a water table. Tension must drop to very near zero before water will cross the interface from the finer to the coarser material, establishing a defacto free water surface at each such discontinuity. Again h cm of water tension would be appropriate for estimating field capacity at the depth of the arrow (at least much more so than l/3 bar).

a) What would be the implications of water crossing the interface from a coarse material into a finer material?

c . Measuring water content at the dry end of the available water range - - the permanent wilting point, the 15 bar convention.

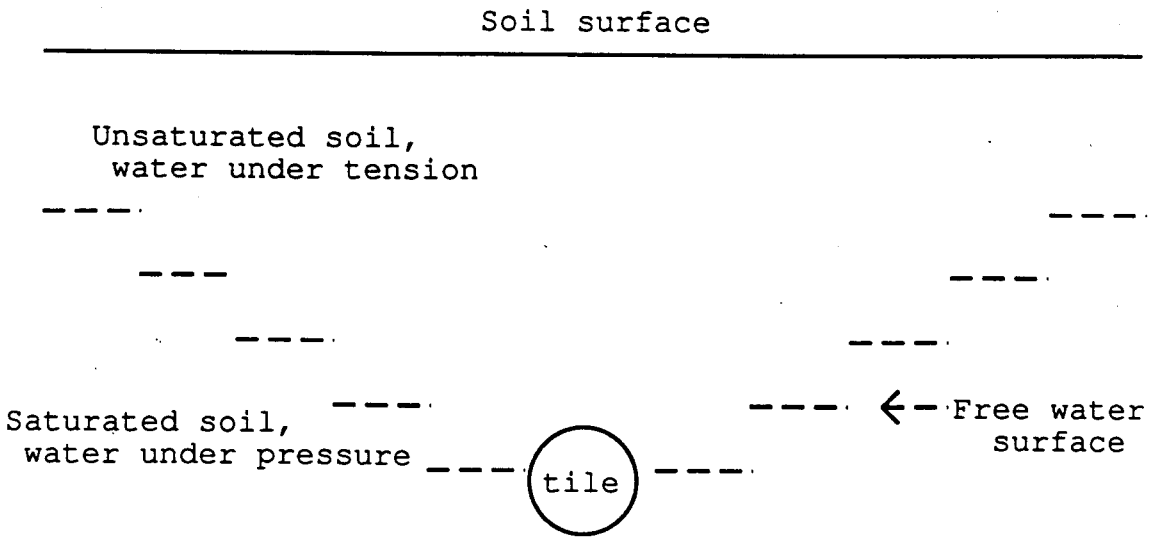
1) Yield loss occurs long before the permanent wilting point.

2) Actual permanent wilting point varies considerably with temperature, relative humidity, air velocity, etc.

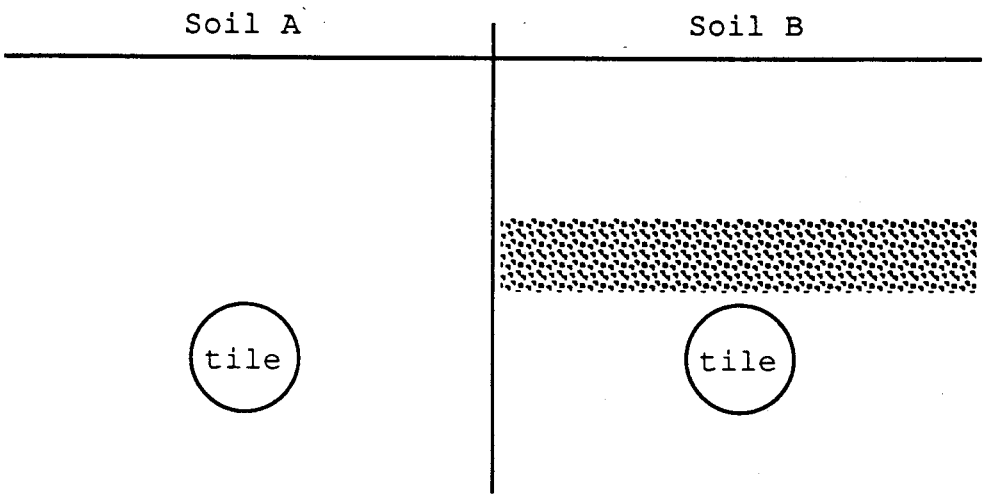
3) Useful as a reference point for comparing the capacity on one soil to another, but certainly lacks precision for predicting the exact amount of water that will be available for a given soil when climatic conditions can not be precisely predicted.

4) Substantial changes in the tension at which the dry end θ is measured generally causes only small changes in the θ measured, there just isn't that much water held under such high tensions. Near the wet end of the available water range, changes in the critical tension level are associated with much greater changes in θ.

9. Water table draw down by subsurface drainage tile.



10. Effects of coarse layers on tile drainage.



Assume that you start with both soils dry and begin to apply water to the surface. Consider the differences in water behavior between soil A (a uniform silt loam) and soil B (having a gravel layer above the tile).

a. In which soil would you expect the wetting front to reach the tile first?

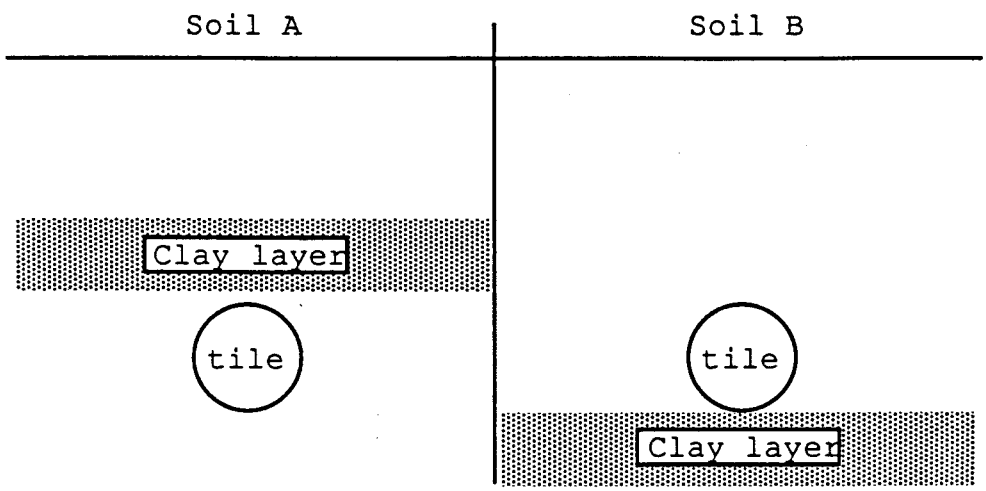
b. In which soil would you expect the tile to run first, all other factors being constant?

c. What effect would you expect the sand layer to have on the performance on the tile system?

d. What would be the effect of a gravel layer below the tile instead of above it?

Bare in mind that tile are installed to remove free water. The tile is in effect a very large pore which outlets to the atmosphere. Gravity is the only force available to move water into the tile. Water under tension will not enter a drainage tile. Saturated flow predominates in water moving to drainage tile.

11. The effect of fine layers on the performance of drainage tile.



a. Consider the effects of the clay layer on performance of the drainage tile for both soil A and soil B.

b. How do the effects of clay layers differ from the effects of coarse layers, and why?

12. Additional applications.

a. Significance of a water table in increasing the water available for plants.

1) The conventional wisdom has it that upward movement of water from a free water surface in response to capillary forces is imperceptibly slow, hence the presence of free water doesn't contribute much.

a) Must consider that the soil above the water table might in some cases have a higher field capacity θ because of the presence of the water table.

b) Must consider that roots will likely penetrate the capillary fringe and take up water from very close to the free water surface.

c) The somewhat poorly drained member of drainage catena's are generally the highest yielders in Illinois.

b. Consider a stratified mound cover to'isolate toxic material.

1) Would it be useful to include a gravel layer between two fine textured layers?

2) Would isolation be improved by adding tile just above the coarse layer?

c . Consider the frost heave phenomenon - - what role might a gravel layer play in controlling the problem?

d. Consider back-filling a tile trench (tile 1 m deep) with gravel to improve conductivity to the tile, then plowing across it so that the gravel becomes separated from the surface by a fine textured plow layer. How effective would the gravel be?

1) Forces - - gravity to move water into the tile.

2) Pore pressure - -the tile will serve as a vent to the atmosphere.

3) If the soil has equal pore characteristics all the way down, the 1 m head might keep the gravel from functioning.

4) An impermeable layer between the tile and the surface soil, or swamping of the pore network around the tile could make the gravel somewhat effective.

13. The Dixon and Peterson paper,

a. Saturated water flow is vastly more efficient in large pores.

1) Flow is proportional to l/r4 .

2) A lmm pore conducts water 10,000 times faster than a O.lmm pore.

b. Large pores are effective in conducting water only when they are open to the soil surface.

1) Capillary forces pull water into the finer pores.

2) Air concentrates in larger pores, building up a positive pore pressure that must be overcome for water to enter them (large pores are blocked first at relatively low pore pressures).

a) Large pores must be open to the surface for gravitational water to enter them readily.

b) Large pores must be open to the surface to enable them to vent air and prevent the build up of pore pressure.

c) Drainage tile can function to vent air as well as to conduct water away.

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Soil Structure and Associated Rooting Behavior in Minesoils

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Soil Structure and Associated Rooting Behavior in Minesoils[1]

K. MCSWEENEY AND I. J. JANSEN[2]

ABSTRACT

The objective of this study was to identify and describe soil structural patterns and rooting behavior in reclaimed minesoiis. The soil chosen for this study consists of approximately 0.4 m of topsoil (A horizon) material placed on approximately 1.5 m of 8 blend of B horizon, mixed paleoloesses Sangamon paieosol, and Illinoian till. Four soil pits were excavated, exposing root systems of the corn test crop. Detailed soil and root pattern descriptions were made in each pit. Root patterns were depicted using the profile wall method. An outline of soil structural pattern was superimposed over the root pattern to provide a pictorial relationship between the two. Differences in the physical condition of subsoils were distinguished on the basis of the soil descriptions and statistical analysis of the root length determinations. An artificial soil structure was characterized and attributed to particular mining and reclamation practices. The structural arrangement consists of rounded aggregates loosely compressed together, that fall within the size classes currently used for blocklike and polyhedral aggregates Plant rooting was distinctly more profuse where this structure was present than where the soil material was massive and compact. It is proposed that structural differences among newly constructed soils are of such significance that they should he carefully characterized and described, and what appropriate used for series level separations. Operations using a mining wheel in combination with belt transportation favor tbe formation of the more desirable fritted structure whereas operations using scrapcn exclusively favor the formation of the less desirable massive pbysial condition.

Additional Index Words: Surface mine reclamation, soil mixing disturbed soils, corn root growth, fritted structure.

McSweeney. K., and I. J. Jansen. 1984. Soil structure and associated rooting behavior in minesoiis. Soil Sci. Soc. Am. J. 48507-612.

EARTH MOVING OPERATIONS carried out during SF face mining result in considerable alteration the structure of premine soils. The resultant co structed minesoil, although showing some relict stn ture from its precursor, typically exhibits a physic

[1] Contribution from the Dep. of Agronomy, Univ. of Illinois, Urbana-Champaign Urbana, IL 61801. Received 21 June 1983. Approved 28 November. 1983

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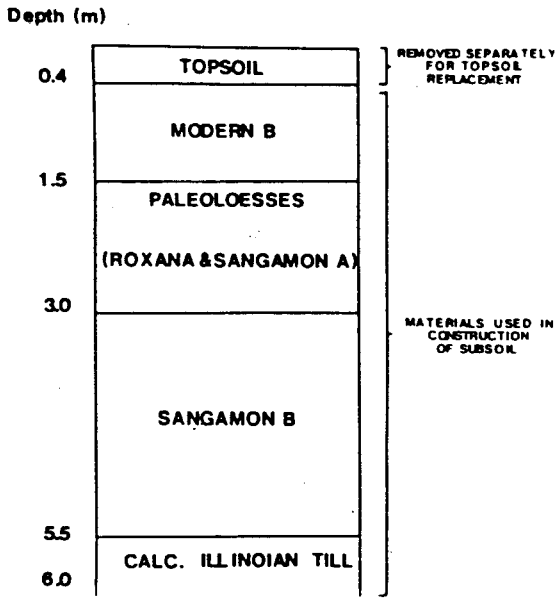

Fig. 1—Idealized profile of high wall showing materials used in construction of A/6 m treatment.

condition dominated by features attributable to the soil construction operation, rather than from the influence of natural soil-forming processes.

Pits excavated in constructed soils at a mine site in southern Illinois revealed considerable variation in soil physical condition and associated rooting behavior. Traditional schemes of soil structure classification were inadequate to describe some of the patterns and features observed in these newly constructed soils.

Soil physical condition is extremely important in influencing soil productivity. It is essential, therefore, that these important differences in physical condition occurring in constructed soils be adequately described and used to assist in classification, mapping, and land use interpretation. Soil series separations can and should be made on the basis of these recognizable structural differences (S. J. Indorante and I. J. Jansen, Perceiving and defining soil units on disturbed land; in review for the Soil Sci. Soc. Am. J.).

The object of this study was to identify and describe soil structural patterns and associated rooting behavior unique to certain types of reclaimed soils. Terminology for describing observed forms of artificial structure is proposed. A new term, *fritted*, is proposed and described.

MATERIALS AND METHODS

A set of experimental plots consisting of six soil treatments was constructed at the Captain Mine, Perry County, IL, to evaluate various combinations of substratum and A and B horizon materials for row crop production. It was possible using a mining wheel (Chironis, 1978, p. 51) to blend varying increments of soil and unconsolidated substratum materials for use in soil construction. An idealized profile of the materials used in this study is shown in Fig. 1.

The soil treatment referred to as A/6 m mix selected for this study consists of approximately 0.4 m of topsoil (A horizon) placed over approximately 1.5 m of a blend of B horizon, mixed paleoloesses, Sangamon B paleosol, and Illinoian till. The constructed subsoil blend corresponds to

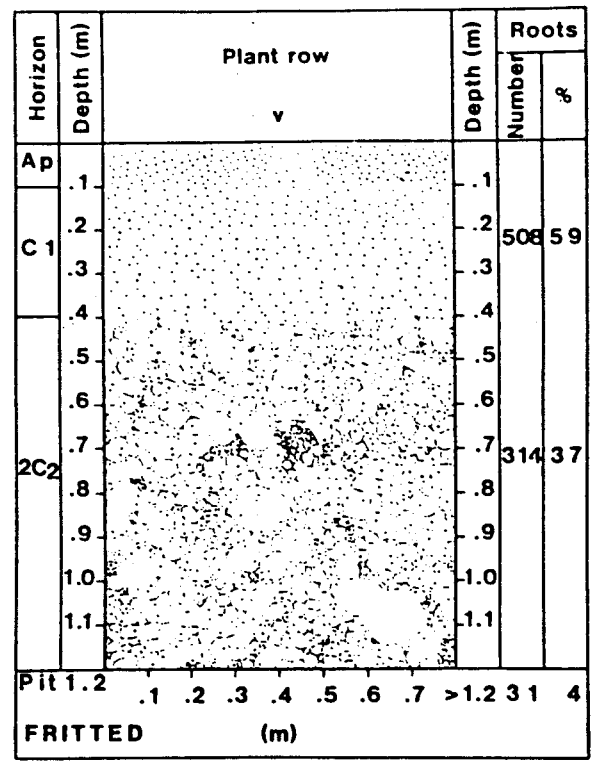

Fig. 2—Diagrammatic representation of fritted structure and associated rooting pattern made in pit 1. [One dot (•) represents a 0.005-m root length seen on the profile. The position of the corn stalk in the plant row is indicated by *V*.]

approximately a 6 m deep lift of material taken by the mining wheel at the pit face. Materials very similar to those used in this study have been evaluated and described in detail by McSweeney et al. (1981) and Snarski et al. (1981). Selected morphological descriptions of subsurface horizons and a replaced topsoil horizon are shown in Table 1.

Soil pits (4 m by 2 m by 2 m deep) were excavated in each of the four replications of the A/6 m mix treatment. The location of pits was restricted to plot borders in order to cause minimal disruption to other experiments being carried out at the experimental site. The location of plot end was determined randomly and pits were located sufficiently far into the plots, such that edge effects were minimal. In all of the plots examined, corn (*Zea mays* L.) was the test crop. Two corn hybrids, FR MO17 × FR B73 and FR MO17 × B84 were planted 29 Apr. 1981, in rows 0.76 m apart. The pits were aligned across the rows such that the sphere of rooting of at least two corn plants was easily accessible.

Detailed soil (Table 1) and root pattern (Fig. 2, 3, and 4) descriptions were made in each pit according to the methods of the Soil Survey Staff (1951) and Böhm (1976). Böhm's method of in situ root length estimation was modified to provide a pictorial relationship between rooting behavior and soil structure. A 0.05-m by 0.05-m grid pattern was etched directly onto a plexiglass sheet (1.2 m by 0.75 m) which was supported by a wooden frame. For each description a piece of mylar film was secured to the plexiglass. The profile was prepared for root counting by the smoothing and washing methods outlined by Böhm (1976). The exposed roots were depicted on the mylar film by one point for each 0.005-m length seen on the profile (Fig. 2, 3, and 4). Roots of 0.01, 0.02, or 0.03 m in length were indicated by two, four, or six points, respectively. The main structure lines of the material below the replaced topsoil (Ap and C1) were then superimposed over the rooting pattern, providing a pictorial relationship between rooting behavior and soil struc-

Table 1—Morphological properties of selected soil horizons.†

Horizon	Depth m	Color	Mottles Pattern	Mottles Color	Texture	Structure	Consistence (moist)	Cutans	Reaction	Boundary	Rooting behavior	Comments
						Replaced surface material						
Ap	0-0.1	10YR 3/2 10YR 4/2	c2d	10YR 5/6	sil	1m&c fgr	friable	none	5.6-6.0	aw	Extensive network of fine lateral and medium and coarse trunk roots.	Inclusion of irregular (0.03-0.1 m) masses of premine B-horizon material. (≅3% of matrix).
C1	0.1-0.4	10YR 3/2 10YR 4/2	c2d	10YR 5/6	sil	1m—fgr 1m & sbk	friable and firm	none	5.6-6.0	as	As above.	As above.
						I. Subsurface mix exhibiting fritted structure						
2C1	0.4-1.5	10YR5/2 10YR 5/4 10YR 5/6 10YR 6/2 10YR 7/2	f2d m2p f2d f2p f2p	10YR 3/2 10YR 3/4 10YR 5/6 7.5YR 4/4 5YR 5/6	sicl, cl, sil & l.	3 f to vc‡ fritted	friable to very friable with increasing depth.	brok. thin and thick clay-org.	range 5.6-8.4 avg 7.4-7.8	aw	No evidence of root zones, extensive penetration of aggregates. Dominant vertical trend to rooting pattern.	Composite of materials from subsoil and substratum aggregates covered in coats of variagated material (≅ 0.001-0.002 m thick), few coarse pebbles.
						II. Subsurface mix exhibiting massive physical condition						
2C2	0.4-1.05	10YR 5/4 10YR 5/6 10YR 6/2 10YR 7/2	f2d f2d f2p f2p	10YR 3/2 10YR 5/6 7.5YR 4/4 5YR 5/6	sicl, cl, and l.	m	very firm to firm with increasing depth.	brok. thin and thick clay—org.	range 5.6-8.4 avg 7.9-8.4	ci	Roots flattened in cross-section, distribution limited and confined to vertical cracks and other planes of weakness.	Matrix dominated by Illinoian till and Sangamon B paleosol (>80%), few coarse pebbles.
2C3	1.05-1.52	10YR 5/2 10YR 5/4 10YR 5/6 10YR 6/2	f2d f2d f2p f2p	10YR 5/6 10YR 5/8 7.5YR 4/4 5YR 5/6	sicl, cl, sil and l.	3 f to vc fritted	friable	brok. thin and thick clay—org.	range 5.1-8.4 avg 6.7-7.3	aw	No evidence of rooting.	c.f. fritted material above.
						III. Subsurface horizon exhibiting massive physical condition and fritted structure						
2C2	0.40-6.4	10YR 5/2 10YR 5/3 10YR 5/4 10YR 6/2	f2d f2d f2p f2p	10YR 3/2 10YR 5/6 7.5YR 4/5 5YR 5/5	sicl, cl, sil and l.	m breaking laterally to 3m-vc fritted.	v. firm breaking laterally to firm	brok. thin and thick clay—org.	range 5.6-8.4 avg 7.9-8.4	gi	Rooting limited in massive material, but extensive and unrestricted in fritted material.	c.f. fritted and massive materials above.
2C3	0.64-0.95	10YR 5/2 10YR 5/4 10YR 5/6 10YR 6/2 10YR 7/2	f2d f2d f2d f2p f2p	10YR 3/2 10YR 3/4 10YR 5/6 7.5YR 4/5 5YR 5/5	sicl, cl, sil, and l.	m breaking laterally to 3m-vc fritted.	firm breaking laterally to friable.	brok. thin and thick clay—org.	range 5.1-8.4 avg 7.4-7.8	gi	As above.	As above.
2C4	0.93-1.47	10YR 5/2 10YR 5/3 10YR 5/6 10YR 6/2 10YR 7/2	f2d f2d f2p f2p	10YR 3/4 10YR 5/6 7.5YR 4/5 5YR 5/6	sicl, cl, sil, and l.	3 f to vc fritted.	v. friable	brok. thin and thick clay—org.	range 5.1-8.4 avg 7.4-7.8	aw	No evidence of root restricting zones, extensive penetration of aggregates. Dominant vertical trend to rooting pattern.	As above.

† Coded according to Soil Survey Staff (1951, p. 139-140). Colors are Munsell notations (Soil Survey Staff, 1951, p. 195-201).
‡ Class of soil structure designated according to same divisions as for blocklike and polyhedral aggregates.

ture. Four root pattern descriptions were made in each pit. Approximately a 0.1-m thickness of material was carefully removed from the pit face prior to the taking of each new description. This provided in a three-dimensional assemblage, the pattern of changes in the root system and structure in each pit.

Differences in root length were statistically analyzed (Table 2) using a completely randomized model. Within treatment, variation of root length was analyzed separately for topsoil and subsoil a priori, because of distinct differences in the two media and their relative proximity to the aerial environment. Selected single degree of freedom comparisons (Table 2) were chosen prior to root length determinations on the basis of observations made while making the soil descriptions.

The study was carried out at the beginning of August 1981, approximately 100 d after planting.

RESULTS AND DISCUSSION

Preliminary observations reveal significant differences in physical condition among subsoils constructed after mining (Fig. 2, 3, and 4). It is crucial that these differences be documented and efficiently mapped so that reclamation methods can be developed that will create the most desirable soil physical condition. Current terminology is suitable to describe some of the artificial (man influenced) physical conditions observed in newly constructed soils, but other

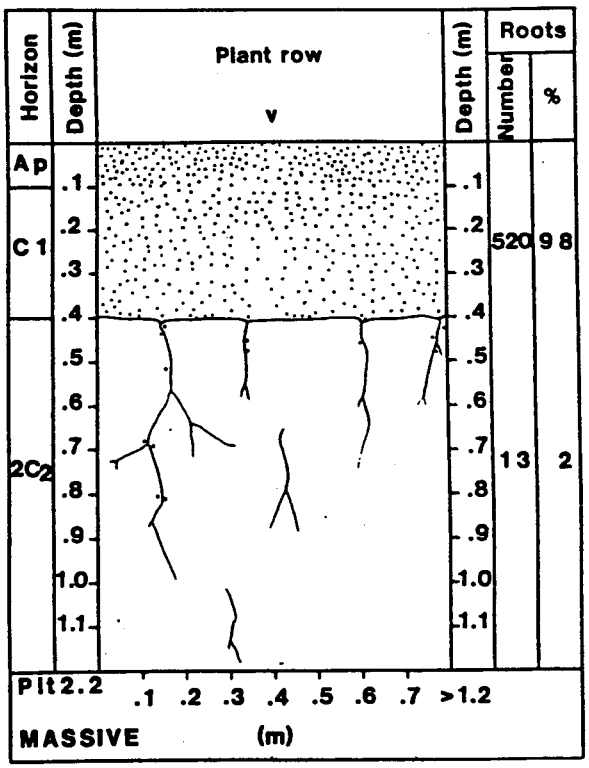

Fig. 3—Diagrammatic representation of massive physical condition and associated rooting pattern made in pit 2. [One dot (•) represents a 0.005-m root length seen on the profile. The position of the corn stalk in the plant row is indicated by *V*.]

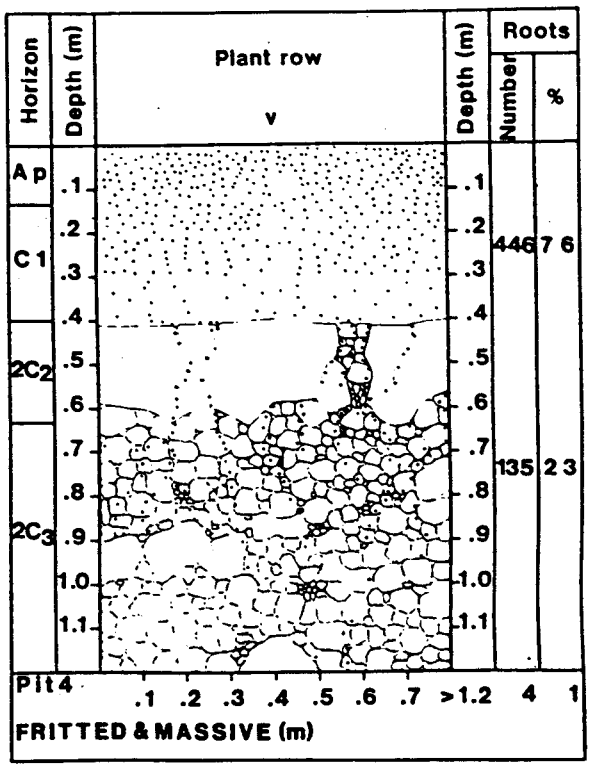

Fig. 4—Diagrammatic representation of the combination of fritte structure and massive physical condition and associated rootin behavior made in pit 4. [One dot (•) represents a 0.005-m roo length seen on the profile. The position of the corn stalk in th plant row is indicated by *V*.]

artificial physical conditions are different from anything found in natural soils.

The character of the subsoil structure is strongly influenced by the method of mining and reclamation used at this mine. Unconsolidated material is dug by a mining wheel, transported by a conveyor belt, and placed on the reclamation site with minimal grading. The material is subject to trundling during transport along the conveyor belt. The degree to which aggregates are trundled on the belt depends on a number of factors, including aggregate size and moisture content. Aggregate size is largely a function of the natural structure and cohesiveness of the individual materials.

The trundling action of the belt results in smoothing

Table 2—Analysis of variance of root length.

Pit	Subsoil structure	df†	Topsoil	Subsoil
			Mean root length/0.005 m‡	
1	Fritted		509.00	347.50
2	Massive		504.50	17.25
3	Fritted & massive		532.25	164.00
4	Fritted & massive		477.25	185.00
	Error mean square	12	361.2083	1106.1462
	Single degree of freedom comparisons§			
3 vs. 1, 2, & 4			10.37**	
1 vs. 2				200.16***
3 vs. 4				NS
1 vs. 3 & 4				72.15***
2 vs. 3 & 4				59.61***

*,**,*** Significant at $p = 0.05$, $p = 0.01$ and $p = 0.005$, respectively.
NS = nonsignificant.
† df = degrees of freedom.
‡ Means are an average of four root length determinations.
§ Based on mean squares.

and rounding of the smaller aggregates in particula Some of these aggregates also acquire an agglomera tive skin, typically 0.03 m thick, composed of a mi of fine particles from the unconsolidated overburden

The action of the mining wheel and subsequen placement from the belt via a spreader to the lan surface below results in disruption to the natural struc ture of the materials. Thus, the material can arrive a its final destination in varying degrees of disaggrega tion or compaction, depending on the prevailin moisture content, the character of the material i question, and the amount of subsequent grading.

The unconsolidated overburden is composed of variety of materials with differing properties (Fig. 1 The Illinoian till, for example, found 4 to 6 m belo ground surface, is characteristically a dense, massive and calcareous material. This material, being ver coherent, passes through the removal and transpo operation relatively undisturbed. Typically, large di crete masses of this material (> 0.2-m diam) we found in the constructed subsoil. Discrete masses the remaining materials are generally smaller in siz than the Illinoian till aggregates. Notably, the pale loesses which occur just above the Sangamon paleosol are friable in character and disaggregate co siderably upon disturbance.

Following emplacement of the subsoil at the recl mation site, the subsoil surface is selectively levele by bulldozer to produce a suitably flat base for topso replacement. A layer of topsoil approximately 0.4 thick is then emplaced by bulldozer. These two o erations result in varying degrees of compactio

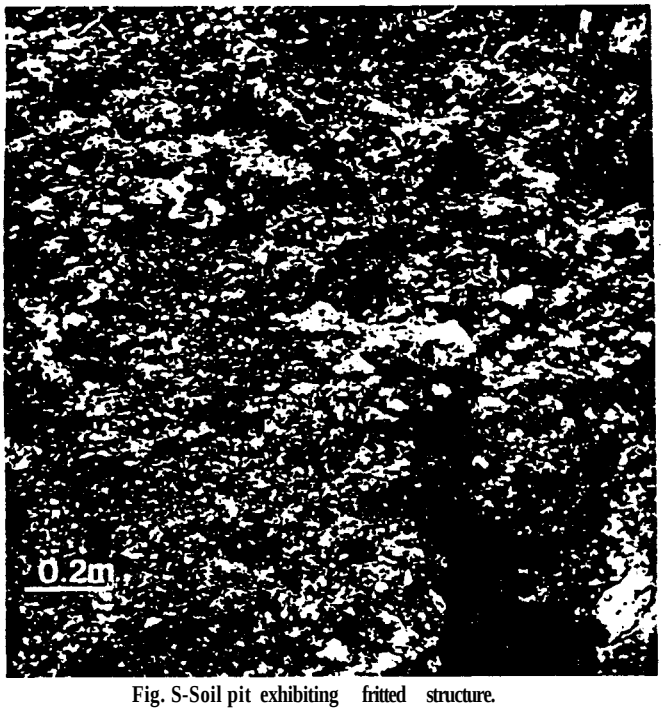

Fig. S-Soil pit exhibiting fritted structure.

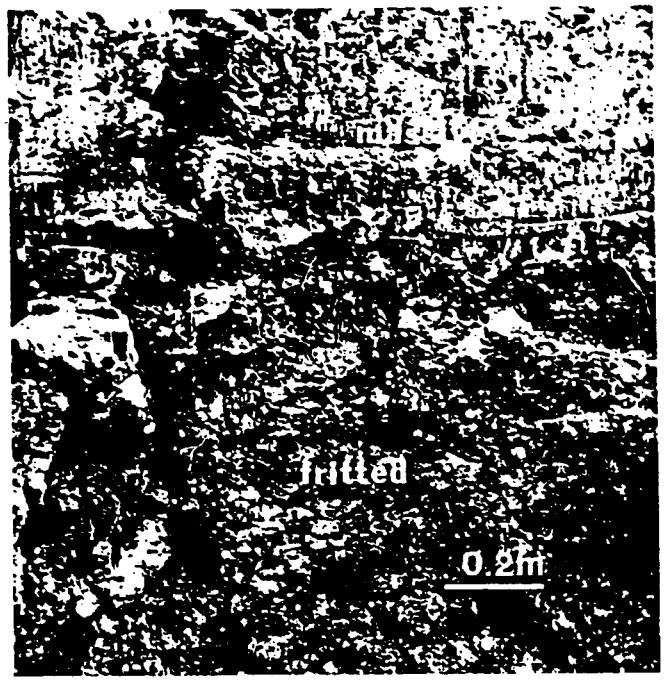

Fig. 6-Soil pit exhibiting the combination of fritted structure and massive physical condition.

around the junction of the topsoil and subsoil. In the four pits examined, considerable variation was observed in composition of the mix and degree of compaction.

Three distinct physical conditions were observed in the constructed subsoils (Fig. 2, 3, and 4). The basis for this division rests on the detailed soil and root descriptions, which are summarized in Table 1 and Fig. 2, 3, and 4, and the analysis of variance of root length (Table 2).

The subsoil structural architecture illustrated in Fig. 2 is defined as fritted[3] This new term is employed to convey the special character of this subsoil, which consists largely (>95% of matrix) of trundled aggregates with agglomerative skins (Fig. 5). The aggregates are loosely compressed together, leaving appreciable void spaces up to 0.02 m wide, and of extensive continuity, perhaps encompassing the whole length of the subsoil profile in places. It is suggested that this structure is coded with the same size designations as for blocklike and polyhedral aggregates, according to the Soil Survey Staff (195 1).

The upper portion of the subsoil (0.05-0. 1 m below topsoil) was somewhat compacted, but this posed little problem for root penetration. Roots penetrated through spaces between the individual compacted aggregates then through and around the aggregates below 0.45 to 0.5 m. Lateral root proliferation seen at the base of the topsoil in other pits was not seen in this pit. There was little evidence of preferred orientation around aggregates below 0.5 m. However, the dominant trend of root growth was vertical, with noticeable lateral root development in and around certain aggregates. This territorial lateral root proliferation suggests localized favorable soil conditions. Sumner and Boswell (1981) have summarized experiments that demonstrate the relationship between root proliferation and favorable nutrient status in the absence of mechanical stress. Root development (Table 2) in the fritted subsoil pit was much more extensive than in pit 2 exhibiting the massive physical condition or pits 3 and 4 with the massive and fritted condition.

The physical condition illustrated in Fig. 3 can aptly be described as massive. There is no structure and mineral grains are bound together into one mass, having only a few desiccation cracks within. This is the most common condition where there has been extensive grading of the constructed subsoil. None of the pits excavated during the summer of 1982 exhibited an exclusively massive physical condition, suggesting that this condition is only of local importance at this research site. It is the dominant condition at other sites where more grading was practiced.

The extensive lateral rooting at the base of the topsoil emphasizes the problem of root penetration into this massive material (Fig. 3). Penetration. was noticeably shallow < 0.35 m) even though the potential root zone was initially moist throughout. Roots were confined to vertical cracks with no appreciable lateral proliferation. Furthermore, roots in this zone were demonstrably flattened and compressed in cross-section. These observations conform with some of the comments made by Taylor (1974) in his review of rooting in vertical cracks and distortion of rooting patterns. Meyer (198 1) has also made similar observations in his study of root growth in a variety of massive constructed minesoils. Root development (Table 2) in this pit was much less than in pits 1, 3, and 4.

The most common physical condition seen during this study and also in pits excavated in the summer of 1982 consisted of a combination of both fritted and massive conditions (Fig. 6). This is a result of considerable localized variability in compaction resulting

[3] *Fritted* is a term coined by the glass industry referring to the partial fusion of components used in glassmaking. This structure as a similar appearance to semifused spheres.

from leveling. Rooting in this situation was most strongly influenced by the physical character of the material in the immediate vicinity of the root. Two major avenues of extensive root penetration can be seen (Fig. 4). In the massive layer, roots were confined to a crack, approximately 0.15 m long. However, extension of these roots into the underlying fritted material was accompanied by noticeable proliferation. The second avenue of rooting was through a vent of fritted material extending up through the massive layer at the top of the subsurface. This vent was an extensive structural feature in this pit and was prominent in each of the root pattern descriptions. Although the fritted material at the top of the subsurface was somewhat compacted, the spacing between the individual aggregates again allowed for sufficient root penetration into the uncompacted fritted material below 0.5 m. Root development (Table 2) under these conditions was not significantly different in the two pits examined. However, it was much more extensive than in the exclusively massive material (pit 2), but not nearly as prolific as in the fritted material (pit 1).

In all of the pits examined, the corn roots adequately exploited the volume of replaced topsoil (Table 2). There was, however, some variation among pits, some of which can be explained by the greater depth of replaced topsoil in pit 3 (0.45 m) than in the other pits (0.4 m).

Rainfall was about 0.3 m above normal during the May through July period in 1981, and the plants exhibited no symptoms of drought stress. However, drought stress is frequently a problem during the growing season in southern Illinois, especially on minesoils. Thus, the design of subsoils that can be readily exploited by plant roots is of prime importance for the construction of minesoils.

CONCLUSIONS

1) Soil physical condition is a very significant variable in newly constructed soils. Differences in soil physical condition must be adequately described to enable meaningful classification and mapping of these soils, particularly some of these artificial soil structures that are quite different from currently recognized structures. Mapability and soil performance effects are such that series level separations should be made on the basis of these structural differences.

2) A new structural term, *fritted,* is proposed to describe an artificial structure unique to constructed soils. The structure is characterized by features that are strongly influenced by soil handling operations rather than natural soil forming processes. The structural arrangement consists of rounded aggregates loosely compressed together. It is proposed that the abbreviation code "fd" be designated for fritted structures and that the size classes be the same as now used for blocky structures.

3) Subsoils with a fritted physical condition favor good rooting. Although subject to compaction at the upper surface, the extensive. void spaces between aggregates allow for adequate root penetration of the medium and subsequent proliferation below the compaction zone.

4) Subsoils with a massive physical condition do not favor profuse root growth. Root systems in these materials are generally shallow and largely restricted to desiccation cracks. Moisture availability was not a major factor in limiting root system development, because all of the soil materials were initially moist.

5) Soil construction operations need to be carefully evaluated to determine their influence on the physical condition of the resultant minesoils. Operations using a mining wheel in combination with belt transportation favor the formation of the more desirable fritted structure, whereas operations using scrapers exclusively favor formation of the less desirable massivr physical condition.

ACKNOWLEDGMENTS

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Physical and Chemical Characteristics of Pre-mine Soils and Post-mine Soil Mixtures in Illinois

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Physical and Chemical Characteristics of Pre-mine Soils and Post-mine Soil Mixtures in Illinois[1]

R. R. SNARSKI, J. B. FEHRENBACHER, AND I. J. JANSEN[2]

ABSTRACT

The chemical, physical, and mineralogical properties of Sable and Darmstadt soils were studied to determine the value of solum and subsolum material as mediums for plant growth. Sable silty clay loam from western Illinois has nearly ideal physical and chemical properties for plant growth, while the more weathered Darmstadt silt loam from southern Illinois has unfavorable chemical and physical properties that limit plant growth.

The suitability of various soils and subsurface overburden mixtures were determined by measuring and defining the chemical and physical properties that have a potential for enhancing or limiting plant growth. The B2 horizon material from the Darmstadt soil has the least favorable properties. The top 3-m mix (topsoil included) and 3-m mix (topsoil not included) have similar properties and appear to be the most favorable materials for use in constructing a post-mine soil. The range of chemical and physical properties in the Sable mixtures are not as great as in the Darmstadt mixtures. The top 3-m mix, 6-m mix (exclusive of the A horizon), and calcareous loess mix from the Sable soil all have similar chemical and physical properties.

Incorporation of the A horizon into the 3 m below the A horizon of both Sable and Darmstadt soils only slightly enhances the chemical and physical properties of the mixtures.

Comparison of tested and calculated soil values indicate that most chemical and textural properties of a solum and subsolum mixture can be predicted prior to mining. The pH of a mixture can also be predicted by using an equilibration technique.

Additional Index Words: soil mixing, disturbed soils, surface mine reclamation.

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THE OBJECTIVES in reclamation of prime farmland after surface mining, as defined in the Federal Surface Mining Control and Reclamation Act of 1977,[3] is to construct soils on the post-mine landscape that are at least as productive as those that existed before mining. A crucial step in the soil construction effort is selecting the best material for use in building each layer of the new soil. Most mine sites in Illinois have a variety of materials available from the overburden and from the pre-mine soils. There are indications that materials other than those from the solum of pre-mine soils should be considered at some sites.

In greenhouse experiments (Dancer and Jansen, 1981) using various soil horizons from Weir silt loam (a fine, montmorillonitic, mesic Typic Ochraqualf) from southern Illinois, soybeans and forage crops grew best on the topsoil (A horizon). Leached loess material from below the B2 horizon was superior to the acid, claypan subsoil (B2) as a medium for plant growth. Perennial ryegrass and red clover grew best where leached loess dominated the mixture, and as more B2 horizon was included, yields decreased. Studies with Darmstadt silt loam (a fine, montmorillonitic, mesic Albic Natraqualf) showed soybean growth was enhanced by blending the B2 horizon with underlying loess material (W. S. Dancer and K. McSweeney, 1980, personal communication).

In New Mexico, plant establishment and growth was best when 4 inches (10.2 cm) of surface soil was mixed into the spoil and an additional 8 inches (20.3 cm) of soil was applied over the top (Aldon, 1978). Only 2 inches (5.1 cm) of topsoil over sodic spoil in the northern Great Plains increased crop growth and water infiltration when compared to bare spoils (Sandoval et al., 1973). Using a Williams silt loam (a mixed Typic Argiboroll) in North Dakota, crop growth increased as total thickness of replaced topsoil and subsoil over sodic spoils was increased to 28 inches (71 cm). Replacement of topsoil and subsoil in separate layers was superior to mixing the two materials (Power et al., 1978).

Due to the lack of definitive information concerning the potential of unconsolidated overburden to support crop growth in mining regions of Illinois, this study was undertaken to (i) analyze the chemical, physical, and mineralogical properties of two complete soil profiles representative of Mollisols and Alfisols in mining areas of Illinois; (ii) evaluate the suitability of various soil and subsurface overburden mixtures by measuring and defining the chemical and physical properties that have a potential for enhancing or limiting plant growth; and (iii) determine if the chemical and physical properties of a mixture of solum and subsolum layers can be predicted by analyses of the individual layers prior to mixing.

MATERIALS AND METHODS

Soil and Greenhouse Sampling

Two commonly occuring soils found in surface mining regions of Illinois were sampled—Sable silty clay loam (Typic Haplaquolls, fine-silty, mixed, mesic) from Mecco Mine, Knox County (western Illinois), and Darmstadt silt loam (Albic Natraqualfs, fine, montmorillonitic, mesic) from Captain Mine, Perry County (southern Illinois). The soils were sampled from exposed highwalls.

In a companion investigation, large quantities of selected materials from the same two soils and underlying geologic materials were collected for a study in which soybeans were grown in various soil mixtures in polyethylene cylinders (15-cm diam, 90-cm long) under greenhouse conditions (McSweeney et al., 1981). Prior to mixing, the soils were sieved through a 1.9-cm screen. Six different blends were designed for each soil. In five of the mixtures, the darkened surface soil (A horizon) was placed on top of the subsurface mix before the start of the experiment (Table 1). It is important to distinguish between the top 3-m mix, where the A horizon was incorporated into the mix, and the 3-m mix, where the A horizon was not incorporated. Once the soybeans were grown and harvested, a representative soil sample was taken from each of the 12 mixtures for laboratory analysis.

Laboratory Analysis

Particle size distribution of the natural soil horizons and soil mixtures was determined by the pipette method (Kilmer and Alexander, 1949), modified by using sodium hexametaphosphate for the dispersing agent, and a 7.5% H_2O_2 treatment was used to destroy organic matter. Cation exchange capacity (CEC) was determined by the procedure of Peech et al. (1947). Exchangeable bases (Ca, Mg, K, and Na) were extracted by the automatic extraction procedure of Holmgren et al. (1977). Exchangeable Na and K were measured with a flame photometer. Exchangeable Ca and Mg were analyzed by atomic absorption. The pH of a 1 to 1 soil:water suspension was measured with a pH meter. Organic C was determined by the Walkley-Black method (Allison, 1965). Readily available and reserve P were measured by the Bray-1 and Bray-2 methods, respectively (Laverty, 1962). Available P was also determined by the Olsen method, using the sodium bicarbonate procedure

Table 1—Profile horizon designation with depth for Sable and Darmstadt soils illustrating the various materials included in the six soil mixtures of each soil.

	Material	Horizon	Depth (cm)	
	Sable series			
	Topsoil	Ap	0-31	
	Topsoil	A3	31-43	
	Subsoil	B21	43-71	Top 3-m Mix
B2 mix	Subsoil	B22	71-86	Total B mix
	Subsoil	B23	86-107	
6-m mix	Subsoil	B3	107-140	3-m mix
	Calc. Peoria loess	C1	140-274	
	Calc. Basal Peoria	C2	274-338	
C-loess mix	Roxana loess	IIC3	338-404	
	Rox. & Sang. mixed	IIC4	404-445	
	Sangamon soil	IIIAb	445-483	
	Sangamon soil	IIIB21bt	483-544	
	Sangamon soil	IIIB22b	544-594	
	Calc. Illinoian till	IIIC	594-633	
	Darmstadt series			
	Topsoil	Ap	0-23	
	Topsoil	A2	23-36	
	Subsoil	B21t	36-66	
B2 mix	Subsoil	B22t	66-94	
	Subsoil	B23t	94-119	Top 3-m mix
	Subsoil	B31t	119-155	3-m mix
6-m mix	Leached Roxana loess	IIB32	155-203	
	Rox. & Sang. mixed	IIB33	203-262	
	Sangamon soil	IIIAb	262-295	
	Sangamon soil	IIIB21b	295-386	
	Sangamon soil	IIIB22b	386-467	Sangamon B mix
Bottom 3-m mix	Sangamon soil	IIIB3b	467-544	
	Calc. Illinoian till	IIIC1	544-559	
	Calc. Illinoian till	IIIC2	559-605+	

[3] United States. 1979. Surface mining control and reclamation act of 1977. United States Statutes at Large 91:487–488. U. S. Government Printing Office, Washington, DC.

outlined by Knudson (1975). Calcium carbonate equivalent was determined by the gravimetric loss of CO_2 described by the U. S. Salinity Laboratory staff (1954). Base saturation was calculated by dividing the sum of exchangeable bases (Ca, Mg, K, and Na) by the CEC.

Mineralogy of clay was determined by x-ray diffraction using copper-Kα radiation. The method described by Kinter and Diamond (1956) was used for slide preparation. Expandable clays were identified by a first-order reflection of 17.8Å on glycerol-solvated samples, and illite was identified by the 10.0Å peak on Mg-saturated samples. Kaolinite and chlorite were identified by the 001 peak of kaolinite and 002 peak of chlorite at 7.15Å. Peak intensities were corrected using the factors 1, 3, 2 for expandables; illite and kaolinite-chlorite, respectively, to determine the relative percentage of each present in the samples.

RESULTS AND DISCUSSION

Sable silty clay loam is a poorly drained soil formed in thick Peoria loess. It is one of the most productive soils in Illinois, where its poor natural drainage has been corrected by tile. The A and B2 horizons are silty clay loam in texture and have very good physical and chemical properties for growth of crops such as *Zea mays* and *Glycene max* (Tables 2 and 3). Calcareous Peoria loess (C1 and C2) occurs between 140 and 338 cm in depth. Calcareous Roxana loess (IIC3) occurs between 338 and 404 cm in depth. The Roxana and Sangamon mixed zone (IIC4) is a mixture of Roxana loess and the A horizon of the Sangamon paleosol. The Sangamon paleosol (IIIA and IIIB) is a buried soil formed in Illinoian glacial till. The upper B of the paleosol qualifies as an argillic horizon. Only 39 cm of calcareous glacial till (IIIC) occurs between the Sangamon solum and bedrock. However, thicker deposits of calcareous till commonly occur just above bedrock in western Illinois.

Darmstadt silt loam is a somewhat poorly drained soil formed in Peoria and Roxana loesses. This soil is more highly weathered and has more distinct horizons than Sable. It also has unfavorable physical and chemical properties that limit plant growth; a high clay content (claypan) in the B2 horizon, a very strongly acid upper B, and a high Na content (natric horizon) in the mid- and lower B horizons. Clays in the mid- and lower B horizons are mostly dispersed, causing poor aeration and low permeability. The Roxana loess and a mixed zone of Roxana and Sangamon soil (IIB3) extend down to the Sangamon paleosol (IIIA and IIIB) and show only weak evidence of soil formation (i.e., loss of carbonates and weak structure development). The Sangamon paleosols formed in Illinoian glacial till are calcareous below 544 cm.

Clay Mineralogy

Clay minerals were grouped into the three major clay types (expandable clay, illite, and kaolinite-chlorite). The expandable clay fraction is mainly montmorillonite with some vermiculite. Kaolinite and chlorite were not differentiated from each other because of the very small amount of chlorite present in the profiles.

Illite is the dominant clay mineral in the A horizon of Sable soil (Table 3). In and below the solum, expandable clays remain the dominant clay mineral through the calcareous loess down to the Roxana and

Table 2—Chemical properties of Sable and Darmstadt soils.

Horizon	Depth	pH 1:1	Organic carbon	$CaCO_3$ equiv.	Exchangeable bases Ca	Mg	K	Na	CEC	Base sat.	Exch. Na	Bray† P_1	Bray† P_2	Olsen† P	K†‡
	cm		%	%	meq/100 g					%		kg/ha			
Sable silty clay loam (Typic Haplaquoll, fine-silty, mixed, mesic)															
Ap	0-31	5.5	2.82	0	16.90	5.94	0.29	0.12	27.22	85.0	0.4	41	54	21	253
A3	31-43	5.5	1.93	0	17.19	6.09	0.27	0.13	25.6	92.5	0.5	9	9	7	236
B21	43-71	5.5	0.77	0	17.03	7.03	0.48	0.17	26.1	94.7	0.7	10	15	8	419
B22	71-86	6.0	0.33	0	13.99	7.12	0.35	0.19	23.0	94.1	0.8	36	76	22	306
B23	86-107	6.7	0.26	0.5	14.28	6.76	0.33	0.24	19.7	100+	1.2	10	81	8	288
B3	107-140	7.5	0.13	0.9	12.33	7.26	0.26	0.16	14.8	100+	1.1	7	172	12	227
C1	140-274	8.0	0.09	13.8	12.82	6.93	0.21	0.16	11.2	100+	1.4	4	155	4	184
C2	274-338	8.0	0.13	15.2	12.49	7.13	0.19	0.16	10.1	100+	1.6	6	124	7	166
IIC3	338-404	7.8	0.13	1.1	11.12	6.77	0.11	0.15	11.8	100+	1.3	15	178	11	96
IIC4	404-445	7.6	0.09	0.1	9.13	5.65	0.15	0.15	10.2	100+	1.5	4	11	10	131
IIIAb	445-483	7.5	0.06	0	10.42	6.08	0.09	0.11	11.4	100+	1.0	3	6	8	78
IIIB21bt	483-544	7.4	0.07	0.8	15.80	6.84	0.22	0.18	17.9	100+	1.0	2	3	10	193
IIIB22b	544-594	7.5	0.07	0.2	14.58	6.80	0.24	0.20	14.3	100+	1.4	2	141	11	209
IIIC	594-633	8.1	0.04	8.2	28.07	3.58	0.20	0.18	9.8	100+	1.8	1	148	4	175
Darmstadt silt loam (Albic Natraqualf, fine, montmorillonitic, mesic)															
Ap	0-23	6.2	0.74	0.0	7.20	1.06	0.16	0.30	8.66	100	3.5	15	40	9	140
A2	23-36	5.0	0.42	0.0	3.56	0.93	0.12	0.26	9.24	52.7	2.8	4	7	6	105
B21t	36-66	4.9	0.49	0.0	9.20	5.41	0.22	2.88	23.67	77.8	12.2	2	7	3	193
B22t	66-94	6.9	0.16	0.0	13.14	6.86	0.18	5.71	23.41	100+	24.4	29	77	32	157
B23t	94-120	7.9	0.09	0.2	11.99	6.61	0.15	5.65	21.73	100+	26.0	48	159	53	131
B31t	120-155	8.2	0.09	0.4	13.34	6.44	0.15	4.39	17.36	100+	25.3	51	184	37	131
IIB32	155-203	8.2	0.06	0.3	13.32	6.43	0.10	3.15	13.76	100+	22.9	54	184	39	87
IIB33	203-262	8.2	0.06	0.3	12.88	6.33	0.13	1.83	14.86	100+	12.3	53	148	35	113
IIIAb	262-295	7.4	0.05	0.1	11.24	7.03	0.23	1.13	17.43	100+	6.5	35	97	23	200
IIIB21b	295-386	7.7	0.05	0	13.39	7.08	0.11	0.80	17.88	100+	4.5	7	30	13	96
IIIB22b	386-467	8.0	0.03	0	12.62	6.70	0.13	0.70	14.51	100+	4.8	3	16	6	113
IIIB3b	467-544	8.1	0.02	0.5	10.58	5.96	0.20	0.52	11.67	100+	4.5	3	148	7	175
IIIC1	544-559	8.4	0.04	8.0	30.60	6.66	0.22	0.32	10.29	100+	3.1	3	141	21	193
IIIC2	559-605+	8.4	0.04	9.2	30.36	6.45	0.20	0.38	9.52	100+	4.0	3	49	7	175

† Established nutrient ranges for Illinois soils. Bray P_1: Low 0-11, slight 12-22, medium 23-34, high 35+. Bray P_2: Low 0-36, slight 37-59, medium 60-84, high 85+. Olsen P: Low 0-6, medium 7-17, high 18+. Potassium: Low 0-202, slight 203-269, medium 270-336, high 337+.

‡ K meq/100 g × 874 = K kg/ha.

Sangamon mixed zone (IIC4). Here the expandable clay content begins to decrease and reaches a minimum of 5% in the Sangamon B and calcareous till. Illite is dominant in the lower Sangamon paleosol and calcareous till.

Kaolinite and chlorite are the dominant clay minerals in the A horizon of Darmstadt. The expandable clay content increases from a low of 15% in the Ap to a maximum of 50% in the lower B2 and upper B3 horizons (Table 3). Expandable clays remain the dominant clay mineral down to the Sangamon B21 and then decreases rapidly to only 10% in the calcareous till. Illite is the dominant clay material in the lower Sangamon paleosol and calcareous till.

Phosphorus

The Sable soil is highest in readily available phosphorus in the A and B22 horizons, while reserve P is highest in the B3, calcareous Peoria loess, Roxana loess, lower Sangamon B, and calcareous till. In Darmstadt, the highest levels of both readily available and reserve P were in the lower Peoria and Roxana loesses.

Two phosphorus tests were used to measure readily available P because of the wide range in pH and carbonate content of the soil materials evaluated. The Bray-P1 test correlates well with crop yield response to P on most acid and neutral soils in Illinois, but it does not work well for calcareous materials. The Olsen phosphorus test is more useful than Bray-P1 for measuring available P in calcareous soils.

The Bray-P2 test was used in this study to indicate if considerable amounts of reserve P (less soluble forms) were present. A high Bray-P2 test indicates that considerable amounts are present. It is not a reliable indicator of the total amount present in calcareous materials, however, because the acid extracting solution will be neutralized before all of the acid-soluble P has been extracted.

Readily available phosphorus, rather than reserve forms, are of interest for fertility management purposes. The reserve P is of interest, however, when selecting materials for soil construction. Some of that reserve will be released in the future by weathering, especially as the new soil is leached of carbonates. Carbonate leaching is a slow process, but in a Nebraska study, the carbonate content of the top 14 cm of a soil was reduced from 11 to 5%, and the pH reduced from 8.0 to 7.5, after 75 years (Andrew and Rhoades, 1947). The leaching of carbonates and subsequent release of P will be accelerated somewhat where materials high in calcium phosphates interface with masses of acid-soil material as a result of mixing during soil construction.

Mixtures from Sable and Darmstadt Profiles

Six mixtures were prepared using solum and subsolum materials from a Sable soil. Table 1 illustrates the kinds of materials composing each mixture. The chemical and physical data for these mixtures, both measured and calculated, are shown in Table 4. The silty-clay loam A horizon of the Sable soil was replaced at the surface on five of the mixtures and included in the mix for the sixth. The B2 mix has a favorable pH (6.2) and the highest available P content of the

Table 3—Physical and mineralogical properties of Sable and Darmstadt soils.

Horizon	Depth	Particle size distribution (mm): Coarse fragments >2.0	Sand 2.0–0.050	Silt 0.050–0.002	Clay <0.002	Clay minerals (<2 μm): Expandable clay	Illite	Kaolinite, chlorite, or both
	cm	%						
		Sable silty clay loam (Typic Haplaquoll, fine-silty, mixed, mesic)						
Ap	0–31	<0.1	1.2	66.5	32.3	25	45	30
A3	31–43	<0.1	1.0	65.7	33.3	35	35	30
B21	43–71	<0.1	1.0	63.0	36.0	50	20	30
B22	71–86	<0.1	0.9	66.0	33.1	50	25	25
B23	86–107	<0.1	0.8	69.2	30.0	50	30	20
B3	107–140	<0.1	1.3	75.6	23.1	50	30	20
C1	140–275	<0.1	1.2	82.8	16.0	45	35	20
C2	275–338	<0.1	0.4	84.5	15.1	45	30	25
IIC3	338–404	<0.1	5.7	75.2	19.1	40	25	30
IIC4	404–445	0.4	17.6	65.2	17.2	15	30	55
IIIAb	445–483	1.4	21.6	55.5	22.9	15	30	55
IIIB21bt	483–544	1.9	28.4	36.1	35.5	5	45	50
IIIB22b	544–594	2.8	36.3	37.0	26.7	5	55	40
IIIC	594–633	3.8	33.7	44.0	22.3	5	60	35
		Darmstadt silt loam (Albic Natraqualf, fine, montmorillonitic, mesic)						
Ap	0–23	0.4	3.4	82.9	13.7	15	35	50
A2	23–36	<0.1	7.7	77.3	15.0	20	40	40
B21t	36–66	<0.1	2.0	49.0	39.0	35	35	30
B22t	66–94	<0.1	4.3	61.3	34.4	45	30	25
B23t	94–120	<0.1	4.2	63.0	32.8	50	30	20
B31t	120–155	0.1	2.6	73.0	24.4	50	30	20
IIB32	155–203	0.3	9.1	68.6	22.3	45	30	25
IIB33	203–262	0.3	13.7	62.2	24.1	40	30	30
IIIAb	262–295	0.4	14.3	58.5	27.2	45	30	25
IIIB21b	295–386	0.5	17.8	53.3	28.4	45	20	30
IIIB22b	386–467	1.0	29.1	43.8	27.1	15	45	40
IIIB3b	467–544	1.1	30.5	43.9	25.6	10	50	40
IIIC1	544–559	2.2	31.5	46.8	21.7	10	55	35
IIIC2	559–605+	2.4	31.1	48.2	20.7	10	60	30

various mixtures. The clay content is moderate (32.5%) but higher than in materials above and below the B2 horizon. The higher clay content could be disadvantageous where the soil structure is partly or completely destroyed during mining and reclamation. In the total B mix, the clay content was slightly lower than the B2 mix, due to the addition of the B3 horizon. The total B mix has a much higher pH (7.7) than the B2. A ph between 6.0 and 7.0 appears optimum for many crops since most essential nutrients are available within this range (Brady, 1974). When mixing in deeper calcareous loess below the solum or in the 3-m mix and top 3-m mix, the clay content is substantially reduced to 20%, giving the mixture a desirable silt-loam texture. However, carbonate content, as well as pH, is greatly increased. The readily available P content (Olsen-P and Bray-P1) is lower, but the reserve P content (Bray-P2) is higher in the 3-m mix and top 3-m mix as compared to the B2 and total B mixtures. The four remaining soil material mixes all have very similar chemical and physical properties. The top 3-m mix and 3-m mix both include the B horizon and calcareous Peoria loess to a depth of 3 m. They differ only in that the former has the A horizon incorporated whereas the A horizon is excluded from the latter, so that it could be replaced at the soil surface. Blending in the strongly acid A horizon reduced the pH of the moderately alkaline mixture by only 0.1-pH unit and increased the organic-C content from 0.1 to 0.4%. In general, incorporating the A horizon did not greatly enhance the properties of the mixture. Replacing the A horizon at the soil surface would make fertility management somewhat easier: the calcareous soil mixture would be covered by a layer of acid material which could easily be limed to bring it to an ideal pH range. Replacing the A horizon would also make seedbed preparation easier and promote a better environment for seedling emergence and growth. The calcareous mixture would have weak and unstable aggregates if it were exposed to the surface (Chepil and Woodruff, 1963). The advantages of replacing an A horizon will disappear as an A horizon develops on the calcareous mixture over time.

The 6-m mix involved the incorporation of the B horizon, calcareous loess, Sangamon paleosol, and calcareous till. This is essentially a mixture of the total unconsolidated portion of the overburden. The C-loess mix is one that would not likely be used in practice, but it has been included to assess its suit-

Table 4—Tested vs. calculated soil test values for Sable and Darmstadt soil mixtures.

Soil mixture	Bray P_1		Bray P_2		Olsen P		$CaCO_3$ equiv.		Organic carbon		CEC	
	Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.
	kg/ha						%				meq/100 g	
Sable silty clay loam (Typic Haplaquoll)												
Total A	26	31	35	40	17	17	0	0	2.66	2.56	26.58	26.73
B2 mix	31	17	74	50	22	11	0	0.1	0.40	0.50	21.72	23.32
Total B mix	21	13	105	92	22	11	0.8	0.4	0.31	0.37	18.86	20.40
Top 3-m mix	11	11	150	116	15	9	7.4	8.4	0.40	0.49	14.00	15.64
3-m mix	9	8	146	128	8	8	7.8	9.7	0.11	0.19	13.15	13.98
6-m mix	7	7	112	106	13	9	5.2	5.6	0.15	0.15	12.86	13.47
C-loess mix	8	7	115	120	13	7	5.9	8.4	0.10	0.10	10.57	11.00
Darmstadt silt loam (Albic Natraqualf)												
Total A	18	11	40	28	13	8	0	0	0.82	0.63	8.57	8.86
B2 mix	12	16	19	40	8	17	0.1	0	0.48	0.33	21.44	23.56
Top 3-m mix	37	38	137	118	27	29	0.1	0.2	0.31	0.19	16.00	16.86
3-m mix	41	41	157	130	29	32	0.1	0.1	0.19	0.13	17.43	17.61
6-m mix	13	21	103	96	11	20	1.0	0.9	0.09	0.05	15.15	15.86
Sang. B mix	5	5	67	62	10	9	0.2	0.1	0.06	0.04	14.29	14.88
Btm. 3-m mix	5	5	97	68	9	10	1.6	1.6	0.07	0.04	13.15	13.96

Soil mixture	Exchangeable cations								pH 1:1 H_2O		Particle size distribution (< 2 mm)					
	Ca		Mg		K		Na				Sand		Silt		Clay	
	Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.	Test	Soil mix	Test	Calc.	Test	Calc.	Test	Calc.
	meq/100 g										%					
Sable silty clay loam (Typic Haplaquoll)																
Total A	17.53	17.00	6.70	5.98	0.31	0.28	0.18	0.13	5.5	5.6	6.9	1.1	58.5	66.3	34.6	32.6
B2 mix	15.27	15.42	6.83	6.97	0.27	0.40	0.13	0.20	6.2	6.3	7.7	0.9	59.8	65.7	32.5	33.4
Total B mix	15.71	14.36	6.68	7.07	0.23	0.35	0.44	0.18	7.7	7.6	1.1	1.0	69.2	69.1	29.7	29.9
Top 3-m mix	18.43	14.62	7.58	6.89	0.30	0.26	0.18	0.16	7.9	7.9	1.1	1.0	76.9	77.0	22.0	22.0
3-m mix	13.25	13.25	7.06	7.02	0.20	0.25	0.21	0.17	8.0	8.0	0.4	1.0	79.7	78.7	19.9	20.3
6-m mix	17.59	13.90	6.99	6.58	0.19	0.21	0.25	0.17	8.0	8.1	10.8	12.0	65.5	65.6	23.7	22.4
C-loess mix	12.37	11.72	7.01	6.69	0.21	0.17	0.19	0.15	8.1	8.1	6.9	6.1	76.3	76.5	16.8	17.4
Darmstadt silt loam (Albic Natraqualf)																
Total A	6.50	5.90	1.39	1.01	0.09	0.15	0.65	0.29	6.1	5.7	3.7	4.9	83.4	80.9	12.9	14.2
B2 mix	11.03	11.10	5.61	6.10	0.32	0.20	3.43	3.80	5.2	5.5	1.6	3.1	61.4	60.1	37.0	36.8
Top 3-m mix	8.97	11.53	4.57	5.77	0.15	0.16	2.63	2.96	6.7	7.2	1.1	7.7	74.2	66.0	24.7	26.3
3-m mix	11.21	12.32	6.07	6.42	0.23	0.16	2.94	3.25	6.9	7.5	0.9	8.1	72.3	64.0	26.8	27.9
6-m mix	16.40	13.87	6.74	6.51	0.26	0.16	1.32	1.85	8.3	8.3	19.2	20.2	53.7	54.2	27.1	25.6
Sang. B mix	11.04	12.28	6.39	6.61	0.13	0.15	0.65	0.68	8.1	8.0	24.1	25.4	48.8	47.3	27.1	27.3
Btm. 3-m mix	18.96	15.86	6.61	6.66	0.29	0.16	0.66	0.62	8.3	8.3	21.7	26.6	51.7	47.2	26.6	26.2

Established nutrient ranges are shown in Table 2.

ability for supporting plant growth. The 6-m mix, C-loess mix, 3-m mix an! top 3-m mixtures all have desirable silt loam textures. They have a medium available-P content (Olsen-P) and a high reserve-P content (Bray-P2). These four mixtures have a less desirable H but a more favorable texture than the B2 and total B mixtures. The exchangeable sodium percentage is low in all the Sable mixtures and presents no problem for the plant growth.

Darmstadt Mixtures

The B2 mix possessed unfavorable chemical and physical properties that would limit plant growth (Table 4). It has 37% clay, predominantly expandable clays. The- exchangeable sodium percentage is high, causing dispersed clays and the consequent reduction of permeability, aeration, and root penetration.

The A horizon has a silt loam texture with an exchangeable sodium percentage of 7.6. It contains the highest organic C content but lowest K content within the profile. Incorporation of the A horizon into the top 3 m does not greatly enhance the properties of the mixture.

The 3-m mix and top 3-m mix contain the highest P levels (Bray-Pl, Olsen-P, and Bray-PP) and have the most favorable pH values of all the mixtures. By mixing the B2 horizons with the deeper leached loess (B3 horizon), the clay content has been reduced from that of the B2 to a favorable silt loam texture. Adding the leached loess also enhanced the supply of available P. (Bray-PI and Olsen-P) over that in the B2 material alone. The 3-m mixtures have high exchangeable sodium percentages (16%) as does the B2 mixture, but the effect, is not as severe because of the lower clay content.

The 6-m mix is a blend incorporating the B horizon, Sangamon, paleosol. and calcareous till to a depth of 6 m. The addition of the deeper glacial till material reduces the exchangeable sodium to 8% from the 16% in the 3-m mix (Table 4). The 6-m mix has substantially less available P (Olsen-P and Bray-PI) than does the 3-m mix, but at least as much as the B2 mix. Reserve forms are substantially higher in the 6-m mix than in the B2 mix. The difference in Bray-P2 test values between the 3-m and 6-m mixes are not necessarily meaningful because of the higher carbonate levels in the 6-m mix. The higher pH in the 6-m mix should be considered a negative feature.

The bottom 3-m mix includes the Sangamon paleosol and calcareous till. The Sangamon and bottom 3-m treatments have similar properties, such as a low organic C content, medium Olsen-P, and high pH (8.1 and 8.3, respectively). The textures are favorable with 27% clay, and exchangeable sodium percentage is relatively low (5%) compared to the other mixtures. The soil mixtures, as well as the natural soil profiles of both Sable and Darmstadt, have Ca:Mg ratios above 1.0. The Sable soil profile generally has a medium K content in the solum; Darmstadt has a low K content. The Sangamon paleosol and calcareous till in Sable and Darmstadt have low K contents.

Soluble sodium was measured in the Darmstadt soil to determine if it was present as a soluble salt which would result in the exchangeable Na percentage being overestimated. It was present as a soluble salt, but the amount present was not enough to appreciably change the exchangeable Na percentage.

Predicting the Chemical and Physical Properties of Soil Mixtures

A weighted average (Table 4) of various soil properties was calculated from each of the six soil mixtures of Sable and Darmstadt soils by using the test results and thickness from the natural soil horizons (Table 1).

The pH values could not be calculated by taking the weighted average of the test values, since pH is a logarithmic function and is influenced by the effect of other factors such as $CaCO^3$ organic matter, and reserve acidity. Titration curves for each material would need to be established before pH values could be accurately calculated. The mix pH values were determined in this study by preparing a sample of each mixture in the laboratory. The mixtures were subjected to five wetting and drying cycles to allow a reasonable amount of time for the various materials in the mixtures to react. Then, pH values for each mixture were measured. The test pH values were from a similar mix of materials that had been prepared several months earlier and had grown a crop of soybeans in a greenhouse.

Calculated soil values were compared to the tested soil values for each mixture using correlation coefficients (Table 5) to provide an indication of how well chemical and physical properties of a soil mixture can be predicted prior to mixing.

Mixing of materials under field conditions is generally less complete than was accomplished in the laboratory. Predictions made from laboratory samples would. be most meaningful for spoil from mining wheels; which generally have moderately sized masses of intermixed contrasting materials. Equilibration time would be longer than for the laboratory samples, but the eventual effect should be similar. Plants growing in most wheel spoils would have exposure to each of the components of the mixture through their root systems. Predictions should be made less confidently where the masses of contrasting materials are large, such as is true in most dragline or shovel spoils. In these spoils, equilibration would be much slower and the root systems of individual plants might commonly be limited to only one or two of the components of the mixture.

Table 5-Correlation coefficients comparing tested values with calculated values for Darmstadt and Sable soil mixtures.

	Particle size distribution							Cation exchange capacity	Exchangeable cation					
	Sand	Silt	Clay	pH+	Bray P_1	Bray P_2	Olson P		Ca	Mg	K	Na	$CaCO_3$, equiv.	organic carbon
Darmstadt	0.967	0.967	0.963	0.956	0.957	0.964	0.649	0.995	0.694	0.968	0.716	0.967	0.992	0.997
Sable	0.703	0.949	0.966	0.996	0.761	0.936	0.491	0.994	0.667	0.271	0.426	0.166	0.966	0.999

• A correlation coefficient of 0.811 and above is significant at tbe 0.05 confidence level.
+ pH was not calculated from the weighted of the individual horizons.

Silt, clay, Bray-P2, CEC, $CaCO_3$ equivalent, and organic-C showed very high correlations between the calculated and tested values for both Sable and Darmstadt. The calculated values for exchangeable bases in Sable are close to the test values. The correlation coefficients are low only because all points cluster too closely for effective correlation analysis.

The tested pH values and pH mix values are highly correlated (Table 5) for both the Sable and Darmstadt mixtures. As previously discussed, using the equilibration technique for predicting the pH of a mixture is simple and efficient. By selectively choosing various materials in the profile, the pH of a mixture can be predicted in the laboratory with a reasonable degree of assurance.

SUMMARY AND CONCLUSIONS

Sable silty clay loam from western Illinois has nearly ideal physical and chemical properties for plant growth. The more weathered Darmstadt silt loam from southern Illinois has chemical and physical properties that limit plant growth, especially the clayey (claypan) B2 horizon, the very strongly acid upper B, and a high Na content (natric horizon) in the mid- and lower B horizons that results in the dispersion of clay minerals.

The B2 mixture from the Darmstadt soil has the least favorable properties for plant growth because of its strongly acid pH, high content of expandable clays, and high exchangeable sodium levels. The 3-m mix and the top 3-m mix are very similar in properties and appear to be the most favorable materials for use in constructing the subsurface horizon of a post-mine soil. They have a higher pH, higher available P, and more favorable silt loam textures than the B2 mix. The 6-m mix has advantages over the B2 mix, including lower clay and exchangeable sodium contents. Both top 6-m and B2 mixes have similar available P contents. One disadvantage of the 6-m mix is its high pH (8.3) due to the presence of carbonates which could cause P and minor element availability problems.

The Sable soils differ from the Darmstadt soils in that the Sable B horizon materials do not have serious chemical or physical problems which limit plant growth. The B horizon material does have more clay than the underlying materials. Although that clay content is not high enough to be deleterious in the undisturbed soil with its genetic structure intact, the silt loam texture of the deeper loess might be preferable in a newly constructed soil. In other respects, the Sable B horizon material appears to be as favorable or more favorable than the deeper materials for use in soil construction. The presence of free carbonates in the substratum materials would be a disadvantage, although not a terribly serious one. Although reserve P is highest in the substratum loess, available P is highest in the Sable Ap and B2 horizons. In summary, the data indicate that the Sable B horizon is favorable for use in subsoil construction but that substratum material is also of high quality. Greenhouse and field studies are needed to determine the effects of mixing these materials.

Mixing the A horizon throughout the top 3 m of both Sable and Darmstadt soils only slightly enhances the chemical and physical properties of the top 3-m mixtures. On the other hand, segregating the A horizon and replacing it at the top of a reconstructed soil makes seedbed preparation and fertility management easier.

Comparison of the tested and calculated soil values indicate that most chemical and textural properties of a solum and subsolum mixture can be predicted with reasonable assurance prior to mining by analyzing the individual horizons included in the mixture. During the process of mining and reclamation, this approach would be most applicable where rather complete mixing of materials is accomplished, as would be expected where a mining wheel was used. Where poor mixing is expected, predictions should be made with less confidence.

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Soil development in coal mine spoils

David Thomas and Ivan Jansen

ABSTRACT: Eight coal surface mine spoils were studied to determine how soils developed over time. The coal mines, located in western, eastern, and southern Illinois, ranged in age from 5 to 64 years old. One pit was excavated by hand at each site, soil morphology was described in detail, and each horizon was sampled for laboratory analysis. The most apparent change in all of the spoil sites was development of an A horizon that was darkened by organic matter. All of the A horizons had developed genetic soil structure. Seven of the eight sites had weak or incipient structure below the darkened A horizon. There were no depth trends in clay content or exchangeable cations that could be attributed to translocation after mining.

SOILS develop as parent material is modified by soil-forming processes. Soil development and the consequent changes in soil properties continue over time. Increasing age is reflected by increased solum thickness and stronger horizon differentiation (*1*). Weathering is most rapid in the early stages of development and slows as the profile thickens. The first changes include development and gradual thickening of an A1 horizon, as indicated by organic matter accumulation and development of weak structure.

Although soil development is slow, significant horizon development can be observed within the span of one lifetime (*3, 11, 13, 14*). A horizon development is most rapid under tillage (*12*).

Coal surface mining necessarily disrupts natural soils. Some features of the soils can be preserved by carefully segregating and replacing all soil horizons in sequence. Even then the natural soil structure is lost or greatly changed. Weak soil structure, or lack of structure, is one of the major deficiencies of young mine soils (*10*). Although some soil changes resulting from disturbance during surface mining and reclamation might be desirable, others are certain to be undesirable.

Soil development modifies disturbed soils over time just as it does natural soils and parent materials. Most of these changes will likely improve those soils for plant growth. We sought to evaluate the effects of soil development in surface mine spoils from 5 to 64 years old.

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Study methods

We studied eight sites in Illinois that had been surface mined prior to the Surface Mining Control and Reclamation Act of 1977. Data were collected in 1974; the time since mining ranged from 5 to 64 years. We measured physical, chemical, and micromorphological properties.

The sites were in areas where mining is or has been widespread (Figure 1). Some sites had received no reclamation treatment. Others had been graded after mining. The original horizons had not been segregated and replaced at any of the sites. Management after mining ranged from nothing to establishment and maintenance of a forage crop. Site 6 involved a crop rotation that included row crops for a 10-year period.

Site 1, in Fulton County (section 29, T6N, R3E), was mined in the 1920s and has not been disturbed since. The ungraded spoil ridge had a 4% slope on top and 30% sideslopes. The site was forested—sycamore, elm, sumac, cottonwood, dogwood, and wild cherry trees—with a thick understory of weeds, grasses, legumes, and vines. One sycamore tree had a trunk circumference of 60 cm. Spoil material was dominantly silt loam, mainly a mixture of Illinoian glacial till and loess. Of the few rocks present, most were rounded fragments from glacial till or outwash. The pH ranged from acid to moderately alkaline. Tree roots extended to a depth of at least 1.2 m.

Site 2, in Vermilion County (section 17, T19N, R12W), was mined about 1920 and has not been disturbed since. The site, on top of a shovel spoil ridge, was covered with an open forest of ash, elm, oak, and cottonwood trees and a thick understory. A red oak 77 cm in circumference and a cottonwood 115 cm in circumference were growing on the site. The loamy spoil was a mixture of loess, silty alluvium, and gravelly outwash. Tree roots extended to a depth of at least 90 cm.

Site 3, in Perry County (section 21, T6S, R4W), had been exposed for about 10 years. The site was on a massive spoil ridge on which peaks had been graded down to leave gently sloping strips at least 5 m wide on each ridge. Surface vegetation included a thick stand of fescue mixed with some sweet clover, except in some highly acid spots that were bare. The predominantly silty clay loam was a mixture of Illinoian glacial till, loess, black shale, and limestone. Masses of clayey material from the Sangamon paleosol and of the premine subsoil were apparent. The soil had 10 to 20% boulders by volume, mostly limestone and black shale. The pH ranged from acid to moderately alkaline. Some masses of pyritic shale were present. Fescue roots extend to a depth of about 30 cm.

Site 4, in Perry County (section 16, T6S, R4W), was 5 years old. The site had been graded and leveled to a 2% slope, and the vegetation was a thick stand of alfalfa. The spoil consisted of a mixture of loess, Illinoian glacial till, limestone, and black shale. Silt loam textures predominated, and there were about 20% coarse fragments by volume.

Site 5, in Williamson County (section 4, T9S, R2E), was 64 years old. The site was on top of an ungraded shovel spoil ridge that had a 6% slope on top and 35 to 45% sideslopes. It was covered with a dense forest of ash, oak, sassafras, red cedar, cotton-

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wood, and sumac trees. A cottonwood with a circumference of 163 cm and an oak with a circumference of 115 cm were growing nearby. There was a thick understory. The spoil was a uniform silt loam—loess and silty alluvium. It was acid throughout. There were no coarse fragments or clayey masses. Tree roots extended at least to 90 cm.

Site 6, in Knox County (section 28, T9N, R3E), was mined in 1944 for number 5 coal. In 1948 it was seeded to alfalfa and brome, which was cut for hay from 1948 to 1951. From 1953 through 1963 the site was in a rotation of oats-alfalfa-corn-corn. Reseeded in 1963, it had been used as permanent pasture thereafter. It was graded to a slope of 2 to 7% for research plots in 1947 (*9*). The silty clay loam was predominantly loess with some inclusions of Illinoian glacial till and black shale. It had less than 20% by volume coarse fragments, mostly small pieces of black shale. Also present were some soft sandstone fragments. The pH varied, but most of the soil was calcareous. Abundant grass roots, worm castings, and earthworms were present in the upper 30 cm.

Site 7, in Fulton County (section 21, T7N, R4E), consisted of 5-year-old wheel spoils that had been graded to a 2% slope. Vegetation was a thick stand of alfalfa with some orchardgrass and red clover. The predominantly silt loam was a mixture of loess and Illinoian glacial till. There were some pockets of firm, clayey, Sangamon paleosol material. The spoil had about 10% volume coarse fragments, mostly gravel or cobble size. There were no large boulders. The spoil was extremely hard. Alfalfa roots extended to at least 60 cm.

Site 8, in Fulton County (section 25, T7N, R2E), was about 10 years old. It had been graded to a 2% slope. A lush growth of alfalfa, bluegrass, and orchard-grass was present. The spoil, mostly silt loam, consisted of loess, Illinoian till, and some shales and soft sandstones. It had about 20% coarse fragments by volume. Most were less than 20 cm, consisting of soft, light-colored sandstone or black shale. The few rocks on the soil surface were soft sandstone. The surface 5 cm of soil was very dark and high in organic carbon due to additions of leonardite, an amorphous coal-like material, that had been applied experimentally to evaluate the material as a soil conditioner, growth stimulator, or fertilizer carrier. The spoil was calcareous throughout. Abundant bluegrass roots extended to a depth of 15 cm, while alfalfa roots extended to at least 90 cm. No earthworms were seen.

We dug a pit by hand at each site on a stable position not affected by erosion or sedimentation. On ungraded spoils, the pit was on the peak of a ridge. On graded spoils, we selected a level, uneroded site with few or no rocks on the surface.

Table 1. Thickness of the A1 horizon and the zone affected by genetic soil structure at eight Illinois mine spoil sites.

Site	*Age (years)*	*A1 Horizon Thickness (cm)*	*Structure Development (depth in cm)*
1	50	10	30
2	55	10	35
3	10	4	15
4	5	3	3
5	64	10	23
6	30	10	30
7	5	3	8
8	10	5	15

The soil morphology of each pit was described. We took two soil samples at each site, one from each side of the pit at 5-cm increments to a depth of 15 cm and at 15-cm increments from there to the bottom of the pit. We took 10 additional samples for preparation of thin sections at site 2 only. These samples were mainly from the top 35 cm where genetic structure had developed during the 55 years since coal surface mining.

Each sample was air dried and crushed with a wooden rolling pin to pass a 2 mm sieve. We weighed material greater than 2 mm to determine its percentage of the entire sample. Particle-size distribution of the fine earth fraction was determined by the pipette method. We determined organic carbon content by the Walkley-Black wet oxidation method (*2*). Total N was determined by the Macro Kjeldahl method to include nitrate and nitrite (*4*). Soil pH was read by a glass electrode pH meter using a 1:1 soil-water ratio. We used the Bray-1 (P1) test to determine available P for plants. Exchangeable cations were extracted with a 1 N solution of ammonium acetate adjusted to pH 7.0. We measured exchangeable Ca and Mg in the extract by atomic absorption and exchangeable K and Na by flame emissions. Thin sections prepared of the samples from site 2 were interpreted and described according to the procedures of Brewer and Cady (*5*, *6*).

Results and discussion

Soil development was evident at all eight sites. All A1 horizons had genetic structure darkened by organic matter. Weak genetic structure extended below the A1 horizon at all sites except site 4. The zone below the A1 horizon, which had apparent soil structure but no darkening by organic matter, was designated a C1 horizon. We did not describe it as a B horizon because weak structure was the only evidence of soil development. There was no sign of color change, leaching, or clay translocation. Herein, the horizons referred to as C1 horizons have soil structure; those called C or C2 horizons do not. At most of the sites, plant roots extended into the C or C2 horizons.

Based on the thickness of the A1 horizon and the depth to which genetic structure had developed, the oldest four soils (sites 1, 2, 5, and 6) were distinctly more developed than the youngest four (Table 1). Of the four oldest sites, site 6, which is only 30 years old, was comparable in development to sites 1, 2, and 5, which ranged from 50 to 64 years in age. The more rapid soil development at site 6 probably resulted from differences in management and vegetative history. Sites 1, 2, and 5 were ungraded. They had never been tilled, fertilized, or cropped and were under trees. Site 6 was graded and had been more intensively managed. It was seeded to an alfalfa-grass mixture and managed for forage production for the first 3 and the last 17 years. In the intervening 10 years, it was used for crop production under the oats-alfalfa-corn-corn rotation. The surface soil was tilled several times during that period. Grasses and legumes promote more rapid development of soil structure than trees, and it is generally accepted that occasional tillage promotes soil development (*7*, *16*).

Site 6 also had the highest clay content and a large, active earthworm population. The older three sites lacked earthworms and evidence of their activity. Earthworms promote soil development by opening up continuous channels through the soil, mixing mineral matter with humus near the soil surface, and carrying organic matter deep into the subsoil and substratum as they retreat downward for moisture in dry weather (*15*). They produce slimes that tend to bind aggregates, making those aggregates more stale.

Differences among the three oldest sites were minimal and of questionable significance. Site 2, which had the deepest structure development and the highest organic matter content, was under an opening in the trees. More weeds, grasses, and legumes were growing on the surface than on sites 1 and 5, which were under more dense tree canopies.

Sites 3 and 8, which are 10 years old, had thicker A1 horizons and deeper structure development than sites 4 and 7, which are 5 years old. Site 4 was unique in that it had no soil structure below the A1 horizon.

Soil consistence showed a clear trend due to soil development. All eight sites had friable consistence in their A1 horizons.

Sites 2 and 5 had both friable and firm consistence in their C1 horizons; the other C1 horizons were all friable. The C and C2 horizons ranged from friable to extremely firm; firm was most common. In general, the horizons that had developed soil structure were friable, but the nonstructured medium- or heavy-textured materials were firm to extremely firm.

There was variability in texture, but the pattern was indicative of random mixing rather than of soil development (Table 2). The dominant texture was gravelly loam at site 2, silty clay loam at sites 3 and 6, and silt loam at the others. There were pockets of gravelly sandy loam at sites 1 and 2 and pockets of clay at sites 1, 3, 4, and 7.

Surface horizons were somewhat more

Table 2. Physical and chemical profiles of soils at eight Illinois mine spoil sites. Each value is a mean of two replicates.

Site	Depth (cm)	Clay	Sand	Gravel	Organic C	Total N	C/N Ratio	pH	Ca	Mg	K	Na	P (ppm)
		%							meg/100g				
1, 50 years old	0-5	24	20	1	1.80	0.19	10	7.2	13.2	4.3	0.44	0.12	7.8
	5-10	22	32	15	0.77	0.08	10	7.4	12.2	3.6	0.28	0.09	3.2
	10-15	18	48	28	0.36	0.05	7	7.6	10.5	3.0	0.18	0.10	3.2
	30	22	22	14	0.34	0.04	8	7.6	13.8	2.4	0.19	0.12	5.8
	45	26	10	1	0.23	0.03	10	7.4	12.9	3.0	0.19	0.12	5.0
	60	26	18	2	0.23	0.03	7	7.4	13.6	4.1	0.23	0.14	8.8
	75	25	24	3	0.23	0.03	7	7.4	11.8	4.8	0.20	0.11	11.8
	90	28	20	3	0.19	0.02	8	7.4	13.0	6.1	0.28	0.16	14.0
	105	23	28	4	0.16	0.02	6	7.4	8.4	4.3	0.20	0.09	9.2
	120	24	14	1	0.20	0.02	8	7.4	10.4	6.0	0.26	0.11	8.5
2, 55 years old	0-5	20	38	20	1.34	0.14	10	7.6	9.7	2.4	0.26	0.16	12.5
	5-10	16	41	27	1.12	0.11	10	7.6	11.6	2.5	0.18	0.14	9.8
	10-15	16	39	17	0.58	0.07	8	7.7	10.8	2.5	0.16	0.16	9.8
	30	17	37	21	1.08	0.13	9	7.4	10.2	2.5	0.18	0.18	10.5
	45	18	42	13	0.99	0.10	10	6.6	7.2	2.8	0.19	0.18	6.2
	60	15	44	21	0.66	0.06	10	6.8	7.6	2.4	0.15	0.18	7.8
	75	20	31	23	0.54	0.06	9	7.1	9.8	3.2	0.16	0.22	6.5
	90	6	69	58	0.25	0.03	8	7.4	18.0	1.6	0.11	0.23	2.8
3, 10 years old, topped	0-5	27	14	4	1.02	0.11	10	7.0	16.6	1.6	0.44	0.24	21.0
	5-10	28	12	4	0.44	0.05	10	6.4	18.4	1.6	0.28	0.23	20.0
	10-15	34	10	2	0.29	0.04	7	6.0	26.0	2.1	0.26	0.26	12.8
	30	26	12	1	0.10	0.02	7	6.4	18.4	5.2	0.26	0.25	8.8
	45	35	10	7	0.33	0.04	9	5.0	19.6	4.8	0.22	0.15	16.5
	60	36	7	0	0.26	0.04	7	3.6	20.6	4.8	0.19	0.22	37.2
	75	28	10	3	0.08	0.02	4	4.8	18.4	7.5	0.28	0.26	17.8
	90	18	18	10	0.12	0.02	5	5.1	21.0	5.4	0.23	0.25	30.5
4, 5 years old, leveled, slurry applied to the surface	0-5	29	12	21	1.21	0.02	53	7.6	24.1	2.6	0.64	0.22	2.2
	5-10	26	14	14	0.54	0.04	14	7.6	25.6	3.4	0.31	0.26	5.2
	10-15	24	13	3	0.22	0.02	9	7.5	20.5	4.6	0.26	0.25	16.5
	30	26	12	5	0.20	0.03	6	7.0	21.3	4.2	0.29	0.42	7.2
	45	24	14	23	0.38	0.02	17	7.4	28.6	6.5	0.30	0.60	7.5
	60	25	14	24	0.81	0.04	18	6.8	32.6	5.7	0.32	0.44	3.5
	75	22	18	42	0.52	0.01	32	7.0	41.9	6.6	0.33	0.40	4.5
	90	28	15	33	0.56	0.03	11	7.2	35.9	7.2	0.34	0.42	10.0
5, 64 years old	0-5	22	6	0	1.24	0.13	9	5.4	7.6	3.3	0.38	0.15	18.5
	5-10	22	6	0	0.39	0.05	7	5.1	7.4	4.2	0.32	0.10	19.0
	10-15	22	6	0	0.18	0.04	5	5.2	7.6	4.7	0.42	0.14	16.5
	30	22	6	0	0.14	0.03	5	4.7	6.5	4.8	0.32	0.12	16.2
	45	22	6	0	0.16	0.03	5	4.8	5.5	4.0	0.32	0.16	15.5
	60	22	6	0	0.12	0.03	4	4.8	6.1	4.6	0.28	0.40	14.5
	75	23	5	0	0.16	0.03	5	4.8	5.5	4.4	0.33	0.39	14.2
	90	22	6	0	0.10	0.03	4	4.8	5.5	4.5	0.33	0.49	13.0
6, 30 years old, leveled	0-5	30	8	3	0.88	0.14	6	7.5	20.6	1.9	0.28	0.19	7.5
	5-10	31	8	5	0.60	0.08	8	4.8	23.0	1.9	0.22	0.24	4.8
	10-15	31	8	2	0.42	0.09	5	6.2	22.9	2.2	0.29	0.25	6.2
	30	34	6	2	0.26	0.05	5	4.0	19.7	3.6	0.28	0.22	4.0
	45	32	10	1	0.21	0.04	6	5.0	23.0	3.4	0.20	0.23	5.0
	60	34	6	2	0.19	0.04	5	5.8	21.2	4.0	0.24	0.26	5.8
	75	36	5	1	0.17	0.05	4	6.5	18.0	4.3	0.26	0.26	6.5
	90	35	2	0	0.12	0.03	4	3.8	12.1	4.2	0.24	0.14	3.8
7, 5 years old, leveled	0-5	24	16	5	0.38	0.06	7	7.7	12.1	3.3	0.35	0.14	11.2
	5-10	22	16	7	0.21	0.04	6	7.8	13.6	4.0	0.24	0.19	6.0
	10-15	24	16	4	0.23	0.03	7	7.8	14.4	4.6	0.22	0.22	6.5
	30	24	16	3	0.21	0.03	6	7.8	12.4	3.7	0.23	0.20	6.0
	45	28	21	7	0.23	0.04	6	7.8	15.4	3.3	0.28	0.20	6.2
	60	22	23	9	0.14	0.02	6	7.8	18.4	3.9	0.26	0.22	7.5
8, 10 years old, leveled, leonardite applied to the surface	0-5	20	27	12	2.40	0.29	8	7.2	14.1	3.0	0.60	0.21	17.2
	5-10	16	27	11	0.79	0.08	10	7.5	17.2	2.8	0.34	0.20	5.8
	10-15	18	24	5	0.52	0.06	9	7.6	16.6	3.0	0.27	0.32	5.0
	30	20	22	8	0.37	0.05	8	7.4	17.0	3.7	0.24	0.22	5.5
	45	24	18	6	0.29	0.04	7	7.1	31.4	4.7	0.24	0.24	5.5
	60	20	28	14	0.17	0.03	6	7.4	17.2	4.0	0.18	0.22	5.0
	75	23	19	7	0.23	0.03	7	7.0	24.6	5.0	0.22	0.21	6.8
	90	26	12	4	0.28	0.05	6	7.2	12.9	6.9	0.24	0.20	7.8

uniform in texture than underlying horizons. Mixing after reclamation was likely the greatest factor. Sites 6 and 8 had been plowed and sites 4 and 7 may have had some form of tillage. Slaking of some soft coarse fragments also was likely.

There was no evidence of clay translocation after mining. Variability of the original material could have precluded detection of changes in clay content, but we observed no clay coatings anywhere. Microscopic examination of thin sections revealed discontinuous, irregular clay domains, but not in channels or pores. We found no oriented clays on walls of voids or around skeletal grains. Apparently, the time has been too short for detectable movement of clay.

Darkening of the surface soil due to the accumulation of organic matter was one of the most apparent effects of soil development. At most sites the A1 horizon was one to two units lower in value (Munsell color system) than the underlying C or C1 horizon. We found no other color effects attributable to soil development. There was also no evidence of oxidation or reduction in place. Many colors were present in most of the C horizons; we described as many as eight colors for an individual horizon. All of the colors appeared to be inherited, and we attributed the mixed pattern to mixing of materials at the time of mining and reclamation. This mixed pattern of colors and materials is a distinctive feature of man-made soils.

Organic C was consistently highest at the surface and declined with depth to a depth of 10 or 15 cm (Table 2). This is in accordance with the color profiles observed. Sites 4 and 8 had carbonaceous material in the form of slurry or leonardite applied to the surface after reclamation. Hence, the organic C enrichment near the surface cannot be attributed entirely to soil development at those sites. That effect was reflected by the very high C/N ratio in the A1 horizon at site 4. Site 6 did not have a high C/N ratio, probably because the C addition was offset by additions of N fertilizer. Contamination by coal at any depth would also increase the C content and should also cause a high C/N ratio. We observed a high ratio only at site 4.

We found no definite patterns in soil pH that could be related to soil development. Other researchers have observed pH effects over similar periods of time (*3, 7, 8*). The background variability in pH at the sites was high, so small changes in pH were undetectable.

Available P (Bray P1) decreased with depth in the top few centimeters at all sites except site 4. We could not distinguish effects of soil development from effects of P additions at the younger sites, but the three oldest sites had not been fertilized. There was no apparent explanation for the very low available-P content near the surface at site 4 unless it was related to the application of slurry at that site.

None of the exchangeable cations showed an increase with depth that would indicate leaching. K was highest at the surface and decreased with depth in the top few centimeters at all sites. As was true for P, only sites 1, 2, and 5 had meaningful patterns of exchangeable K attributable to soil development because of the probability that the other sites have been fertilized. We attributed the higher nutrient levels near the surface at the three oldest sites to base cycling by the vegetation and to weathering from primary minerals.

Summary and conclusions

All eight of the post-mine soils showed some evidence of soil development. Most apparent was the development of an A1 horizon darkened by organic matter. Genetic soil structure was evident near the surface of all of the soils, but depth of structure development ranged from only 3 cm at one 5-year-old site to 35 cm at a 55-year-old site. We observed a clear trend in soil consistence. The top horizons, which had developed soil structure, were friable in most instances and firm at the extreme. Deeper horizons were generally firm to extremely firm.

We found no evidence of clay translocations attributable to soil development. Darkening by organic matter near the surface was apparent at all sites, but there were no other color effects of soil development. Most color and texture patterns resulted from the mixing of materials during mining and reclamation or from relict features of the materials included.

Both soil pH and exchangeable cation levels varied with depth, but there were no consistent trends reflecting leaching. There were indications of enrichment in both available P and exchangeable K near the soil surface. Some of the sites had been fertilized subsequent to soil construction, but others had not.

There was a general relationship between soil development and time since the most recent disturbance. Other factors, such as historical vegetation, tillage, fertilization, and earthworm activity, affected the rate of soil development, however, and must be considered, along with time, when studying post-mine soils.

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Reclamation Methods and Productivity Responses

Prime Farmland Reclamation Research in Illinois

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Abstract

Reclamation research of mined land to be used for crop production has been ongoing by the University of Illinois since 1977. Results of these studies has shown that poor soil physical condition is the most limiting factor to successful row crop production on mined land. Critical to success are selection of the best available soil materials used in soil construction and a material handling method which will minimize compaction. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well low stress years. Total crop failures have occurred on high strength soils in years of weather stress. Some deep tillage practices have been successful in improving compacted soils, but it is preferable to avoid compaction when the soil materials are handled.

Introduction

The decade following the passing of PL 95-87 saw active research programs in several states to develop the technology needed for successful reclamation. In 1977 the University of Illinois with funding from five coal companies initiated a comprehensive research reclamation program. This initial program led to 10 years of research in which university, industry, and regulatory personnel worked side by side to identify and propose solutions to reclamation problems. Congressional action in 1986 established a five-year prime farmland reclamation program to assure continuation of two active prime farmland centers. This five year program is supported jointly by federal (80%) and industry (20%) sources. CSRS (The Cooperative States Research Service in USDA) is administering the program and has selected the University of Illinois as the primary center and the University of Kentucky as the secondary center, from among proposals submitted.

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The purpose of this paper will be to report and summarize to date on research work in Illinois concerning rowcrop response to various reclamation practices. Discussion of results will focus on reporting general yield responses, observations, and summary to date from the Illinois work. Intensive analysis of site specific data has been reported in preceding papers or in manuscripts which are now in progress or in press. There will be little attempt to distinguish between prime and non-prime farmland, even though prime farmland is addressed separately in federal legislation. The principles of reclamation for rowcrops, and to a large degree, the potential for success are quite similar for prime and non-prime farmland. Most prime farmland must by law be reclaimed to row crop capability, but not all row crop reclamation is on prime farmland.

Selection of Soil Materials

Segregation and replacement of horizons from the premine soils is a practice that is required by law under many conditions. Early reclamation research was focused on the evaluation and characterization of selected soil materials to be used for soil horizon replacement or substitution, if the substituted soil material could be shown to be as productive as the natural soil horizon it replaced. Construction of minesoils with good quality soil materials and desirable physical properties is essential to attaining productivity levels necessary for bond release.

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

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

greenhouse studies, most of the early field studies addressed the issue of topsoil and subsoil horizon replacement.

Topsoil replacement has generally been beneficial for seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials (Jansen and Dancer, 1981). Yield response to topsoil replacement has ranged from strongly positive to strongly negative. At the Norris mine in western Illinois, replacement of 45 cm of dark prairie topsoil over graded wheel spoil resulted in a significant positive corn yield response in three of four years with irrigation and two of four when not irrigated. Soybeans responded favorably to topsoil in one of the two years studied (Dunker and Jansen, 1987a). Significant negative yield responses to topsoil occurred in years of weather stress. Year to year variation in corn yield was considerably greater on the unirrigated topsoil than the unirrigated wheel spoil. Compaction caused by the use of scrapers to replace topsoil is assumed to be the reason for low topsoil yields in years of weather stress. The zone directly below the topsoil has a bulk density of 1.7 to 1.9 Mg m3 and very low hydraulic conductivity..

At the Norris topsoil wedge experiment, A horizon material was replaced over wheel spoil by scrapers in thickness ranging from 0 to 60 cm. There was a significant positive yield response to increasing topsoil thickness for corn, but not for soybeans. Year by year results showed positive relationships to topsoil thickness in years of favorable weather, but negative responses in years of moisture and temperature stress (Jansen et al., 1985).

At Sunspot mine, in western Illinois, topsoil and B horizon replaced over dragline spoil was evaluated over an eight year period. Soil treatments consisted of 38 cm of topsoil replaced over replaced B horizon; 38 cm of topsoil replaced directly over dragline spoil; 90 cm of B horizon replaced directly over dragline spoil; and dragline spoil only. Bulldozers pushed the soil materials onto the plot areas and it is important to note that scrapers were never allowed directly on the plots at any time during construction. An undisturbed tract of Clarksdale soil (Udollic Ochraqualf) was used as an unmined comparison. Topsoil replacement resulted in significantly higher corn yields in four out of eight years when replaced over B horizon materials and six of eight years when topsoil was replaced directly over dragline spoil (Dunker and Jansen,1987b). Corn grown on the topsoil replaced treatments had a higher percent stand at harvest, had fewer barren stalks, and a higher ratio of shelled grain per total ear weight than corn on the non-topsoil treatments. Soybean yields were significantly higher on the topsoil replaced treatments in six of seven years whether or not B horizon materials were replaced. The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale in five of seven years while the B horizon treatment without topsoil produced corn yields comparable to the undisturbed in only one year. The dragline spoil was unable to equal corn yields in any of the years studied whether topsoil was replaced or not. Fehrenbacher et al., (1982) found that corn roots penetrated significantly deeper in the B horizon materials than the dragline spoil and that bulk densities were significantly higher in the graded dragline spoil than the replaced B horizon at a depth of 54 cm

and deeper. Bulk densities between the B horizon material and the undisturbed Clarksdale were similar. It is not possible to determine whether the favorable response to the B horizon treatment was due to the B horizon material, or to the lower soil strength which resulted from the careful handling.

Response to soil horizon replacement in southern Illinois has been less dramatic than has been observed at the western Illinois sites. This is understandable considering that A horizons are more highly weathered and average 20-24 cm in depth compared to 40-45 cm in the highly productive western Illinois soils. At River King, in southern Illinois, topsoil replaced by scrapers over wheel spoil significantly increased corn yields in only one of eight years and soybeans in three of six. The River King site does have good quality spoil and rather mediocre topsoil.

Soil horizon replacement and thickness of soil materials from southern Illinois has been studied at the Captain mine where the natural soils have chemical and physical problems which limit productivity. The Captain wedge experiment was used to evaluate corn and soybean yield response to thickness of scraper placed rooting medium (0 to 120 cm thick) over graded cast overburden, with and without topsoil replaced. Yields of both corn and soybeans increased with increasing thickness of hauled material to about the 60-80 cm depth. Meyer (1983) found very few roots below the 60 cm depth and found that roots in the subsoil were largely confined to desiccation cracks. The subsoil physical condition can best be described as compact and massive with very high bulk density levels and poor water infiltration. Soybean yields on the scraper placed root medium were significantly lower than a nearby undisturbed tract in all seven years of the study, whether topsoil was replaced or not. Corn yields were comparable to the undisturbed site in three of the years which can be characterized as low stress years.

Soil Physical Pronerties

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils. Indorante et al. (1981), in a comparison of mined and unmined land in southern Illinois reported that reconstructed mine soils studied had higher bulk densities and they lacked any notable soil structure. Natural improvement in compacted mine soils is a slow process. Thomas and Jansen (1985) studied soil development in eight mine spoils ranging in age from 5 to 64 years looking at physical, chemical and micromorphologicalproperties. All eight minesoils showed some evidence of soil development, but depth of structure development ranged from only 3 cm at the 5 yr old site to 35 cm at a 55 yr old site. No evidence of clay translocation attributable to soil development was found. Color and texture pattern changes were determined to be a result of the mixing of materials rather than developmental processes.

Illinois has an abundance of high quality soil materials to use for soil construction and row crop success on mine land has been as dependent upon the method by which soil horizons have been replaced as

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

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

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

Penetrometer data has proven useful for evaluating the soil strength effects of several reconstruction methods, of high traffic lanes on reclaimed areas and of tillage methods for alleviating compaction (Vance et al., 1987). Soil strength values decreased with decreasing traffic. Scraper soil material handling systems produced the highest soil strengths, soils from truck-haul systems were intermediate, and soils built by a wheel-conveyor-spreader system had the lowest soil strength.

The effect of using a deep soil loosener (Kaeble-Gmeinder TLG-12) on corn grown on wheel spoil was evaluated over a two year period at Norris Mine in western Illinois (Dunker et al., 1987c). The TLG-12 has an effective tillage depth of approximately 75 cm and was successful in significantly lowering penetrometer resistance in the 23-46 cm and 46-68 cm segments when compared to the unripped wheel spoil treatments. Corn yield response to the TLG-12 was significant in both years (1985-86) although the magnitude of response was greater in 1985, a year of greater climatic stress. Significant differences for pollination dates, % barren stalks, shelling %, and soil moisture tension levels at certain depths were observed between the ripped and non-ripped treatments. Two year average corn yields for both topsoil/ wheel spoil and wheel spoil without topsoil were comparable to corn yields from a nearby Sable soil while two year non-ripped mine soil yields were not.

In a companion study in southern Illinois, the effects of the TLG-12 was evaluated on scraper placed rooting medium and 20 cm of scraper placed topsoil (Hooks et al., 1987). Corn and wheat were planted in 1985. Corn, soybeans, and grain sorghum were planted in 1986. The test plots, which totaled 60 acres were located within three adjacent areas with a ripped and non-ripped block within each area. Yield results showed a significant positive response to the deep tillage treatment for all crops in both 1985 and 1986.

Management and Crop Selection

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, herbicides and fertilizer rates are management factors that are generally recognized as affecting crop yields. The effects of these management factors are compounded when row crops are grown on newly constructed mine soils, which may have wide ranging physical and chemical properties, making it difficult to project productivity success. 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 reconstruction treatments in most years for an individual hybrid, but the ranking of treatments has not been consistent from year to year.

Forty corn hybrids in 1984 and thirty-eight hybrids in 1985 were planted on two mine soils and an undisturbed tract at Norris mine in western Illinois to evaluate a wide range of genotypes on newly constructed mine soils (Dunker et al., 1988). The two mine soils consisted of one being 45 cm of topsoil replaced by scrapers over wheel spoil and one consisting of wheel spoil only. A nearby tract of Sable soil (Typic Haplaquoll) was used as the unmined comparison. Results from this study indicate that the potential to minimize the effects of stress exists through hybrid selection of adapted genotypes. Hybrids with the highest potential on unmined soils did not necessarily produce the higher yields on the disturbed soils. Weather variables were found to be more significantly associated with yield variation on the mine soils than on the Sable soil. Significant differences in

pollination dates among soil treatments for a hybrid were observed in both 1984 and 1985. Hybrids on the Sable soil, in general, were the first to pollinate, followed by hybrids on the topsoil treatment, with hybrids on the wheel spoil being last to shed pollen.

Many of the physical problems in reclamation for rowcrop production have been identified and the assumption has been made that chemical amendments can be applied to alleviate perceived plant nutrition problems. However, soil analysis calibrated with crop yield and fertilizer responses on natural occurring soils may not be precisely applicable to reclaimed soils. Dancer (1984) indicated that about twice as much soil P was necessary for maximum yields on reclaimed land as was needed under natural soil conditions. It has been recognized that K uptake is affected by compaction on natural soils and it does not seem unreasonable that compaction during material handling and soil construction might affect K fertilizer response and K uptake on reclaimed land. Changes in organic matter, soil pH and microorganism populations may reduce or enhance levels of available essential elements in reconstructed soils, Research initiated in 1987 is designed to evaluate the nutritional status of corn and soybeans as affected by reclamation procedures and to evaluate crop response and soil test levels to fertilizer rates on mine soils. Corn and soybean leaf tissue samples were chemically analyzed in 1987 and 1988 to determine chemical concentration of N, P, K, Ca, Mg, B, Cu. Fe, Mn, Zn, and S. Relationships between yield, nutrient content and reclamation treatment is being examined using standard analysis of variance and regression model building techniques. Peck et al. (1969) and Walker et al. (1969, 1974) have determined relationships between plant composition and crop yields with various algebraic models for natural soils and will be used as the basis of model development for mined land. Soil samples are being analyzed for all elements.

In summary, results from the Illinois work shows that achieving mine land productivity is attainable if reclamation plans are designed to minimize compaction, use good quality soil materials and use high management levels (herbicides, fertility, adapted crop varieties) in rowcrop production. Deep tillage is an option which may be used to alleviate compaction which is unavoidable in the reclamation process.

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EVALUATION OF MINESOIL PRODUCTIVITY

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Introduction

This project centers around field experiments involving growing rowcrops on postmine soils. It is a continuation of reclamation research of mined land used for crop production that has been ongoing by the University of Illinois since 1977. Research sites vary in the methods of reclamation and how the mine soils were constructed. 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.

Objectives: 1) Continue development of an extensive base-line data base for use in soil productivity modeling. 2) Evaluate the effectiveness of soil development processes over time in improving newly constructed soils.

This report will summarize to date and present 1989 results on research work in Illinois on existing active sites. Discussion of results will focus on reporting general yield responses, observations and summaries from this ongoing research. Intensive analysis of site specific data has been reported in preceeding papers for most sites. Each mine site will be presented and discussed separately.

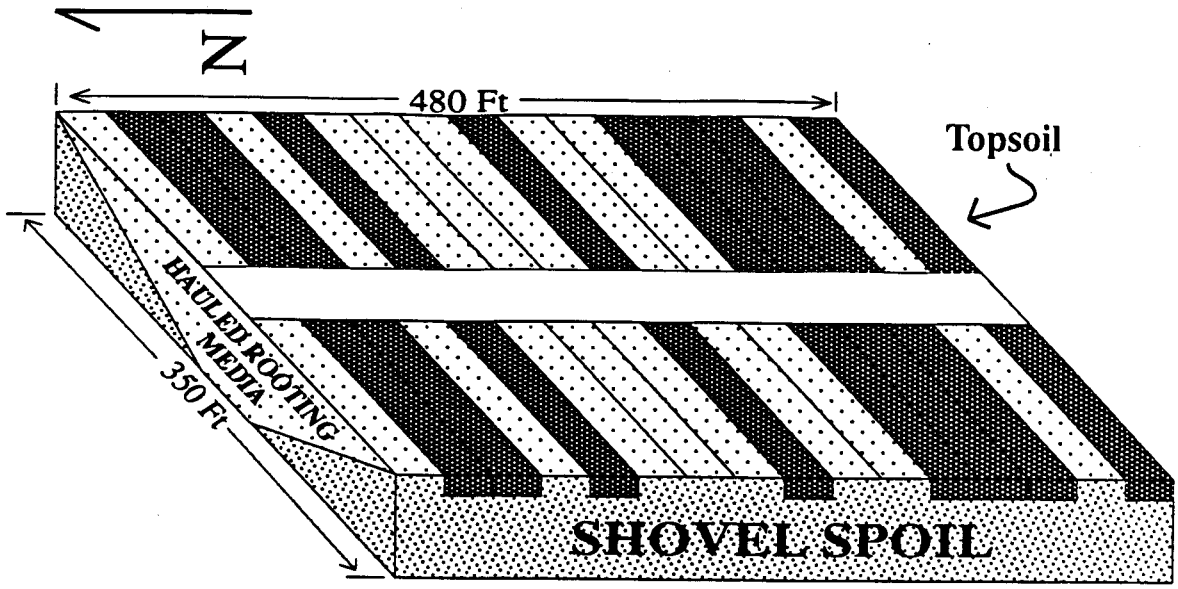
Captain Mine

Site and treatment description: The Captain Mine, Arch of Illinois, Inc., is located in Perry County near Percy in southwestern Illinois. Two experimental field plots exist, differing in design and objective. The first set of plots constructed in is of a wedge design (Figure 1). It consists of shovel spoil (quite rocky) covered by a layer of scraper hauled root media (mostly B horizon material) varying in thickness from 0 to 4 feet. Superimposed are randomly located strips in eight replications that have had A horizon (topsoil) material replaced. Early yield results from this study has been extensively reported in a previous paper (Jansen et al., 1985). In addition to yield response to depth of rooting medium and topsoil replacement being evaluated, adeep tillage treatment has been added as a treatment variable.

The second set of plots at Captain (Mix Plots) were designed to follow up a series of greenhouse experiments which began in 1977. Greenhouse evaluation in that study revealed that replacement or alteration of the claypan subsoils of southern Illinois would increase crop growth by enhancing the chemical and physical properties of reclaimed land (Dancer and Jansen, 1981; McSweeney et al., 1981). Topsoil materials generally produced somewhat better plant growth than did the materials from soil B or C horizons, but mixtures of B and C horizons were

commonly equal to or better than the B horizon materials alone. The purpose of these field plots is to evaluate several different available materials or soil mixtures for use in soil construction.

Figure 1. Captain Wedge Plots.



The mix plots consist of a randomized complete block design with four replications (Figure 2) which was constructed in 1980 with the following treatments:

1) A/3; A and B horizon material from the premine soils replaced in their original sequence.

2) A/10; A horizon material segregated and replaced over a blend of the top 10 feet of premine soils and underlying substratum.

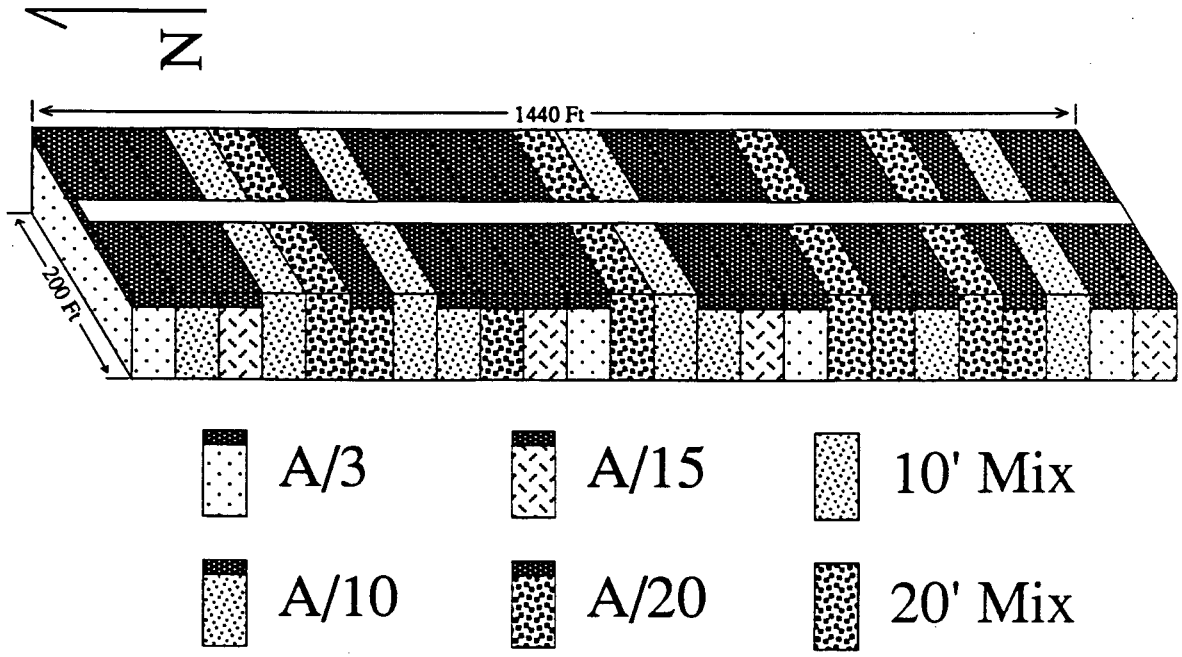
3) A/15; A horizon material replaced over a blend of the top 15 feet of premine materials.

4) A/20; A horizon material replaced over a blend of the top 20 feet of premine materials.

5) 10' Mix; a blend of the top 10 feet of premine materials with no A horizon separation and replacement. The A horizon is a component of the root media blend.

6) 20' Mix; a blend of the top 20 feet of premine materials with no A horizon separation.

Figure 2. Captain Mix Plots.



The blending of varying increments of soil and unconsolidated material was achieved using a mining wheel. The soil material was transported by a conveyor belt and then placed with a soil spreader requiring minimal grading. Thus the term wheel-conveyor spreader system is used to describe this process.

A nearby tract of Cisne silt loam (Mollic Albaqualf) and Stoy silt loam (Aquic Hapludalf) are used as unmined comparisons. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation. Corn (*Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental designs of the wedge and mix plots. Soybeans were not grown during the 1986 and 1987 seasons. A fallow period for each side with supplemental tillage to correct a tillage pan was applied during these seasons. Grain yield samples for corn were harvested after black-layer formation on the kernel indicated physiological maturity and soybeans were harvested when all pods were brown and dry. Grain yield estimates are based on the amount of shelled grain after adjusting for variation in moisture content of grain to 15.5 % for corn and 12.5 % for soybeans.

Objectives of the Captain Site:

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

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 rooting 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.

Captain Results and Discussion:

Captain Wedge: This experiment is designed to evaluate corn and soybean yield response to thickness of scraper placed rooting medium (0-48" thick) over graded cast overburden , with and without topsoil replaced. Yields are presented in Tables 1 and 2. Early years results (1979-84) show that yields of corn and soybeans increased with increasing root media depth to about the 25" depth (Jansen et al., 1984). No significant yield increase was observed beyond this depth. This lack of response to increasing thickness beyond the 25" depth might be caused by high soil strength due to compaction by scraper placement. Meyer (1983) found very few roots below the 25" depth and also found that roots in the subsoil were largely confined to desiccation cracks. The subsoil condition can best be described as compact and massive with very high bulk density levels and poor water infiltration. These scraper built soils lack the macropore network needed to conduct water and to provide avenues for root growth. Thompson et a1.,(1987) measured penetrometer resistance readings from 280-540 psi on these plots and noted that plant roots were conspicuously absent below 26 inches in these high strength soils. McSweeney and Jansen (1984) have reported that root penetration into these subsoils was confined primarily to the horizontal direction. Cross sections of roots were noticeably flattened and compressed.

Some, but a relatively small portion of the total rowcrop yield variation has been associated with root media thickness. A much greater portion of the total variation in yield has been associated with year- to year weather effects, which have been enhanced by the droughty nature of these mine soils. Crops growing on these compacted soils are not able to take up enough water to survive and flourish during periods of even moderate drought stress.

Significant responses to topsoil replacement on these plots have rarely occurred. Topsoil was also replaced with a scraper haul system. While topsoil has been beneficial for seedbed preparation,stand establishment, and early season growth, it has not resulted in increased yields under this situation.

Table 1. 1979-89 corn yields on Captain Wedge.

Depth	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
						Yield, bu/a					
Topsoil/ Root Media:											
3"	81	0	37	63	0	0	0	0		16	0
6"	69	0	37	46	0	0	0	0	105	9	0
10"	77	0	40	65	0	0	0	0	114	9	0
13"	45	0	39				1			15	0
19"	90	0							120		
22"	89	0	51	84	0	0	19	22		27	19
25"	89			72							
30"			51	59	0	0					
32"	89	0		51	0	0	24	14	139	21	10
37"	86	0	43				55*	30*	110*	32*	32*
44"	92	0	50	50	0	0	47*	42*	138*	31*	36*
Root Media Only:											
3"	60	0	31	80	0	0	0	0		18	0
6"	68	2	39	60	0	0	0	0	69	19	0
10"	61	0	52	78	0	0	0	0	84	24	0
13"		1	58				12			29	
19"	77								106		
22"	82	5	68	100	0	0	26	24	123	45	4
25"	94	0									
30"		1	60	71	0	0					
32"	81			67	0	0	28	15	97	36	7
37"	82	0	56				71*	37*	98*	46*	25*
44"	78	5	73	60	0	0	56*	45*	130*	45*	40*
Cisne	102	37	123	160	58				143	109	95
Stoy						0	67	31	149	33	25
Target Yields:											
Base HCL[1]	108	108	108	108	108	108	108	108	108	108	108
Adjusted									97	61	

1/ Base target yields of high capability lands (HCL) for Captain permit area calculated by IL Dep of Agric. This base target yield is adjusted annually by a county success factor to adjust for weather variation.

*, TLG Ripped

Table 2. 1979-89 soybean yields on Captain Wedge.

Depth	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
						Yield, bu/a					
Topsoil/ Root Media:											
3"	19	0	9	16	0	0	14	2/		0	
6"	22	0	11	18	0	0	12			0	
10"	23	0	12	16	0	0	12			0	
13"		0	14	18	0	0					
19"	31						15				
22"	30	0	15	22	0	0	20			0	
30"		0	13	24	0	0					
32"	28	0					17			1	9
37"		0	18	25	0	0	27*				
44"	27	0	17	26	0	0	27*			3*	12*
Root Media Only:											
3"	10	0	9	15	0	0	16			0	
6"	12	0	12	18	0	0	19			0	
10"	11	0	11	18	0	0	24			0	
13"		0	14	20	0	0					
19"	14						25			0	
22"	16	0	18	23	0	0	29			0	
32"	13	0					22			1	9
37"		0	20	27	0	0	31*				
44"	12	0	19	26	0	0	24*			3*	13*
Cisne	42	28	22	48	15					22	26
Stoy						0	36			23	
Target Yields:											
Base HCL[1]	31	31	31	31	31	31	31	31	31	31	31
Adjusted										21	

1/ Base target yields of high capability lands (HCL) for Captain permit area calculated by IL Dep of Agric. This base target yield is adjusted annually by a county success factor to adjust for weather variation.

2/ Soybeans were not grown in 1986 and 1987.

*, TLG Ripped

Little significant yield response to topsoil replacement has occurred during the eleven years studied. Yields of both crops have been extremely low, and total crop failures on these highly compacted mine soils have occurred in years of moderate to severe weather stress. It is probable that response to soil horizon replacement would have been greater had crop yield not been so severely limited by soil physical problems. In order to address this issue, a deep tillage treatment (Kaeble-Gmeinder TLG-12) was applied to the thick end of the wedge design. The TLG-12 vibratory deep ripper uses a cut-lift operation to shatter the soil to a depth of 32-33" under favorable soil conditions. 1985-89 yield results of this tillage treatment is presented in Table 3.

Table 3. Yield response to the TLC deep tillage on the Captain Wedge.

Tillage Trt	1985	1986	1987	1988	1989
			Yield, bu/a		
			Corn		
TLGl	57 a	40a	119a	39 a	33 a
No TLG	24 b	19b	123a	32a	10 b
Target Yield-HCL	108	108	108	108	108
Adjusted			97	61	
			Soybeans		
TLG	27 a			3	12a
No TLG	21 b			1	9a
Target Yield-HCL	31			31	31
Adjusted				21	

1/ TLG refers to Kaeble-Gmeinder TLG-l 2 deep ripper which has an effective tillage depth of 32-33 inches.

Corn yields were significantly higher for the TLG treatment in three of the five years and in one year for soybeans. Yields for the TLG treatment were still well below calculated target yields in most years. Very good corn yields were obtained on both the TLG and No TLG treatment in 1987. Weather in that year was characterized as having considerably above normal rainfall with little or no weather stress throughout the growing season. This data suggests that even though significant responses have occurred, a deeper tillage treatment may be necessary to achieve productivity levels on these highly compacted scraper placed soils.

Captain Mix: Excellent corn and soybeans yields have resulted on these low strength soils in high stress as well as low stress years. Rowcrop yields comparable to those obtained on nearby undisturbed soils have been achieved in all nine years of this study (Table 4). This is due to the excellent physical properties obtained through this soil handling and minimal grading soil reconstruction process. These wheel-conveyor spreader mixture plots have subsoils consisting of pockets of compacted material within **a** framework of loosely compressed aggregates of varying sizes. McSweeney and Jansen (1984) described a "fritted" soil structure in these replaced soil materials. Fritted structure has been defined an artificial soil structure consisting of rounded loose aggregates formed by rolling along the soil conveyor. This structure gives the soil a low strength and a high content of macropores. The extensive void spaces between aggregates allow for excellent root penetration. Roots are diffusely distributed to depths of 60" or more in these mine soils and growing crops persist through much more severe drought periods than on severely compacted soils (McSweeney and Jansen, 1984).

Penetrometer data taken in May 1989 (Table 5) reflect the excellent physical condition resulting from replacement of rooting materials with the wheel-conveyor spreader system. Significant differences in mean treatment penetrometer values exist, however, the magnitude of soil strength levels are quite low compared to the scraper hauled system. Results do indicate that topsoil grading did have an effect on the 9-18" depth segment. Topsoil replaced treatment soil strength readings were significantly higher than the non-topsoiled plots at this depth.

Topsoil, which was replaced with the soil spreader and dozer graded, has infrequently produced any significant yield response. Both topsoil and non-topsoil treatments have been able to produce corn and soybean yields comparable to those obtained on the undisturbed tracts (Figure 3).

Table 4. 1981-89 corn and soybean yields on the Captain Mix experiment

Soil Trt	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean
					Yield, bu/a					
					Soybeans					
A/3[1]	35 a	49 a	18 a	31 ab	45 a	3/		23 a	27 a	32
A/10	29 bc	38 b	14 ab	31 ab	43 a			25 a	24 b	29
A/15	26 c	40 b	15 ab	32 a	43 a			23 a	26 a	29
A/20	27 bc	41 b	13 ab	32 a	40 ab			23 a	23 b	29
10' Mix	25 c	39 b	11 b	27 ab	36 b			21 a	22 b	25
20' Mix	31 b	43 ab	12 ab	27 b	35 b			21 a	19 c	27
Cisne	22 c	48 a	15 ab					22 a	26 a	
Stoy				0	36 b			23 a		
Target Yields:[2]										
Base Prime	36	36	36	36	36			36	36	
Adjusted								27		
Base HCL	31	31	31	31	31			31	31	
Adjusted								21		
					Corn					
A/3	113 a	144 abc	72 a	125 a	109 ab	111 a	152 cd	79 c	123 a	114
A/10	83 c	152 ab	52 ab	113 ab	93 c	115 a	167 ab	89 bc	127 a	110
A/15	105 ab	121 d	69 ab	115 a	110 a	109 a	163 bc	86 c	133 a	112
A/20	92 bc	130 cd	53 ab	108 ab	96 bc	99 a	177 a	85 c	119 a	95
10' Mix	56 d	145 ab	47 ab	98 b	76 d	69 b	152 cd	90 bc	121 a	95
20' Mix	81 c	140 bc	40 b	99 b	81 cd	107 a	146 d	100 ab	155 ab	101
Cisne	123 a	160 a	58 ab				143 d	109 a	95 b	
Stoy				0	67 d	31 c	149 cd	33 d	25 c	
Target Yields:										
Base Prime	119	119	119	119	119	119	119	119	119	
Adjusted							136	85		
Base HCL	108	108	108	108	108	108	108	108	108	
Adjusted							97	61		

1/ Values followed by the same letter within a crop and year are not significantly different at the 0.05 level. Soil treatments are as follows: A/3, topsoil replaced over a mixture of the top 3 ft of original soil; A/10, topsoil replaced over a mixture of the top 10 ft; A/15, topsoil replaced over a mixture of the top 15 ft; A/20, topsoil replaced over a mixture of the top 20 ft; 10' Mix, a mixture of the top 10 ft of original soil, including topsoil; 20' Mix, a mixture of the top 20 ft of original soil, including topsoil.

2/ Base target yields of prime lands and high capability lands (HCL) for Captain permit area calculated by IL Dep of Agric. This base target yield is adjusted annually by a county success factor to adjust for weather variation.

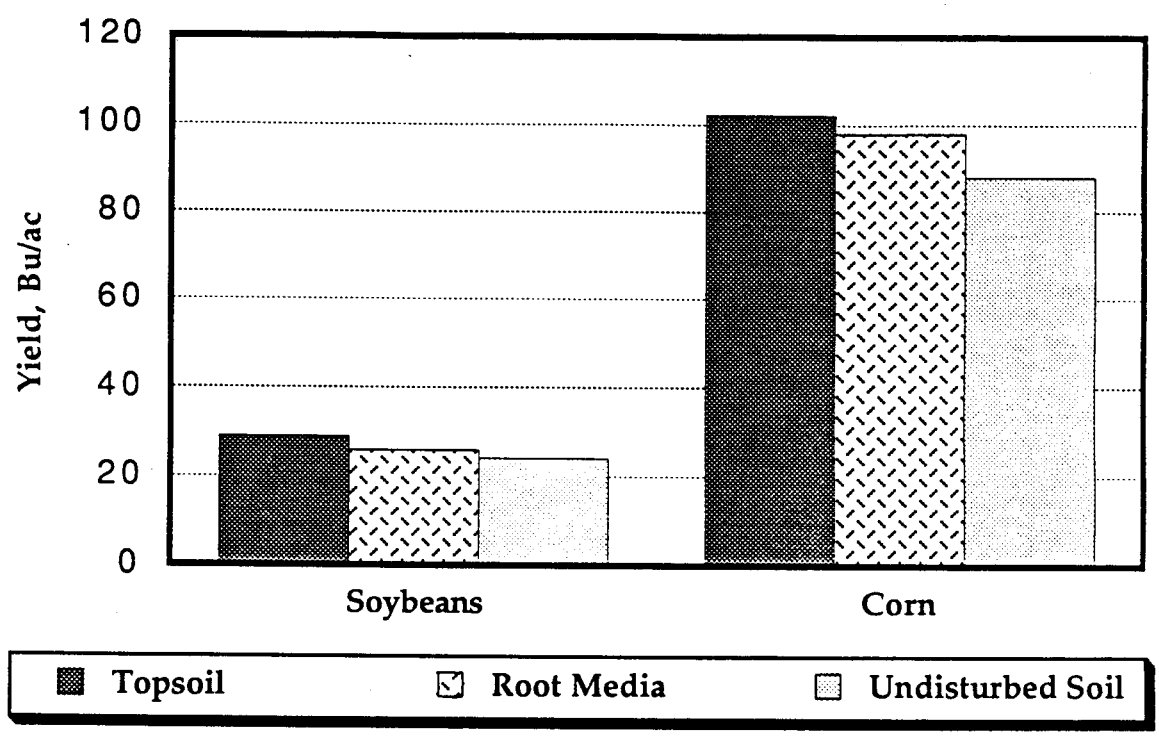
3/ Soybeans were not grown in 1986 and 1987.

Table 5. Mean penetrometer resistance values for soil treatments on the Captain Mix plots.

Treatment	9-18"	18-27"	27-36"	36-44"
		Penetrometer Resistance, PSI		
A/3[1]	178.7 abc	97.4 d	76.7 b	97.9 b
A/10	183.1 ab	135.5 bc	91.4 b	96.2 b
A/15	209.6 a	161.2 ab	124.6 a	111.3 ab
A/20	219.2 a	175.6 a	117.4 a	108.3 ab
10' Mix	134.6 c	102.5 b	100.2 ab	170.1 a
20' Mix	121.4 c	110.0 cd	100.9 ab	111.5 ab
LSD (0.05)	57.6	30.3	37.5	61.9

[1/] Values followed by the same letter within a depth segment are not significantly different at the 0.05 level. Soil treatments are as follows: A/3, topsoil replaced over a mixture of the top 3 ft of original soil; A/10, topsoil replaced over a mixture of the top 10 ft; A/15, topsoil replaced over a mixture of the top 15 ft; A/20, topsoil replaced over a mixture of the top 20 ft; 10' Mix, a mixture of the top 10 ft of original soil, including topsoil; 20' Mix, a mixture of the top 20 ft of original soil, including topsoil.

Figure 3. 1981-1989 mean yields for topsoil and root media treatments.

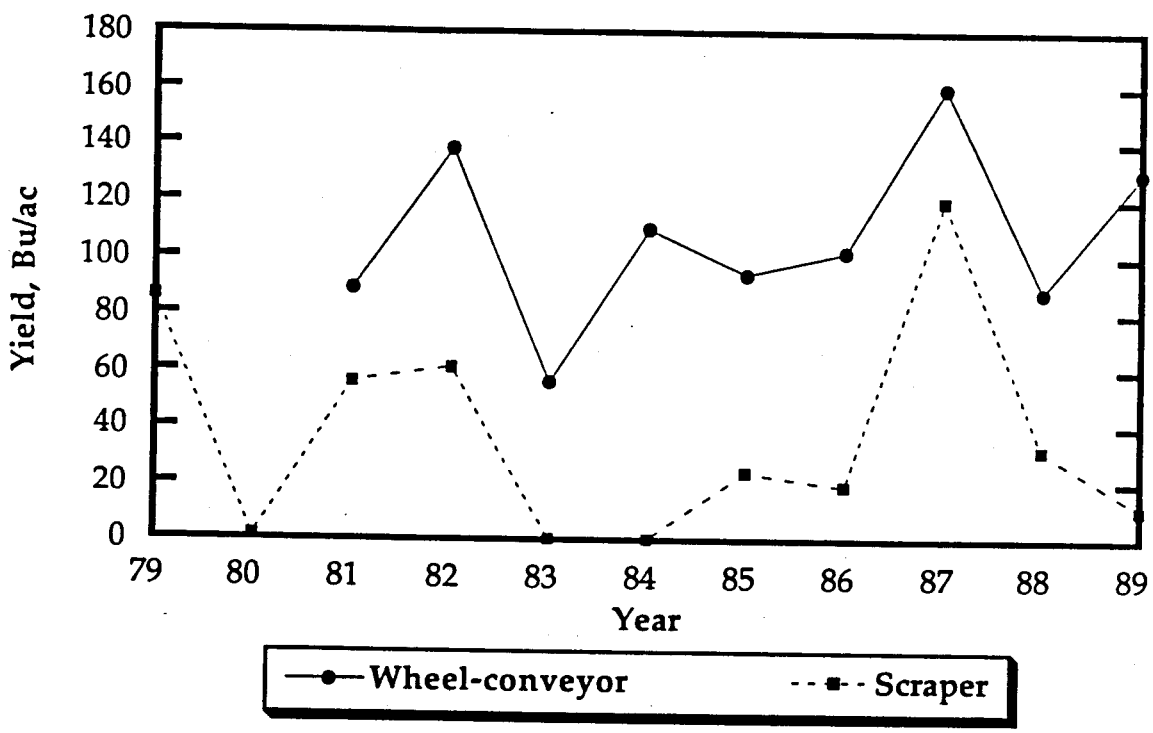


Captain Summary: Results from the Captain Mine experiments demonstrate that poor physical condition is the most severe and difficult limiting factor in the reclamation of farmland soils. Segregation and replacement of horizons from premine soils is a practice that is required by law, and we should strive to select the best possible rooting materials for reclamation, but desirable physical properties is essential to attaining productivity levels necessary for bond release. Productivity

success of this concept becomes quite evident when comparing the A/3 treatment on the wheel-conveyor mixture plots and the topsoil/scraper root media from the wedge plots. These soils were constructed with essentially the same soil materials; A horizon overlying B horizon. But the A/3 mix treatment has produced significantly higher corn and soybean yields in every year studied. The major difference between the two mine soils is the method of soil replacement.

Although the mining wheel-conveyor spreader system has proven successful in constructing productive soils after surface mining, it does not offer a generally applicable solution to the problem of restoring land to agricultural productivity after mining. It is a very inflexible system which can not be used at most mine sites. Evident options are to either develop a method by which excessively compacted soils can be ameliorated to a significant depth or to develop other material handling options which will produce soils with good physical characteristics, and will be more cost competitive and applicable. Natural soil improvement processes are slow, especially at greater depths, as is evident from the 10 year corn yield trends from the wedge and mix plots (Figure 4). Year to year and across years variation is associated more with weather stress and management factors than any measurable natural soil improvement.

Figure 4. Mean corn yields across soil treatments for Captain sites.



Denmark Mine

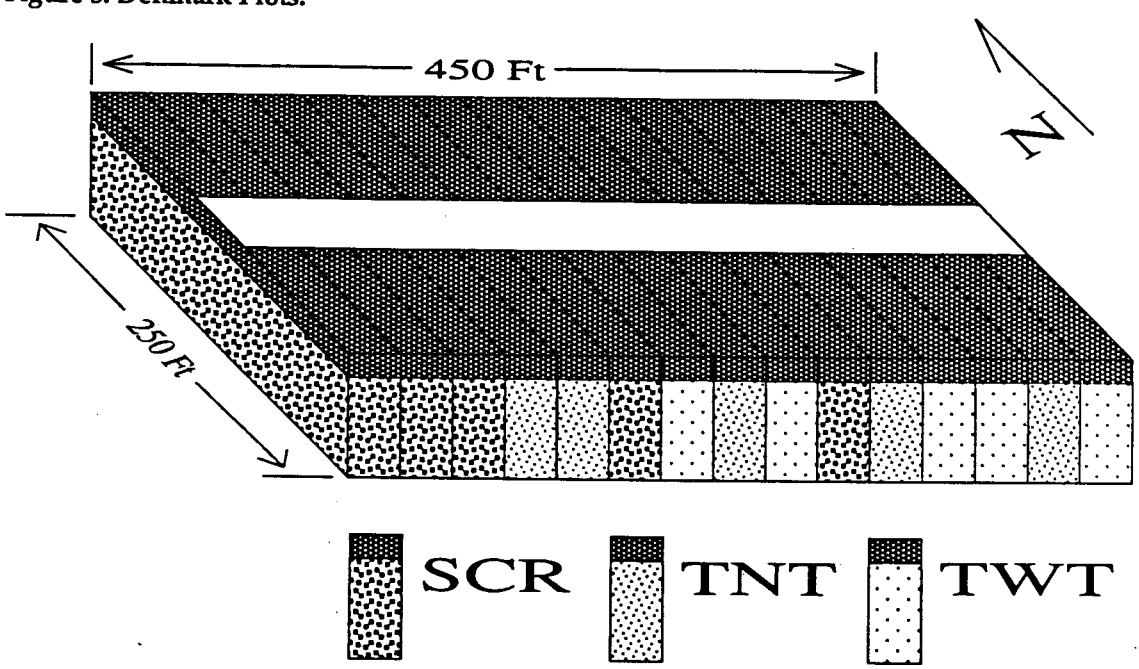
Site and treatment description: The Denmark Mine, Arch of Illinois, Inc. is located in Perry County near Willisville in southwestern Illinois. It is located adjacent and immediately south of the Captain mine. Experimental plots located at this site were established to evaluate an alternative material handling system than scrapers in mine soil reconstruction. The construction of these plots were completed in July of 1984 with the first cropping year in 1985. The experimental design (Figure 5) consisted of completely randomized design with five replications of three material handling treatments:

1) SCR; topsoil replaced over scraper hauled rooting media.

2) TNT; topsoil replaced over truck hauled rooting media without surface traffic on root media. In this treatment the trucks were driven on the base (shovel spoil) material only and never on the root media itself.

3) TWT; topsoil replaced over truck hauled rooting media in which the truck traffic was on the root media itself.

Figure 5. Denmark Plots.



During construction, the base material (spoil) was graded and the scraper plots were completed. Truck hauled material was shovel loaded from a stockpile and placed from the base level. The plots selected for surface traffic were compacted as uniform as possible using an empty DJB rear-dump truck. The soil moisture was quite high and a heavier load could not be supported. Ridges between tire tracks were leveled to provide a more uniform topsoil depth. Topsoil was lifted from the

high-wall side from a field just north of the plot area. Windrows were built on the north and center tumstips of the plots. Topsoil was then pushed out and leveled with dozers.

A nearby tract of Cisne silt loam (Mollic Albaqualf) and Stoy silt loam (Aquic Hapludalf) are used as unmined comparisons. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation. Corn (*Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental designs. Grain yield samples for corn were harvested after black-layer formation on the kernel indicated physiological maturity and soybeans were harvested when all pods were brown and dry. Grain yield estimates are based on the amount of shelled grain after adjusting for variation in moisture content of grain to 15.5 % for corn and 12.5 % for soybeans.

Objectives of the Denmark Site:

1) Evaluate the effect of rooting media replacement methods on rowcrop performance.
2) Determine the rowcrop yield potential of reclaimed land, immediate and the trend over time.
3) Determine the relationship between crop yields on reclaimed land and those on nearby undisturbed land.

Denmark Results and Discussion: The constant rate cone penetrometer was used (April, 1987) to record soil strength measurements of the different soil replacement methods (Table 6). Soil strength levels of the scraper hauled treatment (SCR) were significantly higher than the truck without traffic (TNT) for all four segment depths. The truck with traffic treatment (TWT) was numerically lower than the SCR treatment and numerically higher than the TNT treatment but was not significantly different from either at the 0.05 level of significance. In summary, soil strength values decreased with decreasing traffic.

Table 6. Mean penetrometer resistance values for soil treatments at the Denmark Mine.

Treatment	9-18"	18-27"	27-36"	36-44"
	Penetrometer Resistance., PSI			
SCRl	271.7 a	274.1 a	257.8 a	258.1 a
TWT	123.2 ab	226.9 ab	213.0 ab	216.7 ab
TNT	182.0 b	188.5 b	161.3 b	172.3 b
LSD (0.05)	70.2	60.1	53.7	47.7

1/ Treatments are as follows: TNT. truck-placed rooting media with no traffic allowed on mot media surface; TWT, truck-placed rooting media with the truck traffic directly on root media surface; SCR, scraper-placed rooting media.

1985 to 1989 corn and soybean yield response shows similar trends to that of the soil strength data. The truck hauled without traffic treatment (TNT) has produced the highest mine soil corn yields in every year of the study (Table 7). These yields have also been comparable to the corn yields of the undisturbed soils in every year. Corn yields of the truck with traffic (TWT) and the scraper haul treatment (SCR) have not been significantly

different in any year. Soybean yield response has been somewhat more variable but similar trends have occurred. TNT soybean yields were comparable to the undisturbed soils in three of the five years. TWT and SCR treatment soybean yields were not significantly different in all five years.

Net water extracted by the growing crop has been highest for the truck without traffic (TNT) treatment and the lowest for the scraper treatment. There is no reason to expect significant differences among these treatments in water infiltration, because all three treatments were topsoiled in exactly the same way. The higher net extraction likely indicates that more total water was available to and used by the growing crop. The yield data supports that conclusion, in that the TNT treatment produced significantly higher yields. Teyker (Second Annual Report, 1989) has reported significantly lower root length densities for the scraper treatment at the 18-24" and 28-33" depths compared to the truck hauled treatments.

Table 7. 1985-89 corn and soybean yields at Denmark Mine.

Soil Trt	1985	1986	1987	1988	1989	Mean
			Yield, bu/a			
			Corn			
Truck hauled w/o traffic[1]	98 ab	64 a	146 a	91 a	93 a	99
Truck hauled with traffic	85 bc	48 ab	110 b	56 b	58 b	72
Scraper placed	74 c	37 b	116 b	45 bc	47 b	64
Cisne			143 a	109 a	95 a	
Stoy	115 a	31 b	149 a	33 c	25 c	
Target Yield-HCL[2]	89	89	89	89	89	
Adjusted Target			102	64		
			Soybeans			
Truck hauled w/o traffic	29 b	23 ab	36 a	2 b	24 a	22
Truck hauled with traffic	24 b	18 bc	30 bc	2 b	16 b	19
Scraper placed	26 b	16 c	27 c	3 b	12 b	17
Cisne			36 ab	22 a	26 a	
Stoy	36 a	28 a	32 abc	23 a		
Target Yield-HCL[2]	29	29	29	29	29	
Adjusted Target			29	22		

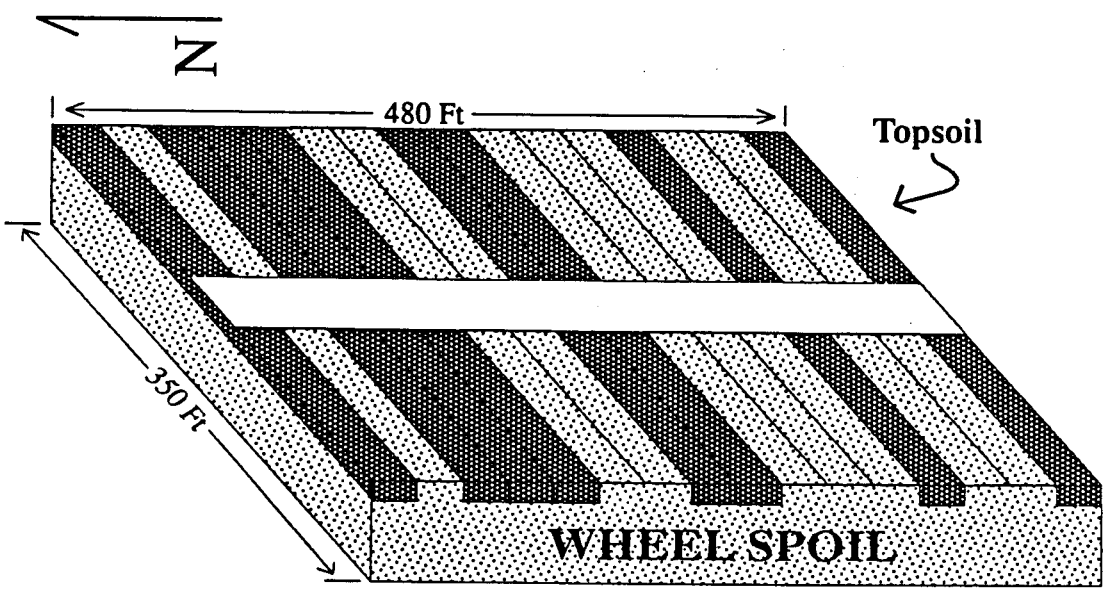
1/ Values followed by the same letter within a crop and year are not significantly different at the 0.05 level.

2/ Base target yields of high capability lands (HCL) for Denmark permit area calculated by IL Dep of Agric. This base target yield is adjusted annually by a county success factor to adjust for weather variation.

River King Mine

Site and treatment description: The River King Mine, Peabody Coal Company, in located near Marissa in Randolph county in southwestern Illinois. These plots were constructed in 1977, first cropped in 1978. The disturbed soils at this site consist of graded wheel spoil with and without replaced A horizon (topsoil) from the premine soils. Topsoil replacement was done with scrapers. The experimental design is a completely randomized design with eight replications of the two mine soil treatments (Figure 6). The overburden materials from which the wheel spoil was derived consisted of about 7 feet of loess with a claypan soil developed in the upper part of it, Illinoian till with a Sangamon paleosol developed in the top 5 feet of it, and some soft shales (Snarski et al., 1981). During excavation, the mining wheel effectively blended the loess, till and soft shales. In an adjacent area, a subsequent treatment of 24" of scraper hauled B horizon material replaced over the wheel spoil was added as an additional comparison. About 9" of previously segregated topsoil was then deposited on the root medium zone using scrapers and dozers.

Figure 6. River King Plots.



A nearby tract of Cisne silt loam (Mollic Albaqualf) was used as an unmined comparison. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation. Corn (*Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental designs. Grain yield samples for corn were harvested after black-layer formation on the kernel indicated physiological maturity and soybeans were harvested when all pods were brown and dry. Grain yield estimates are based on the amount of shelled grain after adjusting for variation in moisture content of grain to 15.5 % for corn and 12.5 % for soybeans.

Objectives of the River King Site:

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

2) Evaluate rowcrop performance response to A horizon replacement.

3) Compare yield response of topsoil/scraper hauled root media to that of wheel spoil.

Results and discussion: Yield results from the River King site are presented in Table 8. Topsoil replaced over graded wheel spoil with scrapers significantly increased corn yields in only one out of nine years. Soybean yields were significantly higher on the topsoil replaced treatment in four out of seven years. Rooting medium replaced to a 24" depth over graded wheel spoil resulted in a significant yield decrease in seven of nine years for corn and five of seven years for soybeans. Compaction caused by the use of scrapers to replace rooting media is attributed to the low performance on these materials.

Table 8. Corn and soybeans yields from River King.

Soil Trt	1979	1980	1981	1982	1983	1984	1985	1988	1989	Mean
					Yield, bu/a					
					Soybeans					
TS/WSP[1]	24 a	12 b	28 a	24 b	3	2/		25 ab	24 a	20
WSP	14 b	19 a	18 b	12 c	2			21 b	19 b	15
TS/RM	14 b	10 b	19 b	23 b	0			11 c	16 b	13
Cisne				34 a	13			28 a	28 a	
					Corn					
TS/WSP	53 b	12 a	109 a	87 b	14 a	60 b	62 ab	41 bc	87 a	58
WSP	67 a	9 a	101 a	66 c	24 a	52 b	52 b	46 b	74 a	55
TS/RM	45 b	1 b	87 b	59 c	0	18 c	20 c	25 c	30 b	32
Cisne				137 a	16 a	106 a	84 a	69 a	89 a	

1/ Soil treatments are as follows: TS/WSP, topsoil replaced over wheel spoil; WSP, wheel spoil only; TS/RM, topsoil replaced over 24" of scraper hauled root media deposited over wheel spoil. Yield values within a crop and year followed by the same letter are not significantly different at the 0.05 level

2/ Soybeans not harvested in 1984 and 1985.

Crop performance on all three mine soils can be characterized as low. Extensive grading and traffic zones between the topsoil and wheel spoil has negatively affected the ability of rowcrops to develop roots systems to adequately take up nutrients and water (Meyer, 1983). Restricted flattened roots are often observed in these mine soils, and roots primarily penetrate along vertical fissures and crack faces. There has generally been little lateral branching and little proliferation into the dense soil matrix. In the subsoil, both the wheel spoil and

hauled rooting medium have high bulk densities (1.7 to 1.82 g cm-3) and structure is described as **massive.** These dense massive materials not only limit root penetration and decrease water uptake, they also prohibit the infiltration of water into the subsoil. Very low infiltration rates of 0.15 and 0.06 cm hr^{-1} have been measured on these plots (Meyer, 1983). Very little subsoil recharge can then occur.

Correlation of Penetrometer Data and Rowcrop Yield

Soil strength measurements with the constant rate recording penetrometer (Hooks and Jansen, 1985) have been recorded on most reclamation research plots. This data has been consistently taken in the spring when soils are uniformly moist to minimize the effects of variable soil moisture on penetration resistance. Sampling of each location has consisted of taking four samples per treatment replicate and two sub-samples per sample. The penetrometer samples sites correspond to the harvest sites for yield determination. Subsamples are are averaged for each of the 50 readings that make up a profile to leave one average profile per sample. The average profile for each sample is then broken down into five segments and an average penetrometer resistance reading is calculated that represents 9" of the total profile. Penetrometer segments are broken down as follows:

Segment 1	O-9"	Segment 1 is not used in any
Segment 2	9-18"	of the analysis because it covers the
Segment 3	18-27"	conventional tillage zone and has
Segment 4	27-36"	been altered from its original
Segment 5	36-44"	condition.

Penetrometer measurements on mined land has resulted in wide ranging values between reclamation treatments. These correspond to wide ranging values in crop yield. In general, reclamation treatments with high levels of soil strength (compaction) have had the lowest crop yields, while those treatments with low soil strength have had the highest yields. Correlation of penetrometer resistance with corn yield has been significant in most years for both corn and soybeans. The purpose of these analyses is to determine the relationship of penetrometer resistance data with long term yield results. Two experiments were selected for the database, the.Captain Mix and the Denmark truck plots in Perry County. These plots were selected for two reasons. 1) Because the mines are adjacent, the weather and natural soils'used in the reclamation process are similar. 2) These two experiments represent a wide range in yield and penetrometer values necessary for meaningful correlation between soil strength and yield response. Corn hybrids, fertility, and tillage management of these were the same. Consequently, any differences in yield variation can be associated to soil reclamation differences.

Figure 7. 1985-89 mean corn yields and soil strength (9-44" Avg).

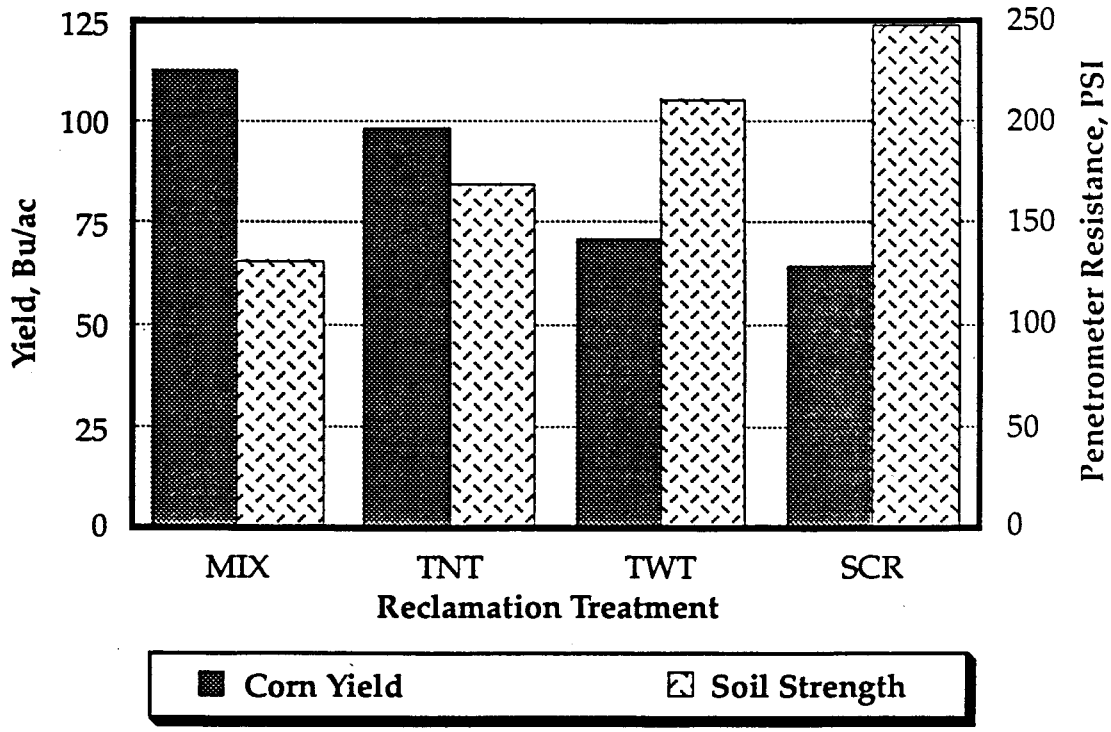


Figure 8. 1985-89 mean soybean yields and soil strength (9-44" Avg).

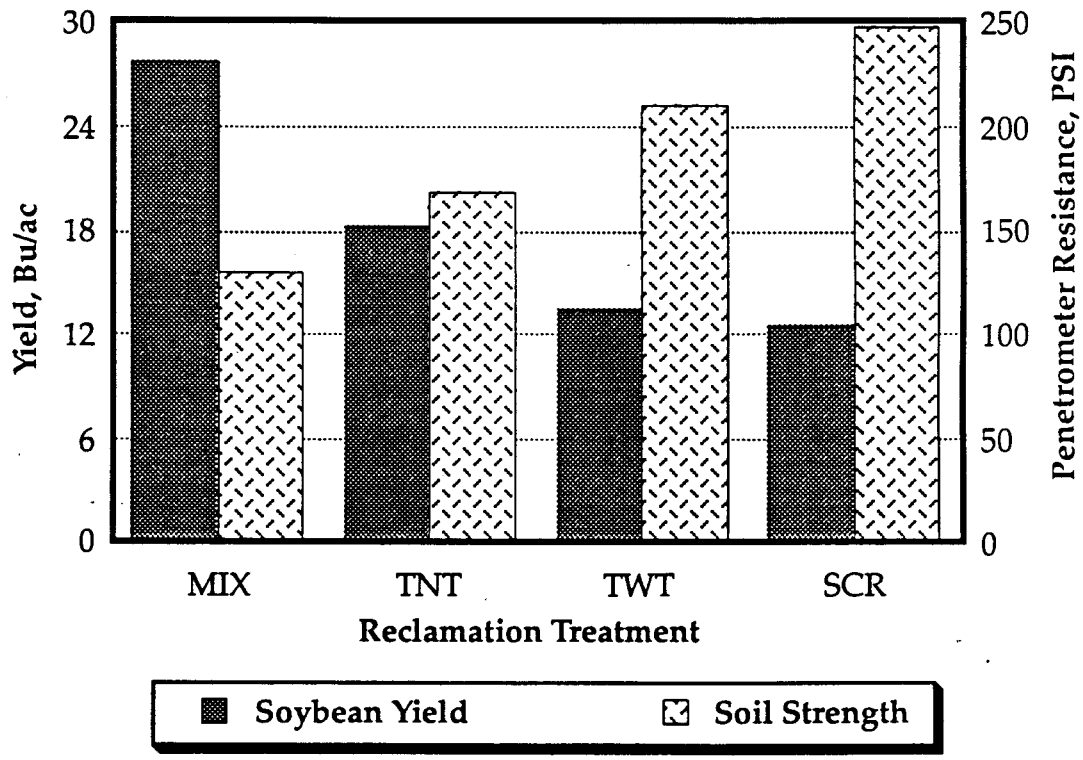


Table 9. Correlation between means of 1985-89 crop yields and penetrometer resistance.

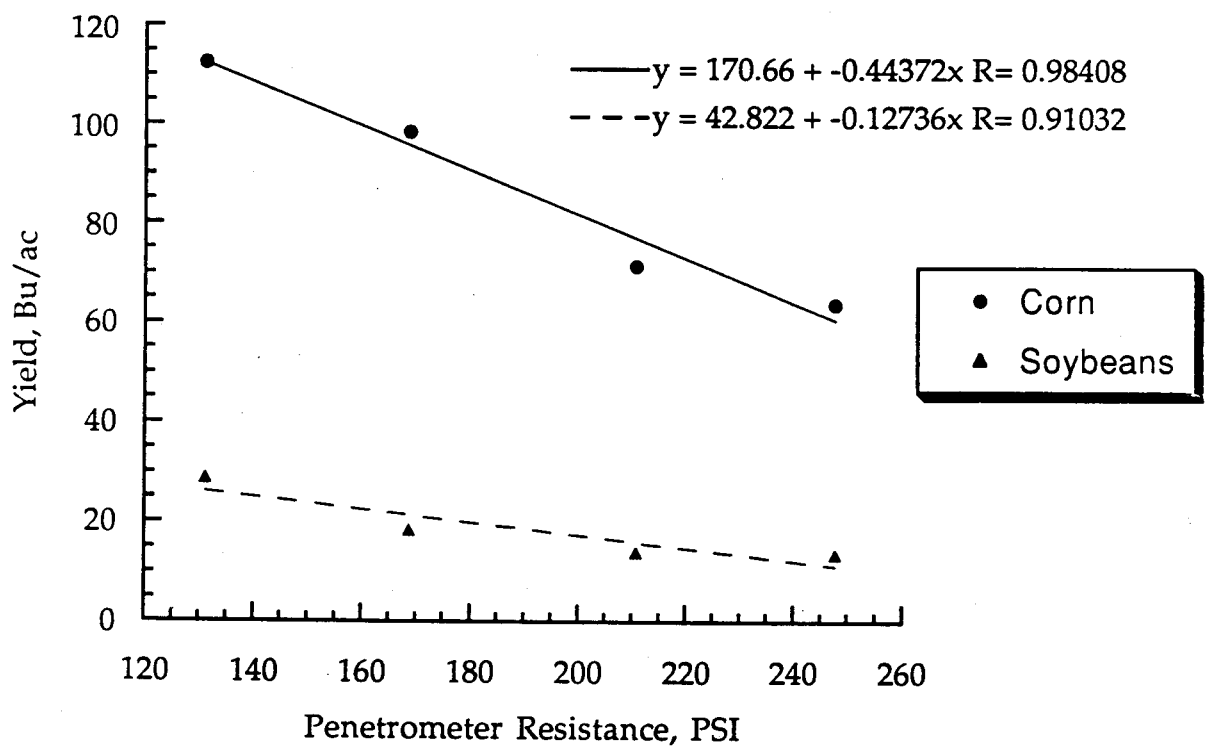
Segment Depth	Corn	Soybeans
	R^2	
9-18"	-0.9329+	-0.7452
18-27"	-0.9731*	-0.9435+
27-36"	-0.9814*	-0.9369+
36-44	-0.9907**	-0.9321+
Ave 9-44"	-0.9841*	-0.9103+

**, Statistically significant at the 0.01 level
*, Statistically significant at the 0.05 level
+, Statistically significant at the 0.10 level.

1985-89 mean corn yields and mean penetrometer resistance values averaged over the 9-44" depth are presented in Figures 7 and 8. Response is similar to that observed in individual years. Soil strength decreases with increasing yield. Treatments represented are; MIX, mean values for all treatments using the wheel-conveyor spreader method of soil construction; TNT, truck hauled rooting media with truck traffic restricted to operating on the base spoil; TWT, truck hauled rooting media with truck traffic on root media surface; SCR, scraper hauled root media.

Correlation of penetrometer resistance by segment depths and profile means (9-44") with five year crop yield means show the significant relationship of soil strength to yields of both corn and soybeans (Table 9). Corn seems to be more sensitive than soybeans to variation in soil strength. Figure 9 shows the relationship between average penetrometer resistance for the 9-44" segments and 5 year mean rowcrop yields.

Figure 9. 1985-89 Rowcrop yields and soil strength (9-44").



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EFFECT OF RECLAMATION METHOD ON MINESOIL PRODUCTIVITY IN ILLINOIS[1]

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Abstract

Reclamation studies have shown that poor soil physical condition is the most limiting factor to successful row crop production on mined land. Critical to success are selection of the best available soil materials used in soil construction and a material handling method that will minimize compaction. Excellent corn and soybean yields have been achievedon low soil strength soils in high stress as well as low stress years. Total crop failures have occured on high strength soils in years of weather stress. Deep tillage practices have been successful in improving compacted soils, but it is preferable to avoid compaction when the soil materials are handled. Soil strength measurements with a cone penetrometer have proven to be useful tools in evaluating rooting media and reclamation practices.

Introduction

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

Selection of Soil Materials

Segregation and replacement of horizons from the premine soils is a practice that is required by law under many conditions. Early reclamation research was focused on the evaluation and characterization of selected soil materials to be used for soil horizon replacement or substitution, if the substituted soil material could be shown to be as productive as the natural soil horizon it replaced. Construction of minesoils with good quality soil materials and desirable physical properties is essential to attaining productivity levels necessary for bond release.

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

Most of the Illinois research has centered around field experiments to evaluate row crop response to soil replacement and various reclamation practices. Premine soils ranged from the highly productive deep loess soils developed under prairie vegetation (Mollisols) at the western Illinois sites to the lighter colored more strongly

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developed Alfisols at the southern Illinois sites. Corn (*Zea mays* L.) and soybeans (*Glycine mar (L.)* Merr) were grown on these newly constructed soils to evaluate productivity. Following up on the greenhouse studies, most of the early field studies addressed' the issue of topsoil and subsoil horizon replacement.

Topsoil replacement has generally been beneficial for seedbed preparation, stand establishment. and early season growth when compared to graded spoil materials (Jansen and Dancer, 1981). Yield response to topsoil replacement has ranged from strongly positive to strongly negative. At the Norris Mine in western Illinois. scraper placement of 18 in. of dark prairie topsoil over graded wheel spoil resulted in a significant positive corn yield response in three of four years with irrigation and two of four when not irrigated (Table 1). Soybeans responded favorably to topsoil in one of the two years studied (Dunker and Jansen, 1987a). Significant negative yield responses to topsoil occured in years of weather stress. Year to year variation in corn yield was considerably greater on the unirrigated topsoil than the unirrigated wheel spoil. Compaction caused by the use of scrapers to replace topsoil is assumed to be the reason for low topsoil yields in years of weather stress. The zone directly below the topsoil has a bulk density of 1.7 to 1.9 Mg m3 and very low hydraulic conductivity.

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

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

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

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

At Sunspot Mine, in western Illinois, topsoil and B horizon replaced over dragline spoil was evaluated over an eight year period. Soil treatments consisted of 15 in. of topsoil replaced over replaced B horizon; 15 in. of topsoil replaced directly over dragline spoil; 36 in. of B horizon replaced directly over dragline spoil; and dragline spoil only. Bulldozers pushed the soil materials onto the plot areas; it is important to note that scrapers were never allowed directly on the plots at any time during construction. An undisturbed tract of Clarksdale soil (Udollic Ochraqualf) was used as an unmined comparison. Topsoil replacement resulted in significantly higher corn yields in four out of eight years when replaced over B horizon materials and six of eight years when topsoil was replaced directly over dragline spoil (Dunker and Jansen, 1987b). Corn grown on the topsoil replaced treatments had a higher percent stand at harvest, fewer barren stalks, and a higher shelling percentage than corn on the non-topsoil treatments. Soybean yields on the topsoil replaced treatments were significantly higher than yields from both non-topsoil treatments in six of seven years. The topsoil/B horizon treatment produced corn yields comparable to the undisturbed Clarksdale in five of seven years while the B horizon treatment without topsoil produced corn yields comparable to the undisturbed in only one year. The dragline spoil was unable to equal corn undisturbed Clarksdale yields in any of the years studied, regardless of topsoil placement (Table 2). Fehrenbacher et al., (1982) found that corn roots penetrated significantly deeper in the B horizon materials than the dragline spoil and that bulk densities were significantly higher in the graded dragline spoil than the replaced B horizon at depths of 22 in. and deeper. Bulk densities between the B horizon material and the undisturbed Clarksdale were similar. It is not possible to determine whether the favorable response to the B horizon treatment was due to the B horizon material or to the lower soil strength that resulted from the careful handling.

Response to soil horizon replacement in southern Illinois has been less dramatic than has been observed at the western Illinois sites (Table 3). This is understandable considering that A horizons are more highly weathered and average 8 to 9 inches in depth compared to 15 to 18 inches in the highly productive western Illinois soils. At River

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

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

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

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

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

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

King in southern Illinois, topsoil replaced by scrapers over wheel spoil significantly increased corn yields in only one of eight years and soybeans in three of six. Row crop yields were lower than productivity goals and soil physical problems became suspect.

Soil horizon replacement and thickness of soil materials from southern Illinois has been studied at the Captain Mine where the natural soils have chemical and physical problems that limit productivity. The Captain wedge experiment was used to evaluate corn and soybean yield response to thickness of scraper placed rooting medium (0 to 48 in. thick) over graded cast overburden, with and without topsoil replaced. Yields of both corn and soybeans increased with increasing thickness of hauled material to about the 24 to 30 in. depth. Meyer (1983) found very few roots below the 24 in. depth and found that roots in the subsoil were largely confined to desiccation cracks. The subsoil physical condition can best be described as compact and massive with very high bulk density levels and poor water infiltration. Soybean yields on the scraper placed root medium with and without topsoil were significantly lower than a nearby undisturbed tract in all seven years of the study. Corn yields were comparable to the undisturbed site in three of the years that can be characterized as low stress years (Table 4).

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

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

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

Soil Physical Properties

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils. Indorante et al. (1981), in a comparison of mined and unmined land in southern Illinois, reported that reconstructed mine soils studied had higher bulk densities and they lacked any notable soil

structure. Natural improvement in compacted mine soils is a slow process. Thomas and Jansen (1985) studied soil development in eight mine spoils ranging in age from 5 to 64 years looking at physical. chemical. and micromorphological properties. All eight minesoils showed some evidence of soil development, but depth of structure development ranged from only 1.5 in at the 5 year old site to 14 in. at a 55 year old site. No evidence of clay translocation attributable to soil development was found Color and texture pattern changes were determined to be a result of the mixing of materials rather than developmental processes.

Illinois has an abundance of high quality soil materials to use for soil construction, and row crop success on mine land has been as dependent upon the method by which soil horizons have been excavated and replaced as the quality of soil materials selected. Excellent corn and soybean yields have been achieved on low soil strength soils in high stress as well as low stress years. Soil horizon segregation and replacement in Illinois has generally shown a moderate positive yield response in most cases; however, the soil physical condition that is established during soil construction is clearly a more significant concern (Jansen and Dancer, 1981).

McSweeney and Jansen (1984) studied the soil structure patterns and rooting behavior of corn in constructed soils. On a site that received extensive grading of the subsoil, the subsoil was severely compacted and massive. Root penetration into these subsoils was extensively horizontal instead of the normal vertical direction. Cross sections of the roots were noticeably flattened and compressed. McSweeney described a "fritted" soil structure in areas where soil materials were handled by a mining wheelconveyor-spreader system where only minimal grading is necessary. Fritted structure was defined as an artificial soil structure consisting of rounded loose aggregates formed by the action of the wheel excavator and the subsequent tumbling at each drop point on the conveyor system. The soil conveyor system resulted in a low strength soil high in macropores. Although subject to compaction at the upper surface, the extensive void spaces between aggregates allow for excellent root penetration. Four year average corn and soybean yields on these plots with well developed fiitted structure were equal to or better than yields obtained on nearby natural soils (McSweeney et al., 1987). By contrast, corn and soybean yields from a nearby set of plots with root media replaced entirely by scrapers were unable to produce comparable yields to the undisturbed soil in any of these four years. The rooting materials for both experiments were similar with the major difference being in the way the soil materials were replaced.

The Captain Mix Plots, constructed using the wheelconveyor-spreader, were designed to follow up a series of greenhouse experiments which began in 1977. Greenhouse evaluation revealed that alteration of the claypan soils in southern Illinois would increase crop growth by enhancing the chemical and physical properties of the reclaimed land. The Captain Mix Plots consist of several treatments that are composed of differents depth mixes of the original soil profile replaced by the conveyor-spreader. Excellent corn and soybean yields have resulted on these low strength soils in high stress as well as low stress years. Penetrometer data from the Mix Plots reflect the excellent physical condition resulting from placing rooting materials with the wheel-conveyor system (Table 5). Rowcrop yields comparable to those obtained on nearby undisturbed soils were achieved in all eleven years of this study (Dunker et al., 1992). Topsoil replaced with the soil spreader on these plots only infrequently produced any significant yield response (Table 6).

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

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	36-44" Depth PSI
Topsoil/3 ' Mix	179 abc	97 d	77 b	98b
Topsoil/10' Mix	183 ab	136 bc	91 b	96 b
Topsoil/l5' Mix	210 a	161 ab	125 a	111 ab
Topsoil/20' Mix	219 a	176a	117a	108 ab
10' Mix	135 c	103 b	100ab	170a
2O' Mix	121c	110 cd	101 ab	112 ab

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

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

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

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

Although the mining wheelconveyor-spreader system proved successful in constructing productive soils after surface mining, it does not offer a generally applicable solution to the problem of restoring land to agricultural productivity after mining. It is a very inflexible system which can not be used at most mine sites. Evident options are to either develop a method by which excessively compacted soils can be ameliorated to a significant depth or to develop other material handling options which will produce soils with good physical characteristics and will be more cost competitive and applicable than the conveyor system.

As an alternative to the wheel-conveyor system, corn and soybean response to mine soil construction with rear-dump trucks and scraper pans was studied from 1985-91 at the Denmark Mine in southern Illinois (Hooks et al., 1992). Two truck-hauled treatments, one which limited truck traffic to the spoil base only, and one which allowed truck traffic on the rooting media as it was placed were evaluated. A third treatment consisting of entirely scraper hauled rooting media was included. The rooting media was comprised primarily of the B horizon of the natural unmined soil and all treatments had 8 inches of topsoil replaced on the rooting media using dozers to prevent wheel traffic compaction. Significant differences in soil strength, a measure of soil compaction, and rowcrop yields were observed among treatments over 'the five year period. The lowest soil strength and highest rowcrop yields occurred on the truck without traffic treatment. Soil strength and yield response were similar for both the truck with surface traffic and the scraper treatments (Table 7 and Table 8).

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

Treatment	9-18" Depth PSI	18-27" Depth PSI	27-36" Depth PSI	3644" Depth PSI
Truck Placed Root Media w/o Traffic	182 b	189 b	161b	172 b
Truck Placed Root Media with Traffic	223 ab	227 ab	213 ab	217 ab
Scraper Placed Root Media	272 a	275 a	258 a	258 a

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

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

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

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

Severe compaction and compacted interfaces between soil layers have proven to be major problems which can limit the productivity of reclaimed soils. A truck handling system, which handles both topsoil and subsoil in one operation, was evaluated at Cedar Creek Mine in western Illinois from 1992-94. During plot construction each rear-dump truck was loaded with the equivalent of 36 in of subsoil and 12 in. of topsoil on top of the load. Subsoil and topsoil dumped in one operation eliminated the need for topsoil replacement by scapers. Some mixing of the topsoil and subsoil occured but the majority of topsoil remained at the soil surface. Thin lenses of topsoil extended into the subsoil material. These lenses could actually encourage root exploration into the subsoil below. Two other treatments, one being rear-dump truck placed subsoil with scraper placed topsoil and the other rear-dump truck placed subsoil without topsoil, were included in the evaluation. Penetometer resistance data collected in 1994 indicated that wheel traffic from the use of scrapers to replace topsoil had a negative impact on the underlying placed subsoil. Soil strength values increased due to scraper tragic by 82% over that of the one operation rear-dump system The 1992-94 mean yields indicate the system using rear-dump trucks to simultaneously replace both rooting media and topsoil is superior to using scrapers to replace topsoil over hauled rooting media. Results also show a significant response to topsoil replacement using this system (Table 9).

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

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

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

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

Penetrometer data has proven useful for evaluating the soil strength effects of several reconstruction methods, of high traffic lanes on reclaimed areas, and of tillage methods for alleviating compaction (Vance et al., 1987). Soil strength values decreased with decreasing traffic. Scraper soil material handling systems produced the highest soil strengths; soils from truck-haul systems were intermediate; and soils built by a wheel-conveyor-spreader system had the lowest soil strength.

The relationship between soil strength levels measured with a recording cone penetrometer and five-year corn and soybean yields of four reclamation methods was studied at two mine sites in southern Illinois (Vance et al., 1992). Reclamation treatments included the wheel-conveyor system, truck-hauled root media with and without surface traffic, and a scraper-hauled rooting media system. Penetrometer measurements have resulted in wide ranging values between reclamation treatments and corresponding wide ranging values in crop yield. Correlation of penetrometer resistance with crop yield has been significant within most years for both corn and soybeans. Reclamation treatments with the highest soil strength had the lowest yields; those with the lowest soil strength had the highest yields. Average soil strength over the 9 to 44 in. profile depth was highly correlated with five-year mean yields across reclamation treatments.

Summary

In summary, results from the Illinois work shows that achieving mine land productivity is possible if reclamation plans are designed to minimize compaction, use good quality soil materials, and use high management levels (herbicides, fertility, adapted crop varieties) in rowcrop production. Illinois has an abundance of high quality materials to use for soil construction and row crop success on mined land has been dependent upon the method by which soil horizons have been replaced and the quality of the materials selected. Excellent corn and soybean yields have been achieved on low strength soils in high stress as well as low stress years. However crop failures have occurred when reclamation methods result in mine soils with high soil strength. Truck handling of rooting media with limited surface traffic has resulted in a more productive and less compacted soil compared to a high traffic scraper haul system for replacing root media. Compaction may be unavoidable in some reclamation systems. Ilhnois has continued deep tillage studies since 1984 to address this issue.

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Excellent agricultural soils after surface mining

I.J. Jansen and C.L. Hooks

Abstract — *Successful soil construction involves preparation of an adequate base, selection of high quality soil materials, and placement of those materials by means which will establish a continuous macropore network and modest to low soil strength. Where such has been accomplished, experiments reveal row crop productivity on reclaimed land which is very competitive with that on undisturbed land. Inferior productivity and sensitivity to drought stress are experienced where the soils are excessively compacted during construction. Some deep tillage practices have been quite successful in improving the compacted soils, but it is preferable to avoid compaction as the soil materials are handled.*

Soil construction considerations

The design for construction of a new soil after surface mining should provide for an adequate base, a suitable surface shape, selection of the best available materials for each layer in the new soil, and a material handling plan which will establish a desirable physical condition in each soil layer as the various selected materials are placed. Where this ideal is not fulfilled, methods of amelioration must be provided to achieve the same ends.

The term "soil" in this paper is used in the pedologic sense rather than in the engineering sense. That is, soil is the mantle of material at the earth's surface that supports or is capable of supporting plant growth. Soil serves as a plant root environment and typically contains living matter. Thickness of the soil mantle is highly variable in nature. We will arbitrarily use 1.3 m as an approximate thickness for constructed soils in the following discussion.

It is useful for planning purposes to think of the base and the soil as separate units, even though both will often be built in one operation. Separate construction of the soil and the base will be necessary at some sites.

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Construction of the base

Physical support is the main function of the base. A stable base can best be provided by selecting a high calcium/low sodium (Gee, et al., 1978) mineral material with a wide particle size range and a material handling method, which will deeply compact the material as it is being placed, to minimize subsequent differential settlement. Options for achieving the foregoing are very limited at most sites. Where the ideal is not feasible, the land surface should be graded to intentionally establish a surface shape with enough relief to minimize the effects of differential settlement, or to at least provide a proximate surface outlet for water when regrading to correct for settlement problems becomes necessary.

Surface shape

Surface shape should be largely established by the base (where the base and the soil are constructed by separate operations). The soil can then be placed over the base much as a blanket of more or less uniform thickness. Major shaping after placement of soil materials would cause unnecessary compaction and have deleterious effects on the soil.

The primary concerns in designing surface shape are: (1) to provide for adequate surface drainage so that ponding will be avoided, (2) to provide for water control so that erosion will be manageable, and (3) to provide for efficient operation of modern equipment appropriate for the intended land use.

Selection and placement of soil materials

It is useful to think of the soil as consisting of two separate layers, a surface layer and a subsoil layer, whether or not the two layers are actually built with different materials or by separate operations. The two layers do serve somewhat different needs in supporting plant growth, hence each has a unique set of optimum characteristics. Assume the surface layer to be 15 cm or more in thickness and the subsoil to form the balance of the 1.3 m soil layer arbitrarily defined before.

The surface layer: The surface soil must provide the medium for seed germination, seedling emergence, nutrient

storage, and effective plant rooting. It will supply most of the nutritional needs of plants and must maintain a soft, open surface that will allow water to infiltrate and be conducted down into the soil. Medium textured materials (moderate clay content and low to moderate sand content) having moderate to high organic matter content and high cation exchange capacity are desirable for the surface soil. Material from the premine topsoil commonly has the advantage of being higher in organic matter than other available materials. The organic matter is effective in adding cation exchange capacity to that provided by the clay minerals and in stabilizing soil structure, which maximizes infiltration rates and minimizes the tendency to form hard surface crusts. There is commonly a positive crop yield response to segregation of premine topsoil material for construction of the surface layer, but negative responses have been observed at some sites (Jansen, et al., 1985; Power, et al., 1981).

The subsoil layer: The most essential function of the subsoil for row crop production is to store water and readily supply it to growing crops. Some plant nutrients are also taken from the subsoil when available, but the nutritional needs of plants could be readily met in a well managed surface soil.

To most effectively serve the water storage function, a subsoil should have a continuous network of macropores (diameter greater than 50μm) to: (1) conduct water readily into and through the soil, (2) provide for good aeration so that plant roots will grow profusely, and (3) provide readily accessible channels for plant roots to follow. It should have a modest to low soil strength to enable growing roots to expand some pores which might otherwise have been too small for root penetration.

There should also be an extensive network of micropores (diameter less than 50μm), intersecting with the macropores, to sop up water as it moves down through the macropores and store it for later uptake by plant roots. Finally, the subsoil must be chemically and physically conducive to profuse root growth and diffuse root distribution.

The macropore network in natural soils is provided by soil structure. Soil structure is the stable physical relationship of individual soil particles to each other, which is established near the land surface over very long periods of time by natural soil developing processes. That natural structure will be disrupted when the soil is disturbed. Some soil construction methods have produced an effective artificial soil structure such that the resulting soils have proven to be highly productive (McSweeney and Jansen, 1984). Other methods tend to produce severely compacted soils which are unproductive due to high soil strength and for lack of an adequate pore network (Jansen, 1982).

The micropore network is largely a consequence of the particle size distribution of the soil material and the degree of compaction. Whereas a broad range in particle size was desirable for the base material, silt loam and light silty clay loam soil materials generally have the highest volume of micropores that are of the best size for storing water which is readily available for plant uptake.

Productivity of artificial soils

Productivity of soils constructed after mining ranges from very poor to excellent. The general practice now in prime farmland soil construction is to use materials that are equal to or better than those of the natural soils before mining. Different material handling methods and the varying degree of consequent compaction result in a wide range in row crop yield capability, even where similar soil materials were used (Table 1).

Table 1. Row Crop Yield Experience on Natural Soils and on Four Different Soils Constructed after Surface Mining.*

	Corn, kg ha⁻¹	Soybeans, kg ha⁻¹
Natural soils	5352	1645
Scraper-built soils		
topsoil replaced	1727	655
no topsoil	2229	702
Wheel-spreader soils		
topsoil replaced	6462	1960
no topsoil	5530	1830

*These data are four-year averages for 1981 through 1984, derived from McSweeney et al.

Evaluation of the soils in Table 1 with a recording cone penetrometer (Hooks and Jansen, 1986) reveals substantially higher soil strengths (Fig. 1) in the scraper-built soils, which are producing very poor yields, at that site than in either the natural soil or the soils built with a mining wheel-conveyor-spreader system. The latter system involves removing soil material from the highwall with a bucket wheel excavator, transporting it around the pit on a belt conveyor, and distributing it on the area being reclaimed with a spreader capable of controlling placement such that only minimal subsequent smoothing is needed (Blakley, 1980). Soil strengths in the 40 to 130 cm depth range are of most interest, because compaction in the top 40 cm can readily be corrected by tillage, or will be slowly improved over time by freeze-thaw and wet-dry stresses. Natural improvement is much slower at greater depths because of less frequent and less complete drying.

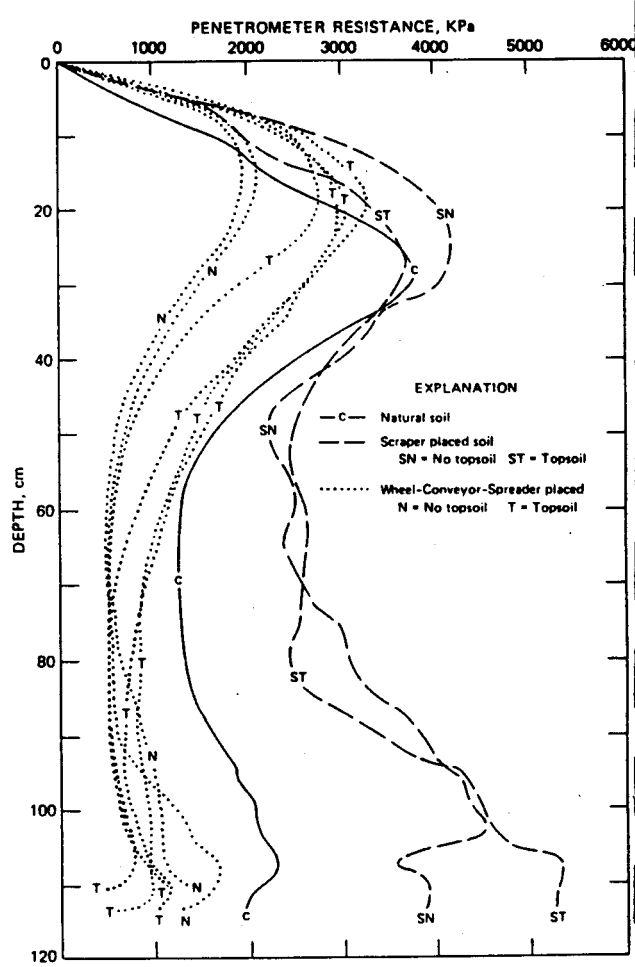

Figure 1 — Soil strength profiles for a natural soil and for artificial soils constructed by two alternative material handling procedures.

The scraper built soils also lack the macropore network needed to conduct water and to provide avenues for root growth. Crop root growth is restricted to approximately the top 60 cm in these soils as compared to 150 cm or more in less compacted soils. Even in that top 60 cm, the roots occur largely as mats in desiccation cracks rather than being diffusely distributed throughout the soil volume. Crops growing on these compacted soils are not able to take up enough water to survive and flourish during periods of even moderate drought stress.

In addition to the low soil strength revealed in Fig. 1, the mining wheel-conveyor-spreader soils have a continuous macropore network throughout much of their volume. Roots are typically diffusely distributed to depths of 150 cm or more in these soils, and growing crops persist through much more severe drought periods than on the severely compacted soils (McSweeney and Jansen, 1984).

Not all scraper built-soils are as severely compacted as those at this site, but most have soil strengths high enough to inhibit root system development and plant performance. Soils formed by grading cast overburden are also commonly too high in strength and too deficient in macropores to have productivity comparable with natural prime farmland soils. The wheel-conveyor-spreader soils vary in density, soil strength, and productivity, but most are less compacted than those built with scrapers, or by grading cast overburden.

Options to be considered

Although the mining wheel-conveyor-spreader system has proven successful in constructing productive soils after surface mining, it does not offer a generally applicable solution to the problem of restoring land to agricultural productivity after mining. It is a very inflexible system which will not be used at most mine sites. Evident options are to either develop a method by which excessively compacted soils can be ameliorated to a depth of about 1.3 m or to develop other material handling options which will produce soils much like those from the wheel-conveyor-spreader system, but which are more cost competitive and generally applicable.

Ameliorating compacted soils

Near surface compaction is readily treated by mechanical tillage, but the problem is complicated for these mine soils by the considerable depths to which treatment is needed. Subsoilers, rippers, and various other rigid shank devices have generally not been effective in these materials to depths of more than about 50 cm. Beyond that depth, plastic flow of soil material around the shank is generally experienced rather than the fracturing and fluffing needed for physical improvement.

Effective soil loosening to somewhat greater depths can be accomplished with equipment designed to assure a considerable vertical component to the soil movement. One example is the Kaelble Gmeinder TLG-12, a German machine with a moving share at the bottom of each of three shanks to lift the soil as it passes over them. Field experience indicates physical improvement to somewhere between 75 and 90 cm depths when operated under favorable conditions. Yield response data are preliminary, but encouraging. The additional rooting depth resulting from the treatment of severely compacted soils appears to be sufficient to carry crops through periods of moderate drought stress. Crops on the TLG treated scraper-placed soil persisted, free of visible stress, longer than the untreated and than the natural soil, but not as long as the wheel-conveyor-spreader soils during a severe drought period in the 1986 season.

Some Illinois mines are using a slip-plow to treat compacted soils. The results have not yet been adequately evaluated, but crop performance on treated soils was quite good in the 1985 and 1986 seasons. Other mines have gotten physical improvement to depths of about 60 or 70 cm with vibrating rippers.

New approaches to the problem of deep compaction alleviation are under consideration. Even if a method is developed to adequately loosen soils to 130 cm depth, it is almost certain to be a costly operation.

Regardless of the amelioration method used, it is essential that it be done when the soils are relatively dry. In humid climates, that generally requires establishment of vegetation first. Then the deep tillage must be done during the growing season at a time when the vegetation has extracted enough water to provide for suitable tilth to the depth to which tillage is desired.

Alternative material handling methods

Placement of subsoil material on a finished base with rear-dump trucks is being practiced by some mines. This procedure involves much less traffic over soil materials after placement than is true with scraper placement. Ideally, all truck traffic should be restricted to the base level (Fig. 2). Each load should be rear-dumped against the advancing soil face, taking care to achieve a sufficiently thick layer so that only minimal leveling will be required after it is dumped. Compaction effects of the finish grading can be minimized by using modest-sized dozers. Soils produced by this procedure look promising from a pedological perspective and experiments are now under way to evaluate their productivity.

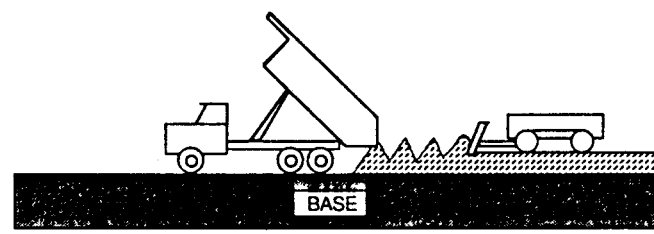

Figure 2 — Truck placement of soil material, all truck traffic being restricted to the base level. Only minimal leveling should be done after subsoil mateial is placed by teh trucks and before placement of any topsoil layer.

Normal procedure, where segregation of the topsoil and subsoil materials is required, would be to place the topsoil on top as a separate operation after finish grading of the subsoil layer. Substantial compaction damage to the subsoil layer commonly results from the topsoiling operation. The result is a sharp discontinuity in pore size, soil strength, and soil materials at the interface between the two layers. This interface discontinuity adversely affects soil performance by acting as a barrier to water movement and root system development.

Figure 3 illustrates a procedure which could concentrate topsoil material near the soil surface at some sites without totally separate handling. Compaction damage from the topsoiling operation would be avoided while also minimizing the separate handling costs. The procedure involves loading trucks with a front-end loader in such a way as to get mostly subsoil material toward the rear of each load and then finishing off the

top front of the load with topsoil material, the objective being to maximize the amount of topsoil material which ends up near the top as the load is dumped.

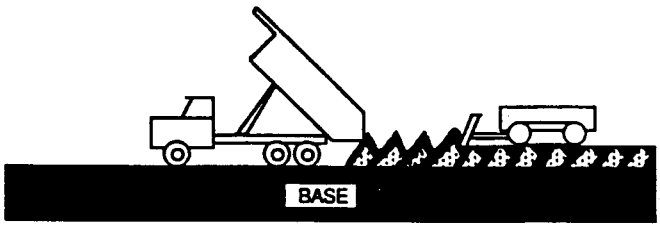

Figure 3 — Some concentration of topsoil material near the surface can be accomplished by preferential loading of topsoil toward the front of each truck load.

Separation of topsoil and subsoil materials with this procedure would be crude at best. Some mixing of subsoil material into the surface layer would not be a serious problem where the subsoil material is also of high quality and where the resulting mixed layer would still be high enough in organic matter and low enough in clay to have stable structure and good tilth. In some instances, the topsoil might actually be improved by some admixture of subsoil material.

The most significant promise of the proposed procedure would be elimination, or at least softening, of the troublesome interface barrier between topsoil and subsoil. Discontinuities at the interface should be much less pronounced than with separate handling, because of some mixing and lack of a compacted surface at the interface.

There are also potential benefits from having some topsoil material mixed into the subsoil. Soil structure of the topsoil tends to persist through the disturbance better than that of the subsoil materials. Because of that, presence of some lenses of topsoil material throughout the subsoil help to form the rudiments of a macropore network in newly constructed subsoils. Plant roots tend to grow more profusely in the disturbed topsoil material than in the disturbed subsoil (McSweeney and Jansen, 1984). Lenses of natural topsoil material in the subsoil will encourage deep and diffuse plant root systems, which will enable crops on these soils to resist drought stress. The deeper root systems will also deepen the effective wet-dry stresses for gradual improvement of surrounding subsoil materials. ♦

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A PEDOLOGIST'S PERSPECTIVE ON RECLAMATION

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INTRODUCTION

Objectives in reclamation after surface mining are not often clearly stated. I suggest that a reasonable objective would be to construct a land resource of maximum feasible utility and versatility for future generations. Utility implies concern that it not only have some productive use but that it complement other land resources in its locality. The concern for versatility relates to providing a land resource that is capable of multiple uses, to keep options open for future generations. Cost is one consideration under feasibility, at least to the extent that a significant increase in the utility or versatility of the finished product should result from any reclamation practice of significant cost. The mention of future generations allows for a time factor. Prompt reclamation and return of mined land to productive use is certainly desirable, but return to full productivity may require some time for soil development processes to finish the job. The present generation might reasonably accept somewhat lower productivity on land to be mined as part of the cost of coal. Future generations will not enjoy the benefits of coal burned now, so we should not make them pay for the coal by leaving them an inferior land resource. Long term quality of the land resource after mining should be of greater concern to us than short term'quality.

Maximizing utility and versatility is not necessarily done by attempting to reproduce the premined resource in every detail. In some instances there will be reason to intentionally vary from the character of the premined land resource to eliminate some undesirable features of the premined land, or to provide a somewhat different type of resource to better complement existing resources in that locality.

Reclamation in Illinois is essentially soil construction. It involves establishing a suitable surface configuration, selecting the-best material for each level in the new soil, and placing that material without inducing excessive compaction.

We are unusually fortunate in Illinois to have at most sites an abundance of good quality materials for use in soil construction. Care in selecting and segregating materials is essential, but most Illinois mines are now capable of doing so effectively.

COMPACTION OF SOIL

Achieving a suitable structure or physical condition in newly constructed soils is proving to be a much more persistent problem. The soil materials are commonly so tightly compacted that water movement and

storage is inhibited and plant root penetration is severely restricted (Fehrenbacher, Jansen, and Fehrenbacher, 1982; indorante, Jansen, and Boast, 1981). In some instances the problem might be due to failure to disrupt the high in-place bulk densities of some of the deeper materials used in final soil construction. In other instances the problem appears to be largely due to compaction by equipment used for placement and final grading of soil materials during reclamation.

Our work to date has shown that excellent rowcrop production can be achieved on carefully reclaimed land in years having favorable weather. Row-crops on newly reclaimed land, however, are commonly more susceptible to weather stress than those on undisturbed soils. Poor physical condition of the newly constructed soils appears to be a major cause of this problem.

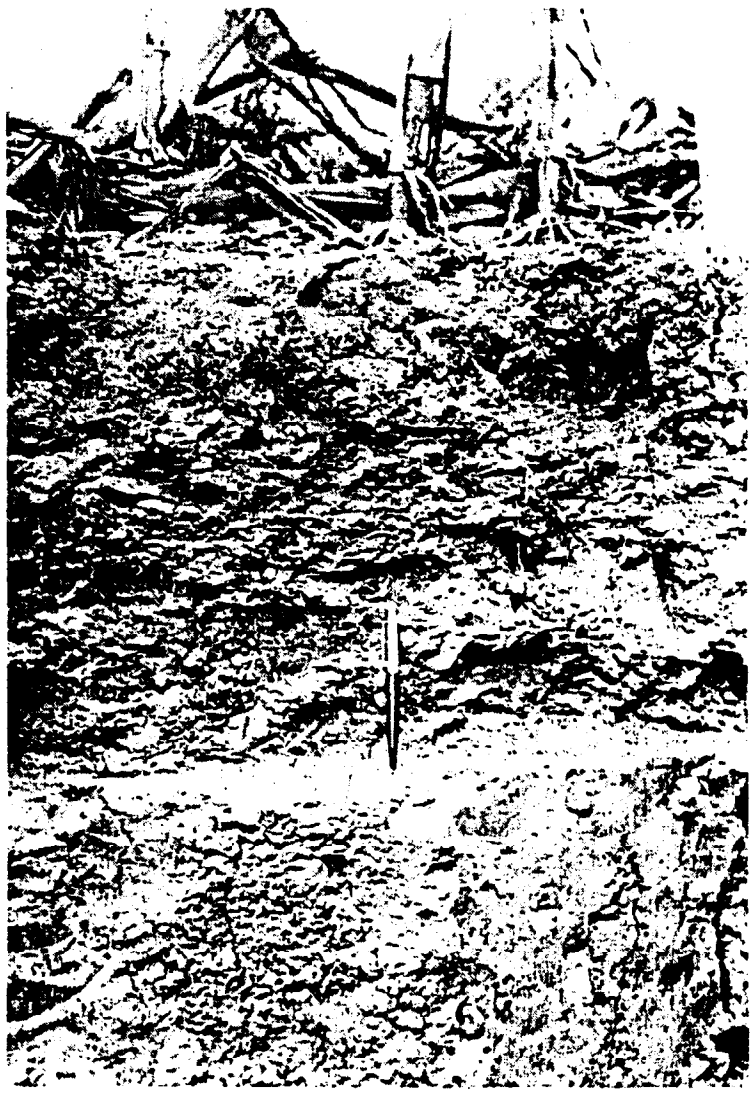

Fig. 1 — A post-mine constructed soil having pour physical condition. The ledge on which the pencil is standing is a severely compacted traffic surface which deflects roots. Material above the ledge has platy structure (note the horizontal linealion) which is also induced hy compaction during soil construction. Material below the ledge is massive, having only a few desiccalion cracks.

EFFECT OF SCRAPPERS

It is apparent that the material handling method used in soil construction has some effect on physical condition of the finished product. Where material is hauled and placed with rubber tired scrapers, the finished soil is typically very firm and massive or compacted throughout. Some density stratification is commonly apparent (Figure 1). The most severe compaction is in a thin layer near the top of each lift of soil material (a compacted traffic surface at each lift interface). Plant rooting in these soils tends to be shallow. Most of the roots present are confined to desiccation cracks, and there is a distinct tendency for roots to stop or turn and grow laterally at each lift interface. Much of the soil volume is not effectively reached by the root system. Such soils are relatively low in water storage capacity, and even the water that is present cannot be taken up fast enough by the restricted root systems to enable rowcrops to survive and flourish during periods of high moisture demand. This results in observed high susceptibility to weather stress.

The pronounced density stratification is largely characteristic of scraper-placed material, but other material handling methods can also lead to poor physical condition and the consequent restricted rooting, drought susceptibility, etc. Soils at any site where there has been extensive grading when moist by dozers, or other means, tend to be too firm and compact for effective rooting. Virtually all deep geologic strata are.highly compacted in-place, due to overburden pressure. When these materials are moved in large masses by shovels, draglines, etc., and left near the surface, that dense, compacted condition remains intact.

EFFECT OF MINING WHEEL, CONVEYOR BELT AND SPREADER

One site that looks encouraging is our newest set of research plots at the Captain mine in Perry County, Illinois. The soil material at this site was dug by a mining wheel, transported by conveyor belt, and placed by a spreader. The spreader was capable of controlling placement so that relatively little subsequent grading was required. For those plots having topsoil segregated and replaced on top, the topsoil was placed in and then spread by dozers. These plots were built late in the fall of 1980 and were cropped in 1981 and 1982. Corn and soybean yields on these plots have been very good, much better than on near-by plots which have soils constructed by scrapers.

The materials placed by a spreader typically have a foot or so of massive, compacted material over loose material having a visible network of large pores (Figure 2). Finish grading after placement by the spreader is likely the major cause of the compacted layer at the top. Close examination of the underlying looser material reveals masses or aggregates, more or less spherical in shape, that are semi-fused together, leaving a substantial network of large voids between them (Figure 3). We have been describing this looser material as having fritted structure.

Plant roots are commonly well distributed throughout any replaced

Fig. 2 — This constructed soil has a massive physical condition in the upper part and fritted structure below. Roots are confined lo the desiccation cracks in the massive layer, but are spread throughout the underlying fritted layer.

topsoil, or throughout the tillage zone where no topsoil has been replaced. Root distribution within the compacted layer immediately below is much like that in scraper placed or intensively graded soil materials. Roots are largely confined to cracks, leaving much soil volume not effectively reached. Roots that make it through the compacted layer proliferate in and do quite effectively explore the underlying fritted soil material. Maximum rooting depth in the soils having fritted structure is much greater than in those soils that are compacted all the way down and not greatly different from that in undisturbed soils. In summary, soils constructed by the bucket wheel excavator-conveyor belt-spreader system have better physical condition and apparently are more productive than post-mined soils that have been compacted throughout during construction.

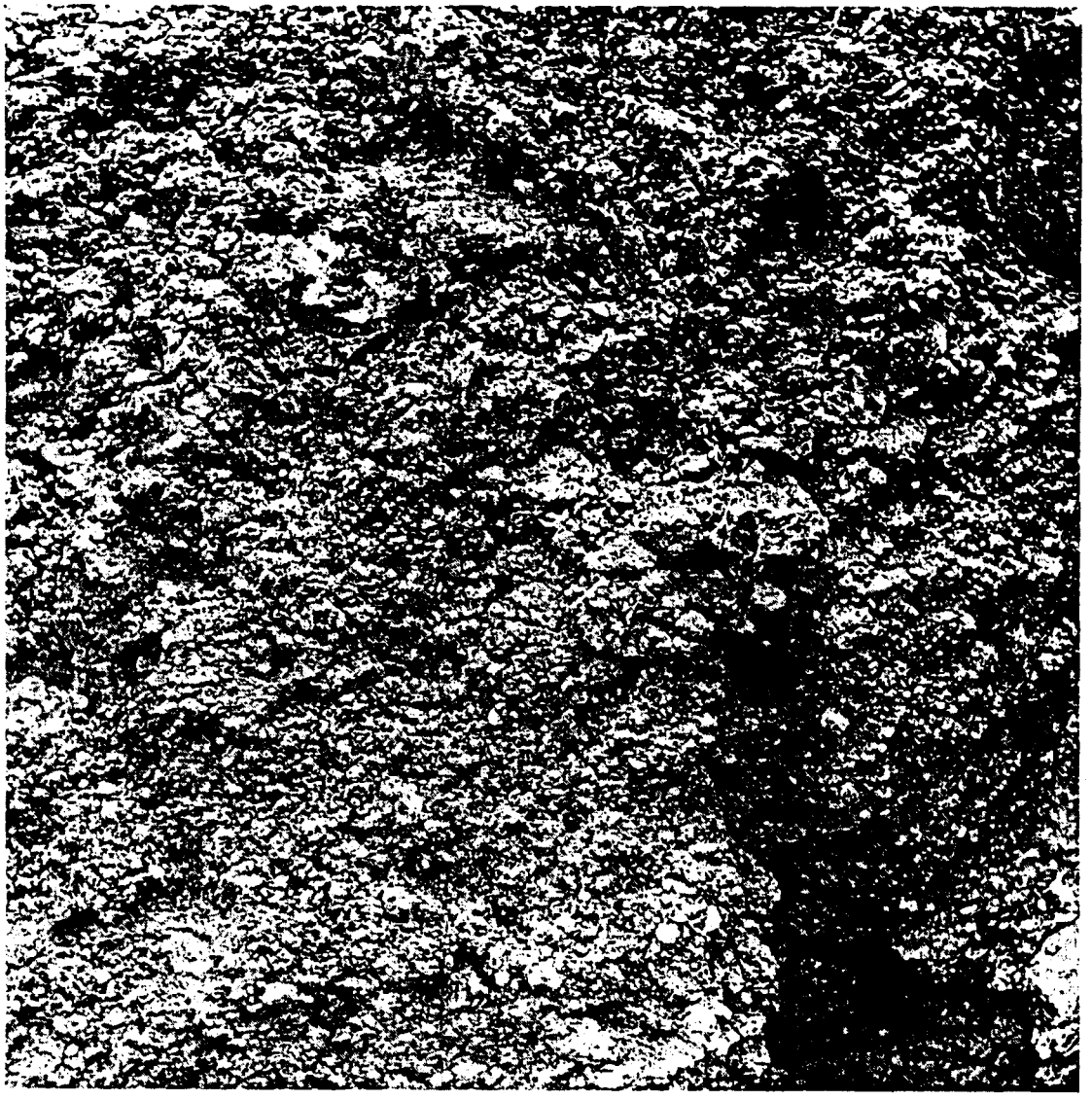

Fig 3 — Soil material exhibiting fritted structure. Note the rounded masses and the visible pores between them.

IMPROVED RECLAMATION METHODS

Even if the wheel-conveyor-spreader system now used at Captain mine is not likely to be a workable system for many Illinois mines, we might learn something from what we observe there to develop improved reclamation methods that would be applicable to most mines. The minimal grading of soil materials and minimal traffic on them after placement appear to be among the desirable features of the Captain system. Are there other ways to control placement of soil materials so that little or no subsequent grading is needed? Trucks appear to be a promising alternative to scrapers for hauling and placing soil materials (from a soil quality point of view). All truck traffic should preferably be on the base level rather than on top of soil materials that are in place.

The miles of transport by belt have a conditioning effect on soil materials. The aggregates or fragments are trundled, rounding edges and reducing aggregate size. This effect might be difficult to duplicate at most mines.

I believe that the mining wheels make a considerable contribution to the success of the Captain system. By peeling the soil material off in relatively thin layers and tumbling or trundling it somewhat, the wheel subdivides soil materials that might be quite dense and massive in-place into fragments or aggregates of modest size. The wheel also effectively blends any contrasting materials in the overburden. Materials having extreme chemical or physical conditions are commonly undesirable when concentrated in large masses, but might be beneficial when intimately blended with other soil materials.

Where trucks are to be used to transport and place soil materials, would loading the trucks with a mining wheel produce better reclamation than loading the trucks with a shovel or front end loader? There is no firm evidence on which to base a conclusion, but wheel loading should result in better blending of materials and perhaps in somewhat better physical condition. It should be tried. A system using wheel loaded trucks, with disciplined truck traffic, would be feasible at many mines that are just not suited to a wheel-conveyor-spreader type system.

CONCLUSION

My concern as a pedologist is primarily the characteristics of the finished soil rather than how the reclamation is done. It is apparent that some material handling methods are producing somewhat better soils than other methods. Perhaps cheaper means can be devised that would produce soils that are as good as or better than the best we are seeing now.

We do expect some improvement in reclaimed land soils over time as natural soil development takes place. The objective of maximum utility and versatility for future generations could be met without controlling soil physical condition at the time of soil construction if we had assurance that soil development would eliminate the effects of compaction within a generation. Lacking that assurance, serious attention to means for avoiding or ameliorating undesirable conditions in newly constructed soils is in order.

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Subsurface Horizon Blending: An Alternative Strategy to B Horizon Replacement for the Construction of Post-Mine Soils

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Subsurface Horizon Blending: An Alternative Strategy to B Horizon Replacement for the Construction of Post-Mine Soils[1]

K. MCSWEENEY, I. J. JANSEN, AND W. S. DANCER[2]

ABSTRACT

This study was initiated to evaluate various combinations of substratum and B horizon materials, as subsurface rooting media. Materials were collected from each solum and substratum horizon to a depth of about 6 m at two surface mine sites. One of the sites was in southern Illinois and had an infertile Darmstadt (Albic Natraqualf) surface soil with a strongly acid (pH 5.2) and natric subsoil. The other was in west central Illinois and had a Sable (Typic Haplaquoll) surface soil which supports high yielding grain crops with proper management.

The experiment was conducted in a greenhouse using large plant containen. The test crop, soybean, was germinated in A horizon material, or in a blend of materials containing A horizon, placed over the given surface rooting medium. This pro. cedurc was employed in order to simulate field conditions where seeds germinate in topsoil and root into the underlying material. Performance of the test crop was best where A horizon was segregated and replaced over a blend of the next 3 m of material for treatments made from the Darmstadt materials from southern Illinois. It was poorest where A horizon material was replaced over material from the Darmstadt B_2 horizon. The other treatments were intermediate in performance between the A/Top 3 m and the A/B, (subsoil). A similar trend was found with the Sable materials from west central Illinois, but the difference between the best performing treatment, A/Top 3 m, and the poorest, A/B_2 (subsoil), was not as marked.

Additional Index Words: **clay pan soils, disturbed soils, mine spoil, prime farmland, surface mine reclamation.**

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LITTLE ATTENTION has been given to use of substratum materials to substitute for or amend infertile acid horizons in highly developed soils because the cost of such extensive earth moving would generally be prohibitive. Such practices are feasible, however, when constructing soils after surface mining. Blending solum and substratum materials where desirable for use in soil construction would be little or no more expensive in some instances than segregating and replacing soil horizons in sequence.

Environmental protection performance standards enacted as part of the Federal Surface Mining Control and Reclamation Act of 1977-Public Law 95-87 (12) require that the A and B horizon of a natural soil be segregated and replaced when prime farmland is disturbed by surface mining for coal. There is, however, provision within the act for the use of underlying strata in combination with or in place of the B horizon of the natural soil. These alternatives must be shown to be "both texturally and chemically suitable for plant growth and . . . to be equally or more favorable for plant growth than the B horizon . . ." (12).

Many of the prime agricultural soils in southern Illinois (7) destined to be disturbed by surface mining have strongly-to-very-strongly acid infertile and sometimes natric subsoil horizons. It has been suggested that a blend of subsoil and selected components of the underlying substrata could produce a subsurface rooting media that would be equal to or more favorable for plant growth than the B horizon with its inherent clay pan (2).

Workers in other areas (3, 4, 9, 10, 11, 13) have reported improvements in soil properties following the addition of selected favorable soil or unconsolidated material to problem soils. Notable improvements include the moderation of extremes of pH (3, 4, 11) and the improvement of infiltration capacity (9, 10).

This study was initiated to evaluate various combinations of substratum and B horizon materials as subsurface rooting media. Materials were collected from each solum and substratum horizon to a depth of about 6 m at two surface mine sites. One of the sites was in southern Illinois and had a soil with a strongly acid infertile natric subsoil (7). The other was in west central Illinois and had a soil capable of supporting high yielding grain crops with good management (6).

The experiment was conducted in greenhouse using large plant containers. The test crop, soybean

[1]Contribution from the Dep. of Agron.. Univ. of Illinois, U-C Campus, Urbana. Part of a thesis submitted by the senior author in partial fulfillment of the rcquiremcnts of the MS. degree at the Univ. of Illinois. Received 18 Mar. 1981. Approved 30 Mar. 1981.

[2]Graduate Assistant, Associate Professor, and Research Associate, Univ. of Illinois, respectively.

(*Glycine max* L.), 'Williams' variety, was germinated in A horizon material, or in a blend of materials containing A horizon, placed over the given subsurface rooting media. This procedure was employed in order to simulate field conditions where seeds germinate in topsoil and root into the underlying material.

MATERIALS AND METHODS

Material Collection and Preparation

A Darmstadt soil (Albic Natraqualf; fine, montmorillonitic, mesic) and a Sable soil (Typic Haplaquoll; fine-silty, mixed, mesic) were selected from the Captain Mine, Perry County, southern Illinois and from the Mecco Mine, Knox County, west central Illinois, respectively. The soils and substrata were sampled according to the horizon divisions indicated on Tables 1 and 2 and stored in closed plastic storage containers for 6 weeks at a temperature of between 12.5 and 15.5°C.

Considerable care was taken during preparation of the materials to preserve their physical and chemical integrity. The objective, while avoiding excessive pulverization during preparation, was to achieve a suitable consistency without allowing the materials to become completely air dry.

All materials were passed through a 20-mm stainless steel wire mesh screen to break down the larger clods, to facilitate mixing, and to avoid the formation of large voids when the materials were placed in the plant containers. Some of the materials were sieved upon removal from the storage containers. Others had to be dried somewhat to achieve favorable tilth. These materials were prevented from becoming excessively dry by frequent turning during the day and coverage with plastic sheets at night. The B_2 materials from both sites and the IIIB (paleosol) materials from the southern site were especially difficult to work. A suitable physical condition was achieved in these materials by the use of two freeze–thaw cycles.

Six different combinations of materials for use in constructing subsurface blends were prepared for each of the two mine sites. This was done by blending materials from the various solum and substratum horizons at each site in different proportions by volume. The composition of each subsurface blend is indicated in Tables 1 and 2; selected soil test values are shown in Table 3. The detailed physical and chemical characterizations of the soil blends and horizon components is contained in a companion paper (11).

Table 1—Simplified horizon designation of Darmstadt soil showing components of each subsurface blend.

	Horizon	Texture	pH	Depth, cm	Material	
	A	Silt loam	6.1	0–36	Surface soil	
A/B2	B2‡	Silty clay loam	5.2	36–94	Subsoil	Top 3-m mix†
	B3‡	Silt loam	7.9	94–155	Subsoil	
A/Top 3 m	IIB3	Silt loam	8.2	155–262	Mixed Roxana loess	
	IIIA	Silty clay loam	7.4	262–295	Paleosol	A/Top 6 m
A/Bottom 3 m	IIIB	Clay loam	8.1	295–544	Paleosol	A/IIIB
	IIIC	Loam	8.4	544–605+	Calcareous till	

† A-horizon material incorporated throughout blend.
‡ Exchangeable Na >15%.

Table 2—Simplified horizon designation of Sable soil showing components of each subsurface blend.

	Horizon	Texture	pH	Depth, cm	Material	
†Top 3-m mix	A	Silt loam	5.5	0–43	Surface soil	
A/B2, B3	B2	Silty-clay loam	6.2	43–107	Subsoil	A/B2
	B3	Silt loam	7.7	107–140	Subsoil	A/Top 3 m
A/C, IIC	C	Silt loam	8.1	140–338	Calc. loess	
	IIC	Silt loam	7.7	338–445	Calc. loess	A/Top 6 m
	IIIA	Silt loam	7.5	445–483	Paleosol	
	IIIB	Clay loam	7.5	483–594	Paleosol	
	IIIC	Loam	8.1	594–633+	Calc. till	

† A horizon material incorporated throughout blend.

Table 3—Selected soil test values for Darmstadt and Sable soil mixtures.

	Bray P_1‡	$CaCO_3$ equiv.	pH 1:1	Exchangeable cations K‡	Na	Ca	Particle size distribution (2 mm) Sand	Silt	Clay
	kg/ha	%		meq/100 g			%		
				Darmstadt silt loam (Albic Natraqualf)					
Total A	18	0	6.1	0.09	0.65	6.50	3.7	83.4	12.9
B2 mix	12	0.1	5.2	0.32	3.43	11.03	1.6	61.4	37.0
Top 3-m mix†	37	0.1	6.7	0.15	2.63	8.97	1.1	74.2	24.7
3-m mix	41	0.1	6.9	0.23	2.94	11.21	0.9	72.3	26.8
6-m mix	13	1.0	8.3	0.26	1.32	16.40	19.2	53.7	27.1
Sang. B mix	5	0.2	8.1	0.13	0.65	11.04	24.1	48.8	27.1
Btm. 3-m mix	5	1.6	8.3	0.29	0.66	18.96	21.7	51.7	26.6
				Sable silty clay (Typic Haplaquoll)					
Total A	26	0	5.5	0.31	0.18	17.53	6.9	58.5	34.6
B2 mix	31	0	6.2	0.27	0.13	15.27	7.7	59.8	32.5
Total B mix	21	0.8	7.7	0.23	0.44	15.71	1.1	69.2	29.7
Top 3-m mix†	11	7.4	7.9	0.30	0.18	18.43	1.1	76.9	22.0
3-m mix	9	7.8	8.0	0.20	0.21	13.25	0.4	79.7	19.9
6-m mix	7	5.2	8.0	0.19	0.25	17.59	10.8	65.5	23.7
C-loess mix	8	5.9	8.1	0.21	0.19	12.37	6.9	76.3	16.8

† A horizon material incorporated throughout blend.
‡ Established nutrient ranges for Illinois soils (kg/ha):
Bray P_1: Low 0–11, slight 12–22, medium 23–34, high 35+.
Potassium: Low 0–202, slight 203–269, medium 270–336, high 337+ (K meq/100 g × 874 = K kg/ha).

Plant containers were constructed from high density polyethylene tubing (Fig. 1). The components of each blend were mixed together in a cement mixer for three minutes. The blends were introduced into the plant containers through a long-necked funnel to minimize separation of the various constituents. To encourage settling, a vibrator was applied to the outside of each column after each 20-cm increment of material had been added. Thus, each subsurface blend was subjected to the same compactive force, but bulk density was not necessarily the same because each was composed of materials of differing particle-size ranges. Each subsurface blend was replicated eight times. Two hundred ml of distilled water was applied to each container daily until free drainage was observed at the base of each. This amount of water was kept constant within subsurface blends.

The same volume of surface material (1,650 cm^3) was placed on top of each subsurface blend (Fig. 1). The surface material constituted the appropriate A horizon in all but the two top 3-m mixes where the A horizon was already incorporated into the blend. In this latter instance, the appropriate amount of fresh Top 3-m mix was placed on top of the subsurface blend in the same manner as for the other blends. A fertility treatment equivalent to 100-kg/ha lime, 75-kg/ha P, and 94.5-kg/ha K was applied to the surface component of one-half the replicates of each subsurface blend. Thus, for materials from both the Sable and Darmstadt sites, six subsurface blends, one-half with a fertilized surface horizon and one-half with an unfertilized surface horizon, were constructed, resulting in 12 treatments each.

Environmental Control, Planting, and Harvesting

The columns having fertilized and unfertilized surface material placed over Darmstadt and Sable subsoil and substratum materials were each arranged in randomized complete blocks in adjacent benches in the greenhouse. Temperature was maintained at a minimum of 21°C during the night (8:00 P.M. – 6:00 A.M.) and 25.5°C during the day (6:00 A.M. – 8:00 P.M.).

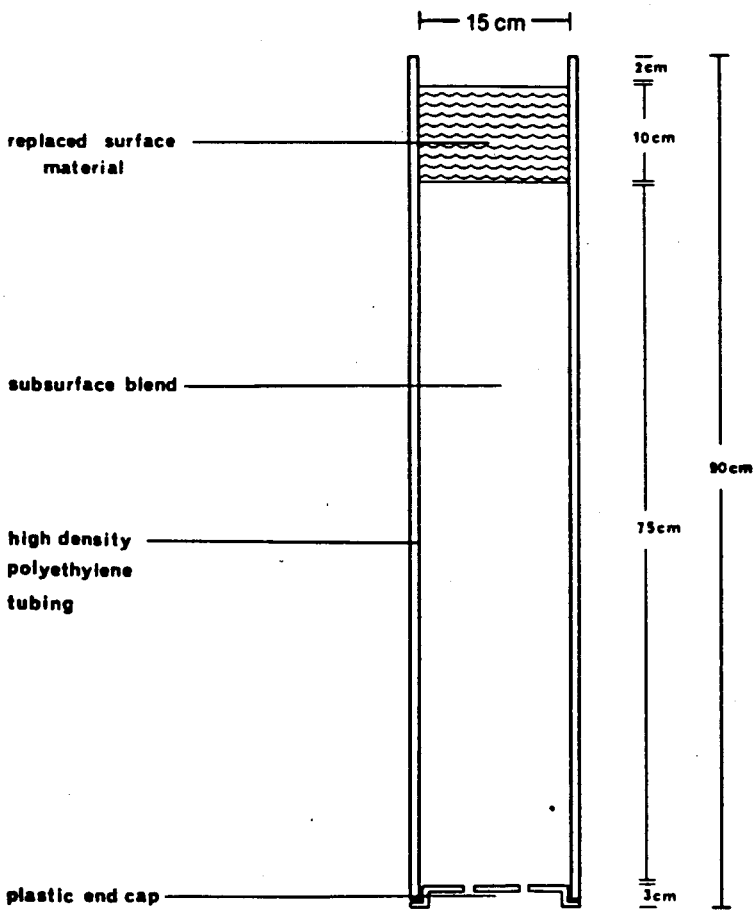

Fig. 1—Plant container showing relationship of surface material to subsurface blend.

Four 'Williams' (Wayne XL 57-0034, 1972) variety soybean (*Glycine max* L.) seeds previously soaked in liquid Rhizobium inoculum (supplied by Urbana Laboratories, Urbana, Ill.) were planted at a 2-cm depth in each column. At the time of seeding, 150 ml of distilled water was applied to each column. The majority of the seedlings emerged 3 to 4 days after planting; percent emergence on the different soil treatments is given in Tables 4 and 5. The subsequent soybean development was recorded according to the method of Fehr and Caviness (5). When the seedlings had reached the V1 stage they were thinned, leaving one in each column. Artificial illumination was operative during the day, from emergence-VE stage until the majority of plants had reached the R3 stage, the onset of pod formation.

The water status of the plant containers was monitored by tensiometers installed at a soil depth of 60 cm in one replicate of each treatment. An adequate watering regime was maintained during the majority of the vegetative stage, VE to V8, by applying 150 ml of distilled water three times per week. The watering regime was then increased to four applications of 200 ml per week to compensate for the increase in evapotranspiration caused, in part, by an increase in daytime temperatures. A drought stress, which is common in the latter half of the growing season on reclaimed soils in Illinois, was imposed soon after the majority of plants had reached the full pod-R4 stage. All treatments were limited to one 150-ml application of distilled water during a 6-day period. The previous watering regime was resumed at the conclusion of the drought stress.

The plants were harvested when the majority of the plants had reached full seed-R6 stage, by cutting the main stem 1.25-cm above the soil surface. Plant height was recorded and then the above-ground portions of the plants were dried in an oven (60 to 70°C) for 6 days. Standing-crop (stem, leaves, and pods) weight determinations were made on each plant. Pod weight was then recorded for each plant to give an estimate of yield. The bottom ends of two plant containers randomly chosen from each treatment were examined to observe extent of root penetration and moisture status.

RESULTS AND DISCUSSION

Plant height provided an indication of performance and was most useful during the early growth stages. Most of the general trends reflected in the weight data (Tables 4 and 5) were evident at the 5 week-V5/V6 stage (5) in the height data. By the 10th week-R4 stage, however, individual plants were exhibiting noticeable variation in pod number, height, and extent of branching. By harvest time, treatment differences were more clearly expressed by standing crop and pod weight than plant height.

Previous work by Dancer and Jansen (2) using materials from a surface mine in southern Illinois has shown that some subsurface materials were more responsive to added fertilizer than others. In this study, the fertilized treatments performed significantly better ($P = 0.05$) overall with respect to yield (pod weight) and standing crop (stems, leaves, and pods) than the unfertilized treatments, but this difference was not reflected in the seedling emergence data. The following fertilized Darmstadt soil materials performed better than their unfertilized counterparts, A/B2, A/Bottom 3 m, and A/Top 6 m. The subsurface blends of these treatments are low in natural fertility which could explain the marked response to fertilization. From the Sable materials, only the Top 3-m mix (no discrete A horizon replaced at surface) showed a significant response to fertilization. The overall performance ranking of the various soil blends was similar for both fertilized and unfertilized treatments. Thus, the remainder of the discussion will consider the fertilized and unfertilized treatments of a given subsurface blend together.

Table 4—Performance of soybeans grown in soil columns containing A horizon material† placed over various subsurface rooting media made from soil and substratum components of a Darmstadt soil.

Treatment	Emergence*	Standing crop mean wt.*	Yield (pods) mean wt.*	Yield/standing crop ratio
	%	g		
		Fertilized treatments‡		
A/Top 3 m	75 ab	24.22 a	7.70 a	31.8
A/Sang. B	81 a	23.53 a	6.34 b	26.9
A/Top 6 m	75 ab	23.04 a	6.35 b	27.6
Top 3-m mix	44 bc	22.40 ab	5.73 b	25.6
A/Bottom 3 m	69 ab	20.05 b	5.86 b	29.2
A/B2	56 b	15.24 c	4.49 c	29.5
		Unfertilized treatments		
A/Top 3 m	75 a	23.89 a	6.64 a	27.8
A/Sang. B	69 ab	22.12 ab	6.11 ab	27.6
A/Top 6 m	69 ab	20.11 b	5.47 abc	27.2
Top 3-m mix	38 c	20.42 b	5.07 bc	24.8
A/Bottom 3 m	63 ab	16.49 c	4.79 c	29.1
A/B2	50 bc	12.02 d	3.53 d	29.3

* Values followed by different letters are significantly different at the 0.05 level of probability according to Fisher's L.S.D.
† In Top 3-m mixes, A horizon material is incorporated throughout the blend.
‡ Surface material to a depth of 10 cm fertilized with lime, P, and K.

Table 5—Performance of soybeans grown in soil columns containing A horizon material† placed over different subsurface rooting media made from soil and substratum components of a Sable soil.

Treatment	Emergence*	Standing crop mean wt.*	Yield (pods) mean wt.*	Yield/standing crop ratio
	%	g		
		Fertilized treatments‡		
A/Top 3 m	81 a	26.21 a	9.02 a	34.4
A/Top 6 m	75 a	25.76 a	8.78 ab	34.1
A/C, loess	81 a	25.57 a	8.61 ab	33.7
A/Total B	75 a	24.68 ab	8.01 abc	32.5
Top 3-m mix	56 b	24.12 ab	7.64 bc	31.7
A/B2	75 a	22.16 b	7.15 c	32.3
		Unfertilized treatments		
A/Top 3 m	75 a	23.74 a	7.97 a	33.5
A/Top 6 m	75 a	23.77 a	7.68 ab	32.3
A/C, loess	75 a	22.86 ab	7.93 ab	34.7
A/Total B	69 ab	22.09 ab	7.67 ab	34.7
Top 3-m mix	56 b	20.40 b	6.84 ab	33.5
A/B2	63 ab	20.95 b	6.53 b	31.2

* Values followed by different letters are significantly different at the 0.05 level of probability according to Fisher's L.S.D.
† In Top 3 m mixes A horizon is incorporated throughout the blend.
‡ Surface material to a depth of 10 cm fertilized with lime, P and K.

Darmstadt Site

The Darmstadt soil (Table 1) is a relatively highly weathered soil formed in loess, with a moderately dark surface layer (A horizon). The subsoil (B2 and B3) horizon is high in clay (32%), characteristically sticky, plastic when wet, and it is very hard when dry. The adverse physical problems are further compounded by relatively high levels of exchangeable Na (Tables 1 and 3). The silty clay loam subsoil is inherently infertile with a strongly acid upper B. Infiltration of water is slow in these soils, and root growth is restricted in the subsoils if they are chemically unamended (7). A transitional zone, the mixed Roxana loess (IIB3) horizon and Sangamon paleosol till A horizon (IIIA), underlies the subsoil. It contains less clay (24%) and is higher in nutrients than the overlying subsoil (11). Glacial till underlies the transitional zone and is composed of the Sangamon paleosol B horizon (IIIB) which has a clay loam texture and the relatively unweathered loamy calcareous till (IIIC).

Soybean productivity was lowest on the A/B2 (subsoil) treatments. The subsurface material of these treatments had an appreciably higher clay, exchangeable Na content, and acidity than the other subsurface blends made from the Darmstadt materials (Table 3). The surface material of these treatments was frequently saturated; it ponded following irrigation, which severely limited plant performance. Seedling emergence of the A/B2 (subsoil) treatments was low compared to the other treatments except for the Top 3-m mixes (Table 4). Oxygen deficiency was probably one factor which caused lower plant emergence in the water-saturated surface materials. The A/B2 (subsoil) treatments performed poorest with respect to both standing crop and pod weight (Table 4). Examination of the plant roots from these treatments showed them to be very poorly developed and consequently only a small soil volume was available for nodulation and intake of water and nutrients. In contrast, root development in the other treatments was much more extensive, proliferating throughout and to the bottom of the plant container. A more extensive soil volume for nodulation and exploitation of nutrient and water resources was thus provided. This is suported by the tensiometer data. The tensiometers installed (60-cm soil depth) in the A/B2 (subsoil) treatments remained in range throughout the whole experiment, indicating that roots were not effectively exploiting moisture at that depth. Those in all the other treatments went out of range (below 1 bar) over a 10-day period between the R3 and R5 stage.

Soybeans grown on the A/Top 3-m treatments performed best overall (Table 4). The subsurface blend pH (6.8) is in the optimal range for soybean growth, and these treatments also benefited from a balanced nutrient supply and a good texture (11). The Top 3-m mix, A/Top 6-m, and A/Sang. B (paleosol) treatments were intermediate in performance (Table 4). These treatments all had good physical properties, but the A/Top 6-m and A/Sang. B (paleosol) treatments had subsurface blends with high pHs', 8.2 and 8.1, respectively (11).

In the Top 3-m mix treatment, where A horizon was not segregated and replaced at the surface, water management was a problem. Seedling germination was slow and plant emergence was very low in these treatments (Table 4). This may be partly attributable to slow and limited water infiltration and a poor soil-seed contact. Treatments with a lower surface organic matter content were subject to periodic surface crusting throughout the course of the experiment. Soybean growth on the Top 3 m-mix treatments was limited by poor water infiltration, especially after flowering. The evapotranspiration was much higher during this period of pod and bean development. Plants in this treatment lagged physiologically behind the plants of the other treatments. This could at least explain the lower yield/standing crop ratio. Plant growth on these materials, however, was superior to those grown on the A/B2 treatments.

The subsurface blend of the A/Bottom 3-m (till)

treatments has a high pH (8.3), induced by the presence of free carbonates. Mortvedt (8) has suggested that the availability of N, K, Cu, Fe, and Zn could be reduced under conditions of high pH induced by calcium carbonate. The soybeans grown on these treatments exhibited no marked signs of specific nutrient deficiencies, but overall performance was poor. Perhaps the presence of the fertile A horizon masked any nutrient deficiencies that might otherwise have been apparent.

Sable Site

Sable soil (Table 2) has a black silty clay loam surface (A horizon), rich in organic matter and natural fertility. The subsoil (B2) horizon is a light brownish gray silty clay loam. The soils have moderate permeability and a very high available water capacity (6). The subsoil is underlain by the following horizons: calcareous loess (C and IIC); Sangamon paleosol (IIIA and IIIB); and calcareous glacial till (IIIC). All these substratum materials have favorable textural prop erties and are alkaline, although the paleosol contains no free carbonates (Table 3).

The contrast in performance between the various Sable treatments (Table 5) was not as marked as for the Darmstadt treatments. Roots proliferated throughout and extended to the bottom of the containers in all Sable treatments. All the tensiometers went out of range (below 1 bar) over a 12-day period between the R3 and R5 stage.

It is somewhat surprising that plants grown on the A/B2 (subsoil) treatment were lowest in the given measures of performance. because the physical properties of this treatment did not differ greatly from the other treatments (11). The clay content of the subsurface component of these treatments, though not excessively high, is somewhat higher than that of the other treatments, and occasional surface saturation was a problem.

The A/Top 3-m, A/Top 6-m, A/C Loess (calcareous), and A/Total B (subsoil) treatments supported the best overall plant growth with respect to both standing crop and pod weight (Table 5). It had been hpypothesized prior to the experiment that the presence of free carbonates in the subsurface blends of all these treatments (except the A/Total B) would have adversely affected nutrient availability (8). Again, the presence of a fertile A horizon may have masked any adverse nutrient unavailability that might otherwise have been apparent. The subsurface blends of these treatments (A/Top -3 m, A/Top 6 m, A/C Loess, and A/Total B) all had favorable silt loam textures and pH's not exceeding 8.1 (Table 3). The reason for a beneficial effect from mixing deeper materials with Sable B2 horizon material B2 not readily apparent from the physical and chemical data.

Performance of the Top 3-m mix treatments (no discrete A horizon replacement) as with the corresponding Darmstadt treatments was likely inhibited by the problem of water management. Low and slow seedling emergence resulting in physiological lag can be partly attributed to slow and limited water infiltration and a poor soil-seed contact. Surface crusting and poor water infiltration was also a problem during other critical growth stages.

CONCLUSIONS

Large container experiments with soybeans, grown in the greenhouse on various combinations of soil horizons and underlying unconsolidated materials, support the following general conclusions:

1. The Darmstadt soil has a strongly acid (pH 5.2) and natric subsoil that can be amended by b ending in the less acid and less sodic materials from the sub stratum: The best performance was achieved by segregating and replacing the A horizon over a blend of the next 3 m of material. Poorest performance was from the treatment consisting of A horizon material replaced over disturbed B2 horizon material. Treatments which included materials from below 3 m, or which had an A horizon material blended with the balance of material in the Top 3 m, rather than segregated and replaced, were intermediate in performance. The observed relationships are in general agreement with what might be predicted on the basis of the physical and chemical properties of the materials.

2. Soybean performance with materials from the Sable soil was better when A horizon material was segregated and replaced over a mix of the next 3 m of material than when it was replaced over disturbed B2 horizon material. Plant growth differences were not as great as those observed on materials from the Darmstadt site.

3. Segregation and replacement of A horizon material at the surface facilitated water management and gave a favorable response when all other factors were constant. With materials from the Darmstadt soil, however, a blend of the Top 3 m without A horizon segregation and replacement was a superior medium for plant growth than the treatment consisting of A horizon and B2 horizon materials segregated and replaced in sequence.

4. A treatment consisting of a Darmstadt A horizon replaced over material from the Sangamon B horizons (IIIB) compared favorably with other treatments. This suggests that there is no need to exclude the Sangamon B2 material from mixes to be used for subsurface horizons in constructed soils. It is important to note that, at this site and commonly in southern Illinois, the Sangamon paleosol has been resaturated with carbonates leached from the loess mantle.

5. Fertilization improved the performance of all treatments, notably t ose with subsurface blends low in natural fertility: but it did not change the relationship between corresponding fertilized and unfertilized treatments.

These results suggest that for some mining areas, particularly in sout ern Illinois, selective subsurface horizon blending would produce a better post-mine soil than segregation and replacement of the B horizon from the natural soil. This is consistent with what would be predicted on the basis of the physical and chemical properties of the various materials available at these sites. Areas where subsurface horizon blending is likely to be beneficial can be readily identified by interpreting soil maps. The alternative material substitution option provided for in Public Law 95-87 (12) should be considered for these mining areas.

There is reason to expect that post-mine soils carefully constructed by blending selected subsurface horizons to dilute or favorably amend undesirable material will eventually be superior to the natural soils in some

areas. Further work is needed to determine the productivity of such constructed soils under field conditions and their response to varying environmental factors.

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Row Crop Productivity of Eight Constructed Minesoils

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Abstract

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

Research plots were established at a mine site in southern Illinois to evaluate the 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 the presence or absence of topsoil and in the mixture or depth of materials used to construct the subsoil. The best 4-year average yields (2216 kg ha^{-1} soya bean; 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, howeve-, produced only 655 kg ha^{-1} soya bean and 1727 kg ha-' corn, the poorest 4-year average yields of all soils evaluated. Yield variation was principally related to differences in the 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

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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; Dancer and Jansen, 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 strong 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 Lindsay, 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 development in compacted subsoil layers (Meyer, 1981). Greenhouse studies (Stucky and Lindsay, 1982) have correlated yield reduction with increased compaction for soya beans 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 horizon, 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,

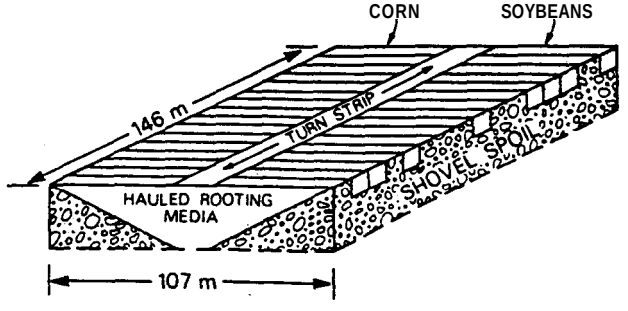

Fig. 1. Diagrammatic representation of wedge plot layout, Captain Mine. Shaded plots have replaced A horizon material. Corn and soya beans are shown in their 1982 and 1984 configuration.

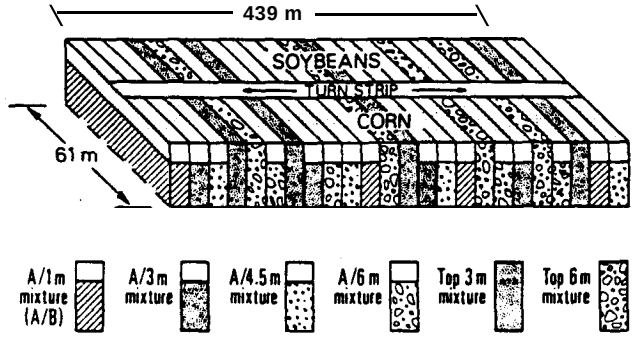

Fig. 2. Diagrammatic representation of mix plot layout, Captain Mine. Top 3-m and top 6-m mixtures do not have a separately replaced A horizon. Corn and soya beans are shown in their 1981 and 1983 configuration.

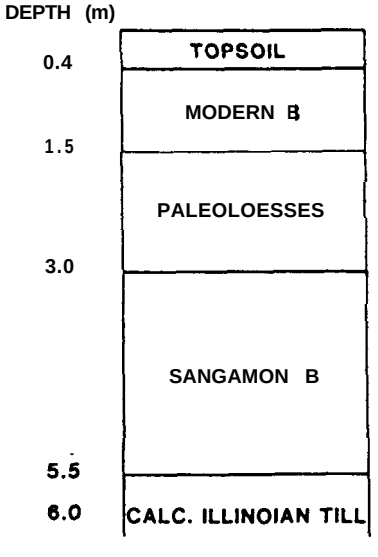

Fig. 3. Idealized profile of high wall showing materials used in construction of mix plot treatments.

the soil design correspondsin soil material composition to the A/l-m 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 the presence or absence of a separately replaced topsoil layer and in material composition of the subsoil. The two treatments without replaced topsoil, the top 3-m mix and top 6-m mix include A horizon material blended throughout the soil. The blending of varying increments of soil and unconsolidated sub-stratum materials (Fig. 3) was achieved using a mining wheel (Chironis1978). 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).

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 1981-1983 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 Illiinois. The 1981 and 1982 growingseasons 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 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

TABLE I

Row crop yields (kg ha^{-1}) at Captain Mine, 1981-1984

Treatment[1]	Corn yield[2]					Soya bean yield[2]				
	1981	1982	1983	1984	4-year average	1981	1982	1983	1984	4-year average
Mix plots										
A/1 m	7094a	9040ab	4520a	7848a	7126a	2350a	3290a	1142a	2082ab	2216a
A/3 m	5211c	9543ab	3265b	7094ab	6278bc	1947bc	2552b	940ab	2082ab	1880b
A/4.5 m	6592ab	7596d	4332a	7220a	6435b	1746cd	2686b	806ab	2149a	1847b
A/6 m	5776bc	8161cd	3332b	6780ab	6011c	1813bcd	2753b	873ab	2149a	1897b
3-m mix	3516de	9103ab	2511b	6152b	5411de	1679d	2619b	739b	1813b	1713c
6-m 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	5352e	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.

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 are 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 ~ 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). 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). This favorable sub-surface 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/1-m, 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 soya bean 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 the suitability of uuconsolidated sub-stratum 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-year field evaluation of the various mixtures (Table I), however, demonstrated that the A/l-m 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/l-m treatment is not clear. Simply mixing a l-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).

The two treatments, 3-m mix and 6-m 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 6-m mix for soya beans. However, yields on these non-topsoil treat-. ments 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 successfully 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 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

(i) Yield on the A/1-m 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.

(ii) 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.

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

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Corn and soybean response to topsoil replacement and irrigation on surface-mined land in western Illinois

R. E. Dunker and I. J. Jansen

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 6-year period. Two constructed soils, one with 45 cm of topsoil replaced over wheel spoil and one consisting of graded wheel spoil only, were studied in tests to evaluate crop yield response to topsoil replacement and irrigation. Both soils are Typic Udorthents. An abandoned incline lake supplied good quality water to a solid-set irrigation system that was randomly placed within each soil treatment. A nearby, unirrigated tract of undisturbed Sable silty clay laom (fine-silty, mixed, mesic, Typic Haplaquoll) served as an unmined comparison. A substantial yield response of both corn and soybeans grown on the mined land resulted during years having stressful weather during critical periods of growth, but no yield response to supplemental water occurred in years with favorable weather. Topsoil replacement resulted in higher yields under irrigation in 3 of the 4 years that corn was grown and in 1 of the 2 years for soybeans. Without irrigation, yield response under topsoil was positive in 2 of 4 years for corn and 1 of 2 years for soybeans. Corn yields ranged from 7,780 to 10,860 kg/ha on the undisturbed site to 1,250 to 10,360 kg/ha on the unirrigated topsoil and 4,390 to 6,840 kg/ha on the unirrigated wheel spoil. Soybeans were less sensitive to weather variables than corn; yields ranged from 2,485 to 3,080 kg/ha on the Sable soil to 1,750 to 3,580 kg/ha on the unirrigated topsoil and 1,480 to 2,700 on the unirrigated wheel spoil.

RECLAMATION practices and topsoil replacement required by the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) often involve extensive traffic by large earthmoving equipment. This traffic creates compaction zones with poor soil physical properties. The benefits of replacing the high quality A horizon from the premine agricultural soils may be offset by these root-restricting zones or layers. Any negative effect like this on plants' ability to take up water and nutrients makes row crops, such as corn and soybeans, grown on mined land more susceptible to temperature and moisture stress during the growing season than crops grown on undisturbed soils (*8*).

Many areas strip mined for coal have a large acreage in ponds and final cut lakes left from the mining process. The ponds and lakes are well suited for irrigation if water quality is satisfactory. Water acreage on surface-mined land in Illinois exceeds 14,000 acres, and there are more than 12,000 lakes developed in final cuts and abandoned inclines (*4*). These lakes generally are recognized as wildlife management or recreational resources. Their potential to provide good quality water for agricultural purposes has not been fully developed.

Previous research on yield performance of row crops on reclaimed surface-mined land resulted in wide-ranging yield responses, depending upon reclamation techniques, management, and weather. In a national survey (*10*), corn yields reportedly varied a great deal, depending upon the original soil, fertility, initial planning of legumes and grasses, soil replacement, weather variability, and age of spoil. Corn yields in Illinois, Ohio, and Pennsylvania ranged from 4% less to 90% less than yields on adjacent, undisturbed soils.

Jansen and colleagues (*6*) studied the yield response of corn and soybeans to topsoil replacement at two mine sites in southern Illinois over a 4-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 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 there were no yield differences between the topsoil and no-topsoil treatments at the other site.

Soil replacement and thickness of soil materials were studied at the Captain Mine in southern Illinois and at the Norris Mine in western Illinois (*5*). 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 study years because of shallow rooting of corn and weather stress. Yields of both corn and soybeans increased with increasing root media thickness to the 60- to 80-cm depth. No response was observed at greater root media depths because roots were not exploiting depths deeper than 80 cm.

The Norris topsoil wedge, with topsoil thicknesses ranging from 0 to 60 cm, showed 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 occurred during years of moisture stress. Dunker and associates (*2*) have 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 2 years after reclamation.

The objective of this research was to evaluate the yield response of corn and soybeans to topsoil replacement, with and without irrigation, on recently reclaimed mine soils. Use of irrigation as a treatment allowed 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 6-year period from 1979 to 1984 at 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 under favorable moisture conditions using a bucket wheel excavator to remove the unconsolidated soil materials and bulldozers for final grazing. 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.

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These soils are highly productive, dark-colored soils developed under prairie vegetation; they have thick A horizons high in organic matter, a desirable medium-textured B horizon, and an underlying C horizon favorable for plant growth (3). Table 1 shows the 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) 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 of 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° application pattern, and it was necessary to restrict this to 180° 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 in the abandoned incline lake provided irrigation water of good quality for the irrigation systems. Soluble salts (390 ppm), pH (8.2), Ca (64 ppm), Mg (26 ppm), Na (18 ppm), and Boron (.15 ppm) all met recommended maximum concentration limits for continuous irrigation in the Midwest (9).

Irrigation treatments were initiated when tensiometers showed soil tension levels at the -60 KPa of soil water pressure at the 1-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 to reduce runoff. When rainfall occurred, irrigations were adjusted, if possible, so rainfall plus irrigation per week did not exceed 3.9 cm. The soybean irrigation rate was 1.9 cm rainfall plus irrigation per week. Irrigation ceased 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. Yield estimates were based on the amount of shelled grain after adjusting for variation in moisture content to 15.5% in corn and 12.5% in soybeans. Fertilizer rates, seeding rates, and management practices used in our study are described in table 2.

Results

Irrigation Response. Yield response of both corn and soybeans to irrigation on mined land related directly to temperature and

Table 1. Chemical and textural properties of topsoil and wheel-spoil at the Consolidation Coal Company's Norris Mine in Illinois at the time of plot construction.

Core No.	Depth (10^{-3}m)	Soil Material	pH	Bray P_1 (mg)	Bray P_2 kg^{-1}	Exchangeable Bases Ca	Mg	Na	K	Organic C	Particle Size Distribution (mm) Coarse >2.0	Sand 2.0-.05	Silt .05-.002	Clay <.002
						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.	0.8	18	248	462	272

Table 2. Description of field plots at Consolidation Coal Company's Norris Mine in Illinois.

	1979	1980,1981,1983	1982,1984
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 kg N/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	May 30	May 16, 1980 May 8, 1981 May 18, 1983	May 11, 1982 May 18, 1984
Herbicide (1/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 diskings	Fall chisel 2 diskings	Fall chisel 2 diskings

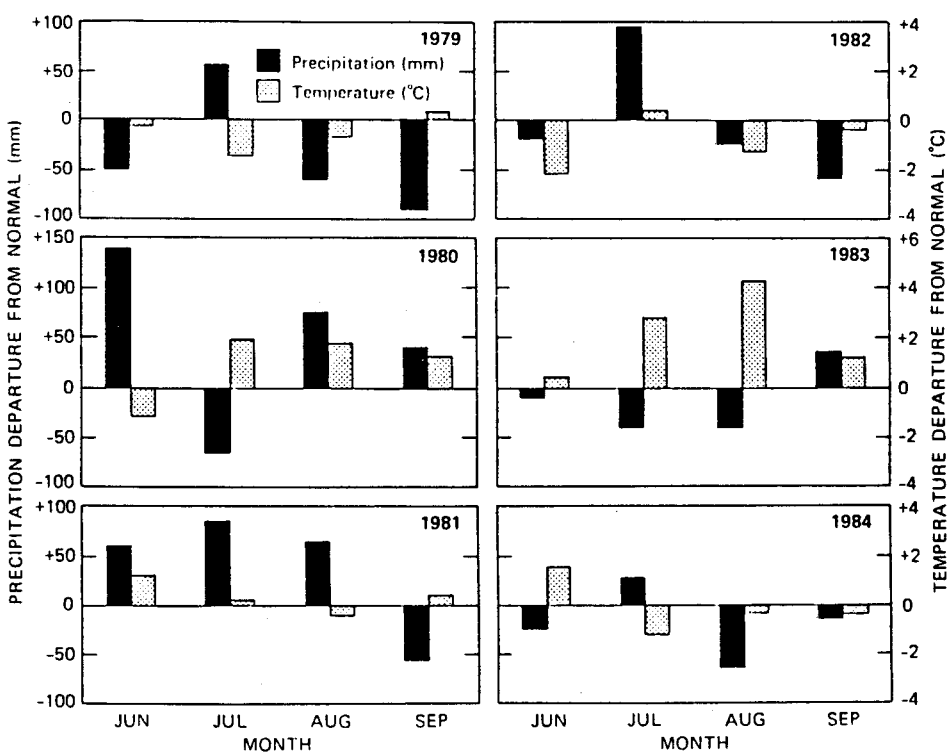

Figure 1. Temperature and precipitation departures from normal for the 1979-1984 growing seasons at the Consolidation Coal Company's Norris Mine in Illinois.

moisture stress. Both topsoil and wheel spoil treatments produced a significant corn yield response to irrigation during the 1979, 1980, and 1983 growing seasons; no measurable response occurred in the minimal stress year of 1981 (Table 3).

Figure 1 presents departures from normally occurring temperature and rainfall during the 1979-1984 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 peaked when precipitation levels were lowest. Temperatures were 33° C to 38° C during pollination; there was little precipitation from 2 weeks before until 1 week after pollination. The 1981 and 1982 seasons had near normal temperatures with adequate rainfall; this resulted 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. Soybean yields increased significantly with irrigation in 1984 on both the topsoil and wheel-spoil treatments because of the well-below-normal rainfall during the critical pod-filling period from mid-August to mid-September.

Irrigation results overall showed a significant, positive response by corn on 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 2-year, mean soybean yields showed no response to irrigation for the topsoil treatment, while irrigated wheel-spoil yields were significantly greater than those of soybeans in the unirrigated spoil. Irrigated corn and soybeans produced yields comparable to the crops on 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 in that year (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 that occurred at frequent intervals, there was poor infiltration in the wheel-spoil. Ponding was frequent and drainage was slow. In an earlier study at this location, Lah (7) 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.

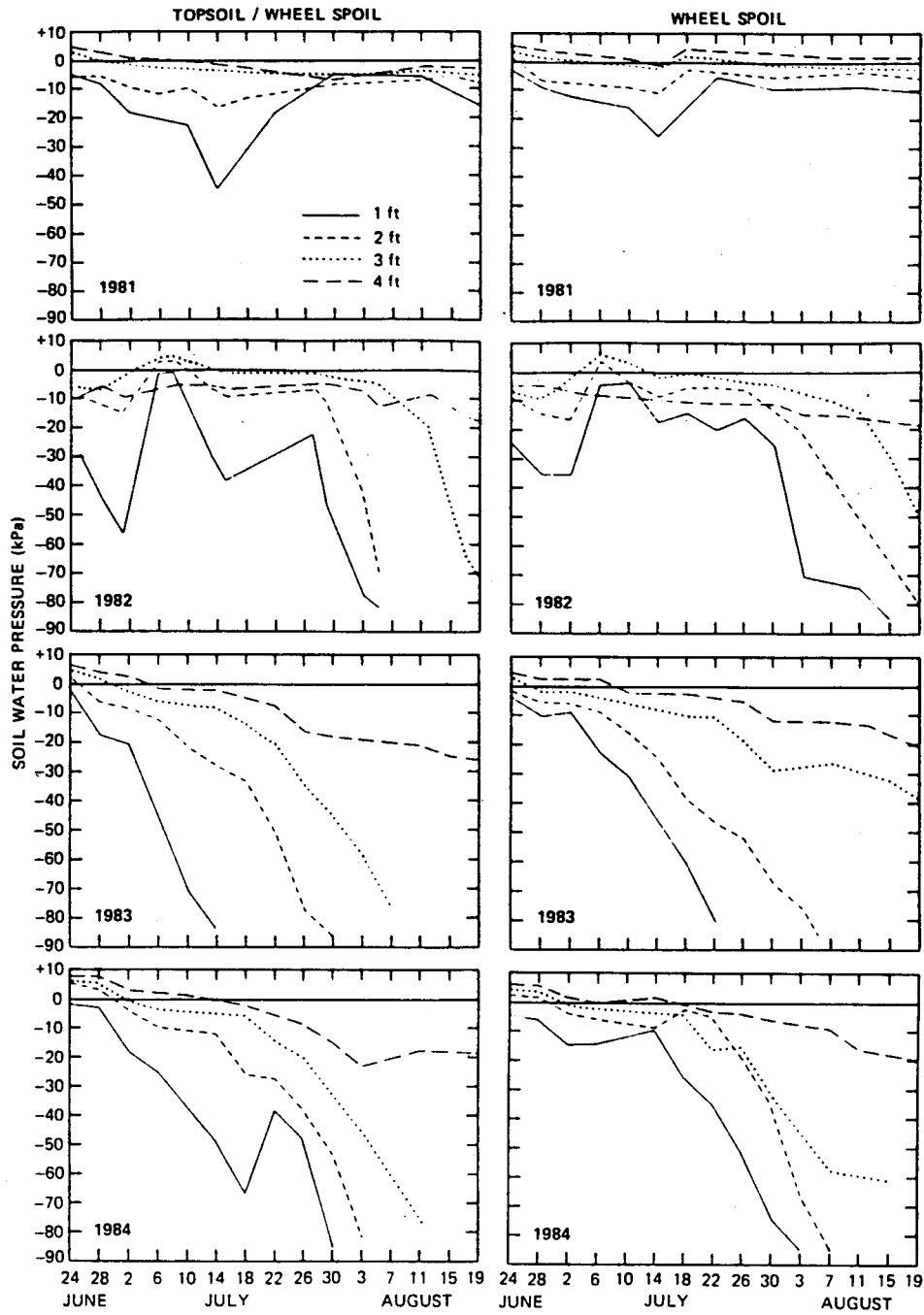

Figure 2. Soil moisture tension levels for the unirrigated mine soils, 1981-1984, at the Consolidation Coal Company's Norris Mine in Illinois.

Topsoil replacement. Yields increased significantly after topsoil replacement under irrigation for corn in 3 of the 4 years and in 1 of the 2 years for irrigated soybeans (Table 3). Without irrigation, topsoil replacement resulted in significantly higher yields for corn in 1979 and 1981 (lower stress years) and lower yields during the higher stress years of 1980 and 1983. One reason for lower yields could have been the delayed pollination that normally occurred on the wheel-spoil treatment. Corn on the wheel-spoil plots pollinated about 1 week later than corn on the topsoil. In 1980 and 1983 corn on the wheel spoil had the benefit of pollinating under cooler temperatures as well as a 4.2-cm rain in 1980 and a 3.8-cm rain in 1983. Corn in the topsoil plots pollinated under considerably higher stress. In both 1980 and 1983 silks on the unirrigated treatments were late to emerge, resulting in a high percentage of barren stalks (Table 4). Table 4 also reflects that while the topsoil plots generally had a higher rate of plant survivability, corn on these plots was more subject to aborting ears under high stress than on the wheel-spoil treatment.

Year-to-year variation in corn yield was considerably greater on the unirrigated topsoil compared to the unirrigated wheel-spoil

Table 3. Corn and soybean yields at the Consolidation Coal Company Norris Mine in Illinois in response to irrigation and topsoiling.

Treatment	Corn 1979	Corn 1980	Corn 1981	Corn 1983	Corn Mean	Soybeans 1982	Soybeans 1984	Soybeans Mean
	kg ha⁻¹							
Irrigated topsoil	11,990	10,420	10,990	12,120	11,370	3,580	2,350	2,965
Unirrigated topsoil	9,730	4,390	10,360	1,250	5,975	3,580	1,750	2,665
Irrigated wheel spoil	8,910	9,040	6,590	10,610	8,790	2,950	2,010	2,480
Unirrigated wheel spoil	6,280	5,590	6,840	4,390	5,620	2,700	1,480	2,090
Undisturbed Sable soil	9,790	7,780	10,860	4,360	8,200	3,080	2,485	2,780
LSD (0.05)	1,641	1,076	800	1,720	595	370	510	310
CV (5%)	11.6	17.7	11.6	23.7	16.9	7.0	23.8	16.1

Table 4. Survival rate and percentage of barren plants for corn grown at the Consolidation Coal Company's Norris Mine in Illinois.

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

(Figure 3). This may have been due to the fact that soil moisture levels for topsoil were considerably lower at the 1- and 2-foot levels than in the wheel-spoil plots during the critical anthesis periods of the high stress years. We made no rooting depth evaluation, but we assumed that restricted root system development on the topsoil plots might have been a factor. Compaction caused by scrapers to replace topsoil created a zone directly beneath the topsoil where bulk densities of 1.7 to 1.9 Mg m^{-3} exist and saturated hydraulic conductivity levels are only 7.59 cm/day. Figure 3 shows that irrigation reduced the year-to-year yield variation resulting from climatic and physical stress factors.

Soybeans showed significant positive responses to topsoil replacement with and without irrigation in 1982, but no response differences existed between the topsoil and spoil plots in 1984. Soybean yields were considerably lower in 1984 due to below normal precipitation in 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) showed 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 and colleagues (*1*), who concluded (a) that the highest soybean yield response was obtained when irrigation was applied after flowering and (b) that the pod-filling stage was the most critical period for adequate moisture to maximize yields.

The overall analysis showed that the replacement of 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 4-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 2-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 soil only in 1979 and 1981, years of favorable weather. The unirrigated wheel-spoil produced comparable yields only in 1983.

Conclusions

Corn and soybean yield data from the Norris Mine site support the following conclusions:

► Corn and soybeans grown on recently constructed mine soils that have favorable chemical and textural properties can produce yields comparable to those of row crops grown on undisturbed natural soils under favorable weather conditions. Temperature and moisture stress adversely affect crops on mine soils more than those on undisturbed soils.

► 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.

► Topsoil replacement on mine soils pro-

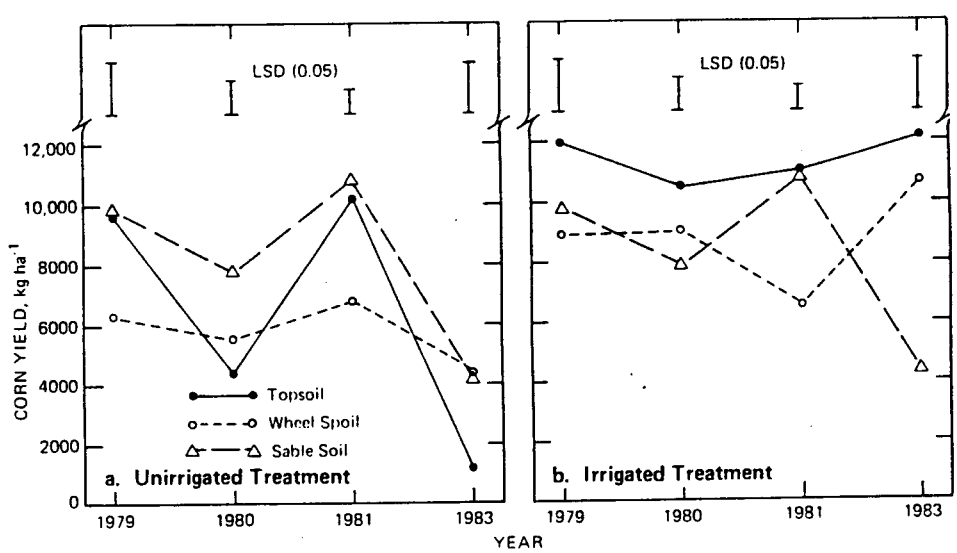

Figure 3. Average corn yields for irrigated and unirrigated mine soils and for unirrigated, undisturbed Sable soil.

duced a significant, positive soybean yield response, when averaged over years, both with and without irrigation.

► 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.

► Where not irrigated, topsoil replacement on mine soils produced a significant, positive corn yield response in those years having favorable weather, but a negative response in years having severe temperature and moisture stress.

► Yield responses of both corn and soybeans to irrigation were directly related to the amount of temperature and moisture stress in that growing season.

► Irrigation produced significantly higher corn yields, averaged over all years, on mine soils, both with and without topsoil replaced.

► Irrigation produced significantly higher soybean yields, when averaged over all years, on mine soils without topsoil, but not where topsoil had been replaced.

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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 penetromcter 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 I I2 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.

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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.

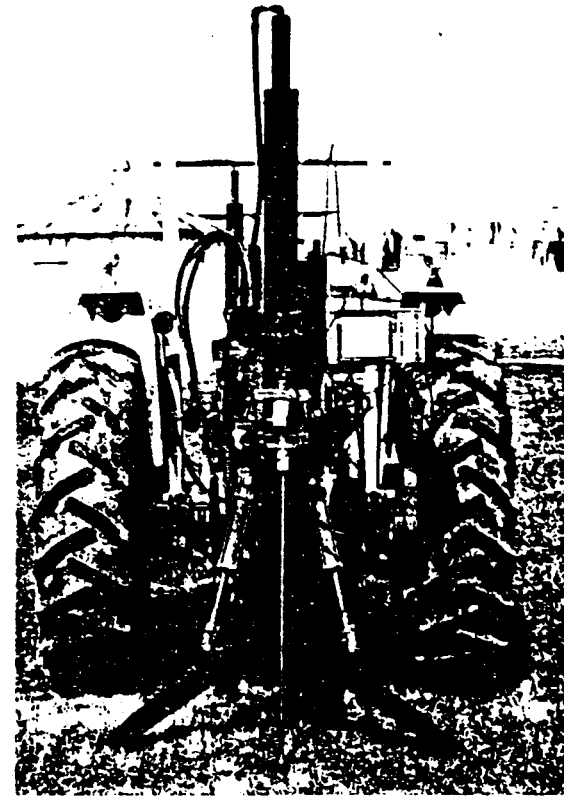

Fig. 1. Penetrometer installed on Ciddings coring machine with modified foot supports.

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 SR65 12) 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. 3/4 in) rod. A 30^0 right circular cone point of 6.45 cm^2 (I in^2) cross-sectional area was fabricated from 1060 steel, welded to the

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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 (O-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

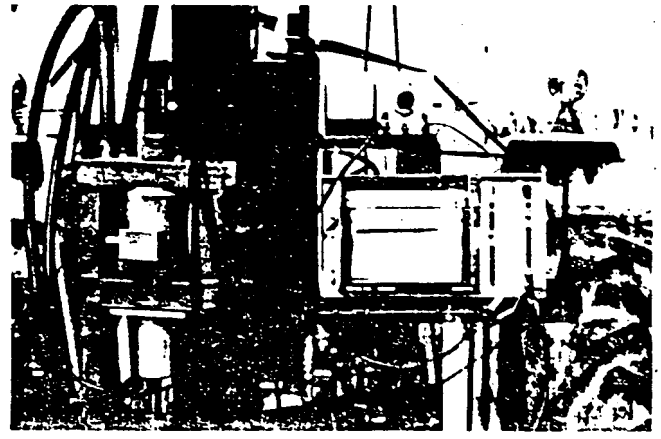

Fig. 3. Mounting bracket with controller and recorder, as mounted on Giddings coring machine.

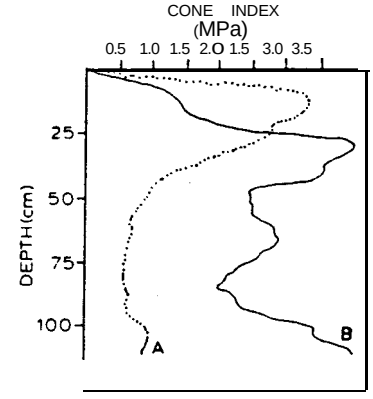

Fig. 4. Single representative cone index profiles of two reclaimed strip mine soils: (A) Topsoil over wheel-excavated/belt placed material. and (B) Topsoil over scraper-placed material.

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 I5 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 foreieen.

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

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

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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.

Additionul Index Words: surface mine reclamation, root length density, soil compaction.

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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. 1984). 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. I961). 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 O_2 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 Meredith and Patrick (1961) found a linear relationship between bulk density and the root penetration of sudangrass *(Sorghum vuigare sudanense),* 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; Taylor and Burnett, 1964). Phillips and ham (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). Meredith 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

Fig. 1. Location of research plots in Illinois.

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through existing voids narrower than the diameter of the root tip. But in a nonrigid 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 in mine soils.

MATERIALS AND METHODS

The study was conducted on three mine soils (two Typic Udorthents, fine-loamy, mixed, nonacid, mesic, and one Typic Udorthents, fine-silty, mixed, nonacid, mesic), constructed after surface mining in southern Illinois. Two were located at the Captain Mine, in Perry County and the other at the River King Mine, Randolf County (Fig. 1).

One set of research plots located at the Captain Mine, the Captain Mix Plots (Fig. 2), were constructed with a mining wheel-conveyor-spreader system. These plots consist of six treatments representing various blends of soil materials. The soil here is generally quite loose and porous, and has relatively low penetrometer resistance and bulk density values (Table 1).

The other set of plots located at the Captain Mine, the Captain Wedge Plots (Fig. 3), consist of shovel spoil covered by a layer of hauled rooting media (mostly composed of B horizon material) varying in thickness from 0 to 122 cm. The rooting material was hauled and placed using rubber tired scrapers. The subsoil at these plots is quite compacted and massive. Penetrometer resistance and bulk density values are somewhat greater for these plots than they are for the Captain Mix Plots (Table 1). Superimposed are randomly located strips that have topsoil replaced.

The River King Plots (Fig. 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. Table 1 shows the variability in penetrometer resistance and bulk density for these plots.

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 6.45-cm (1-in.^{2}) cone was driven into the soil at a rate of 2.9 cm/s. Measurements were taken on 6, 7, and 8 June 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 2).

Locations for penetrometer measurements are shown in

Table 1. Average pentrometer resistance, bulk density, and average root length density data for the final 14 sites used in regression analysis.

Plot no.	Avg pentrometer resistance				Bulk density				Avg root length density			
	23-44 cm	45-66 cm	67-88 cm	89-110 cm	23-44 cm	45-66 cm	67-88 cm	89-110 cm	23-44 cm	45-66 cm	67-88 cm	89-110 cm
	kPa				g/cm^3				cm/cm^3			
					Captain Mix							
1	1464	1049	787	647	1.74	1.58	1.45	1.51	0.70580	0.54837	0.39640	0.49273
	(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	0.73010	0.62513	0.70267	0.64783
	(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	0.74813	0.60787	0.41833	0.24207
	(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	--	0.63220	0.16607	0.00000	0.00000
	(19.8)	(12.1)	(20.9)	(14.8)					(42.2)	(87.0)	( )	( )
7	1905	2410	2969	--	1.70	1.79	1.73	1.62	0.86953	0.21153	0.00000	0.00000
	(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	0.74500	0.50060	0.13160
	(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	0.72383	0.58830	0.32430	0.04777
	(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	0.57733	0.53893	0.38857	0.03213
	(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	0.50530	0.11597	0.00313
	(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	0.96587	0.41677	0.37837	0.18490
	(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	0.83117	0.68153	0.39797	0.27497
	(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	0.71207	0.45903	0.11753	0.00000
	(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	0.59460	0.40110	0.24257	0.14337
	(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	0.86485	0.57930	0.11755	0.03050
	(22.0)	(18.0)	(16.2)	(6.9)					(30.3)	(46.0)	(41.6)	(86.6)

† Numbers in ( ) are coefficients of variation.

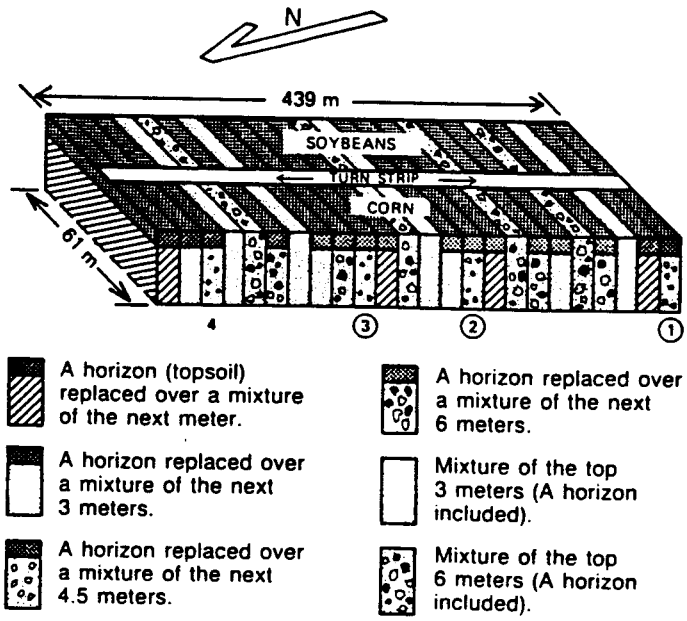

Fig. 2. Captain Mix Plots. Penetrometer measurements taken on topsoil (A horizon) over 4.5-m mixture (numbered 1–4). Sites used for root and bulk density analysis are circled.

Fig. 2, 3 and 4. At each sample site, six penetrometer measurements were taken three on either side of a FR MO17 × FR B73 hybrid corn (*Zea mays* L.) plant. This plant was located approximately 1.5 m (5 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 to 44 cm; segment 3, 45 to 66 cm; segment 4, 67 to 88 cm; and segment 5, 89 to 110 cm.

Depth segments will be referred to, hereafter, by segment number. A mean penetrometer resistance value was obtained for each segment and averaged over the six profiles at each site (Table 1). Segment 1 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 Fig. 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 18 and 19 July 1984 with the assumption that root maturity had been reached. Cores were taken using a 7.6-cm diam coring tool.

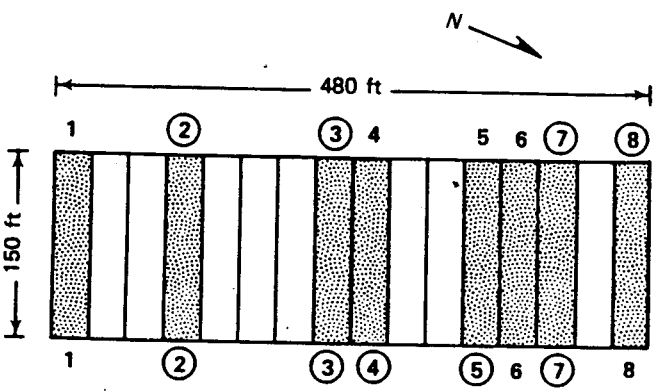

Fig. 4. River King Plots. Penetrometer measurements taken on topsoil over wheel spoil treatments (numbered 1–8). Samples taken from both east and west sides of the plots. Sites used for root and bulk density analysis are circled.

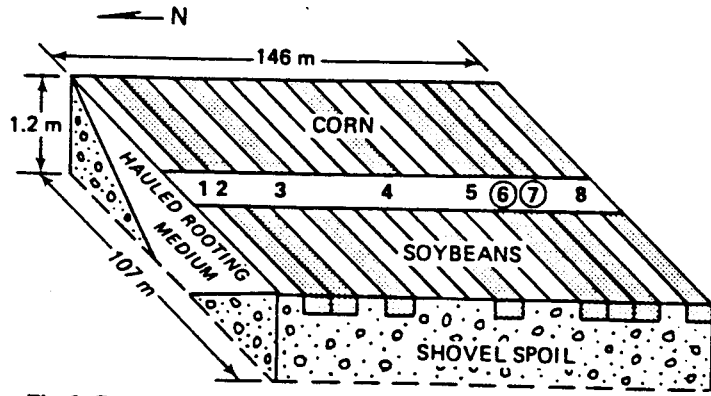

Fig. 3. Captain Wedge Plots. Penetrometer measurements taken only on the topsoil over hauled rooting medium treatments (numbered 1–8). Sites used for root and bulk density analysis are circled.

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.

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. Dry bulk density was determined by dividing the dry weight of these core segments by their moist volume. Bulk density data are given in Table 1.

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 average root length density value was obtained for each segment (Table 1).

Regression analysis was used to determine the following relationships between (i) penetrometer resistance and root length density, (ii) bulk density and root length density; and (iii) penetrometer resistance and bulk density. The Statistical Analysis Package (SAS) was used for data analysis (SAS Institute Inc., 1985).

Table 2. Percent soil moisture values for the final 14 sites used in regression analysis (gravimetric method, measurement taken on 6, 7, and 8 June 1984).

		% soil moisture		
Location	Plot no.	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	187	16.9
	7	18.6	15.5	16.5
	8	16.6	15.8	15.6

Table 3. Results of regression analysis: Dependent variable is root length density (cm/cm³) in the given segment.

Predictor variable	Segment no.	Probability > 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

RESULTS AND DISCUSSION

The Captain Mix Plot soils had the lowest soil strengths, as revealed by penetrometer resistance values ranging from 647 to 1628 kPa (Table 1). The scraper-hauled material in the Captain Wedge Plots had the highest soil strengths, with penetrometer resistances ranging from 1905 to 3709 kPa. Soil strength at the River King Plots ranged more widely than at the other two sites, and tended to be intermediate in value. The bulk density data followed a similar pattern. Plant roots were conspicuously absent below 66 cm in the high-strength Captain Wedge soil (Table 1).

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. Figures 5 and 6 show, graphically, the results from this model. A model including segment 5 into the average for the predictor variable was also fitted, but including segment 5 did not improve the fit.

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 in the above order. 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.

Table 4. Multiple linear regression models using average pentrometer resistance and bulk density as predictor 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	Probability > 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
CV = 50.6

Model 2: RLD (seg. 4 + 5) = 9.25 − 2.11 [ϱ_b(seg. 2)] + 0.52 [ϱ_b(seg. 3)] − 3.77 [ϱ_b(seg. 4)]

Source of variation	df	Sum of squares	Probability > F
ϱ_b(2)/a	1	0.0189	0.4890
ϱ_b(3)/ϱ_b(2), a	1	0.8872	0.0006
ϱ_b(4)/ϱ_b(3), ϱ_b(2), a	1	0.6193	0.0021

Residual error = 0.0367 (df = 10)
R^2 = 0.81
CV = 42.6

† RLD = root length density, PR = penetrometer resistance, ϱ_b = bulk density; a = intercept, numbers in ( ) represent segment numbers.

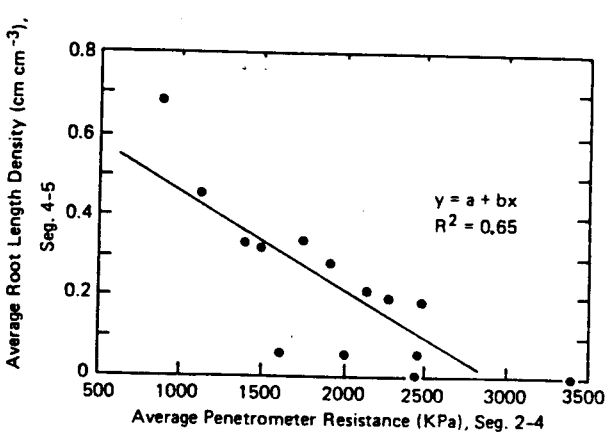

Fig. 5. Relationship between the average root length density of segments 4 and 5 and the average penetrometer resistance of segments 2 through 4.

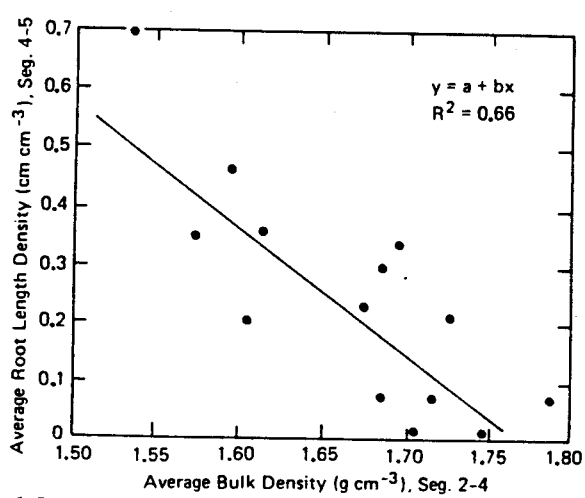

Fig. 6. Relationship between the average root length density of segments 4 and 5 and the average bulk density of segments 2 through 4.

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 significantly 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 a better predictor. 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 svstern 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 variabilitv 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 R = 0.49.0.68. and 0.75. for segments 3, 4, and 5, respectively). 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. 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 + $\rho_b 2$ + $\rho_b 3$ + $\rho_b 4$, where RLD = root length density, PR = penetrometer resistance, and ρ_b, = bulk density. This model has an R_2 = 0.90. Although this is the best fitting model investigated, the time and effort needed to collect and analyze the complexity of data is a distinct disadvantage. Investing the available 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 subtillage 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 pene-. trometer resistance data can be collected and analyzed more quickly, easily, and economically than bulk density data, it might be more useful;

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University of Kentucky, Lexington, Kentucky, December 7-11, 1987

A Comparison of Soil Construction Methods Used After Surface Mining for Coal

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Abstract. This study compared several soil replacement methods used in prime farmland reclamation after surface mining for coal in Illinois. The soil physical condition and productivity of min roils are related to the amount of grading and traffic practiced during soil construction. Equipment used for placement and grading of the roil material commonly induces excessive compaction. Soil atrength, measured with a constant rate recording cone penetrometer to a depth of 112 cm was found to be a useful parameter in evaluating soil physical condition. Soil strengths below 1.0 MPa were found in areas that had minimal gradfng and traffic. Soil strengths of 2.0 MPa or more were typical of areas constructed with scrapers that require a lot of traffic and grading. Significant correlations were found between 9011 strength and yield in some areas. Southern Illinois corn yields of 6100 kgha-1 are typical of the areas with the lowest soil strength and yields of less than 2000 kgha-1 are typical of the area with the highest soil strength. Profile9 of soil strength can show tones of deep compaction induced when heavy equfpwnt is used to place topsoil over root media of low soil strength material as well as the sequence of high soil strength layers commonly found in scraper placed material.

Introduction

Reclamation practices carried out after surface mining for coal can significantly affect the final constructed soil. Indorante et al. found that conatructcd soils had higher bulk densities and lacked structure compared to undisturbed soils. Grading and traffic during soil construction plus the moderately fine textures of these soils result in compacted and poasibly poorly aerated soils. McSweeney and Jansen[2] found that a bucket wheel excavator-conveyor-spreader system allowed the formation of a desirable fritted structure which is fairly loose and contains a network of void9 up to 0.02 m wide. A less desirable massive physical condition was found to varying degrees where scraper9 are used exclusively, leaving no structure and most voids consisting of deslccacion cracks. Truck methods of soil handling produced lower bulk densities when compared to scraper method9 and crops showed response to the difference in Kentucky prime farmland reclamation .

The effects of compaction on the growth and yield of soybeans (Glycine max (L.) Herr) was studied in a greenhouse by Stucky and Lindsey[4] . Soil from prima farmland in southern Illinois was compacted to several levels of bulk density. Yield was positively correlated with root weight and plant development stage, and negatively correlated with bulk density.

The effects of wheel traffic compaction on a silty clay loam in Minnesota was studied by Voorhees et al.[5]. They found that penetrometer resistance was a more sensitive indicator of soil compactlon than was bulk density. Wheel traffic increased bulk density by 20% or less, whereas penetrometer resistance was increased by as much as 400%. Wheel traffic affected bulk density only down to 30 cm, while penetrometer resistance was affected down to 60 cm in some cases.

Soil strength (penetrometer resistance) is affected by bulk density, dense roil angle of response, and soil moisture Stitt et al.[6]. Soil moisture can be controlled by taking penetrometer readings in the spring while soils are at field capacity and fairly consistent within the soil profile. Taylor et al[7]. recommends that roil strength must be recognized and evaluated in moat

experiments dealing with plant-soil interactions. They found that as soil strength increa es root penetratfoa decreases. Thompson et al.[8] found that penetrometer resistance vaa a good predictor of root system performance, particularly the extension of roots deeper in the profile. It is clear that the use of a penetrometer vould be a reasonable vay to evaluate soil construction methods. A tractor mounted constant rate recording cone penetrometer provides for fast collection of a large amount of data compared to sampling for bulk density and other physical paramesters[8,9].

Study Areas

The study looked at four reclamation methods used on three different mines in Perry County in southern Illinois. The first site is at the Captain mine vere a bucket wheel excavator-conveyor-spreader system was used to build a set of plots for comparing soil horizon blending vith and without topsoil. The two soil treatments consisted of approximately 1.5 m of a B horizon, which was a blend of the top 3 m of premine soil. One had no topsoil replaced and will be referred to as 3 m mix and the other hsd 30 cm of topsoil replaced and will be referred to as A/3 m mix. This system used a spreader which controlled soil placement so that only minimal grading was. required both for final grading and leveling off prior to topsoil placement.

The second site is a set of plots at the Denmark mine where a truck-scraper comparison is being evaluated. Three treatments include: 1) scraper treatment which has 1 m of rooting media placed with scrapers over the graded cast overburden base; 2) material placed with rear dump trucks placing 1 m of rooting media with all truck traffic on the base level and dozers used to level the material, referred to as truck no traffic; 3) truck traffic placed on the material and is referred to as truck with traffic. Topsoil vas then placed in windrows on the turn strip borders and dozers pushed it onto the plots to a depth of 25 cm.

The third site is at the Fidelity mine on some recently reclaimed land using a cross pit wheel with the objective of evaluating the method of topsoil placement. In the first treatment, topsoil was placed with scrapers on the graded wheel spoil and is referred to as scraper TS/WS. The other treatments are were they had placed a topsoil berm (windrow) with scrapers and pushed the topsoil out with dozers. Data was collected both on the topsoil berm referred to as berm TS/WS and between the berms were only dozers had been on the graded wheel spoil and is referred to as dozer TS/WS.

Methods

Penetrometer resistance vas measured to a depth of 112 cm with a constant rate recording cone penetrometer constructed at the Univ. of Illinois[9]. It is a modified tractor mounted Giddings coring machine vith a modified hydraulic system allowing pressure monitoring and the control of f lov to a standard rate of 2.9 cm/s. The output voltage from a strain gage load cell goes to a data acquisition system which takes a reading every 2.24 cm.

The sampling at the Captain site consisted of four replicates per treatment vlth four samples per replicate and two sub-samples per sample. The Denmark site had five replicates per treatment with four samples per replicate and two sub-samples per sample. These two sites were sampled in this method so that sample sites corresponded to the harvest sample sites. The Fidelity site was an open field rather than experimental plots. Six samples (replicates) per method were taken vith three sub-samples per sample at this site.

The sub-samples were averaged for each of the 50 readings that make up a profile to leave one average profile per sample. The average profile for each sample was then broken down into five segments of ten readings each and an average penetrometer resistance over the ten readings 'is calculated and they each represent 22.4 cm of the total profile. Table 1 shows the five segments and their corresponding depths. They will be referred to by segment numbers from nov on. Segment 1 will not be used in any of the analysis because it covers the conventional tillage zone and has been altered from its original condition. Analysis of variance procedures were run by segment for the Captain and Denmark sites. The Fidelity site was analyzed using a t-test procedure by segment.

Table 1. Segments and their corresponding depths.

Segment 1	0.0-22.4	cm
Segment 2	22.4-44.8	cm
Segment 3	44.8-67.2	cm
Segment 4	67.2-89.6	cm
Segment 5	89.6-112.0	cm

Results and Discussion

A penetrometer resistance profile can allow for the observations of local site patterns in the soil. Figure 1 is a single observation from a area reclaimed with scrapers. The profile has a series of jagged peaks from the topsoil interface to the bottom of the profile which may coincide with the lift interfaces due to scraper placement. In Figure 2 there is a peak of high penetrometer resistance just below the depth of topsoil placement by scrapers over wheel spoil. There is also some smaller variation below this zone in the wheel spoil. This pattern in the wheel spoil has been observed to various degrees on other sites and is believed to be related to the uneven amount of grading required on the wheel spoil.

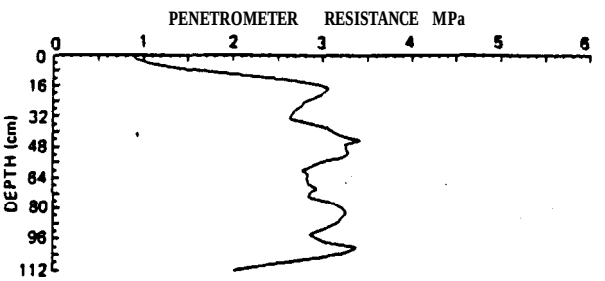

Figure I Profile of a scraper treatment.

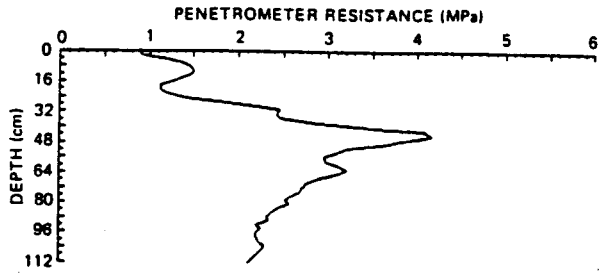

Figure 2 Profile of a scraper TS/WS treatment.

The profiles of the Captain site in Figure 3 show that both treatments have fairly low soil strength. Table 2 shows that there is no significant difference between the two treatments in any of the four segments. Both of these two treatments allow for deep rooting and crops usually show relatively little moisture stress. The two treatments have usually yielded as good or better than undisturbed sites over 6 years.

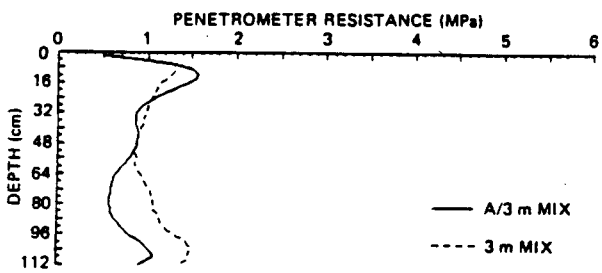

Figure 3 Profiles from the Captain site.

Table 2. Captain site penetrometer resistance.

Treatment	Segment 2	Segment 3	Segment 4	Segment 5
	- - - Penetrometer Resistance, MPa - - -			
3 m Mix	1.080 a	0.935 a	1.058 a	1.340 a
A/3 m Mix	1.040 a	0.910 a	0.671 a	0.828 a
LSD (0.05)	0.789	0.997	1.463	1.811
CV (%)	43.58	31.56	13.28	69.04

The Denmark site shows a little more variation between treatments than did the Captain site. In Figure 4 the scraper treatment was highest of the three over most of the profile while the truck no traffic was the lowest and the truck with traffic was intermediate. Crops on these treatments have followed similar trends with the scraper showing the most stress and truck no traffic showing the least. In Table 3 the truck no traffic had significantly lower soil strength than the scraper treatment over all four segments, but the truck with traffic treatment was not significantly different from either of the other two. This same relationship has been found in the two years of corn yields from this experiment. The range of penetrometer resistance between treatments at this site was wide enough for meaningful correlation of penetrometer resistance by segment to corn yields for two years. Table 4 shows a significant negative correlation between yield and penetrometer resistance in segments 2, 3, and 4, for both years

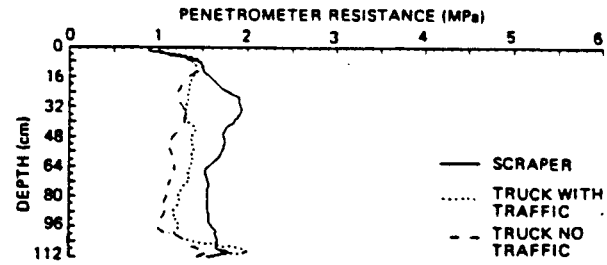

Figure 4 Profiles from the Denmark site.

Table 3 Denmark site penetrometer resistance

Treatment	Segment 2	Segment 3	Segment 4	Segment 5
	- - - Penetrometer Resistance, MPa - - -			
Scraper	1.875 a	1.891 a	1.779 a	1.781 a
Truck ~~no~~ WITH Traffic	1.540 ab	1.566 ab	1.470 ab	1.495 ab
Truck ~~with~~ NO Traffic	1.256 b	1.301 b	1.113 b	1.189 b
LSD (0.05)	0.485	0.415	0.371	0.329
CV (%)	29.07	26.58	29.57	38.62

Table 4 Denmark site correlations of corn yields with penetrometer resistance

	1985	1986
Segment 2	-0.42419 *	-0.30964 *
Segment 3	-0.41651 *	-0.46060 **
Segment 4	-0.42318 *	-0.40208 **
Segment 5	-0.17258 n.s.	-0.10500 n.s.

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

The Fidelity site in Figure 5 shows little difference between dozer TS/WS and scraper TS/WS except in the lower half of the profile while the berm TS/WS was dramatically higher thru the whole profile. Table 5 does not show a significant difference between scraper TS/WS and dozer TS/WS over the four segments while the berm TS/WS was higher than the other two in segments 2 and 3.

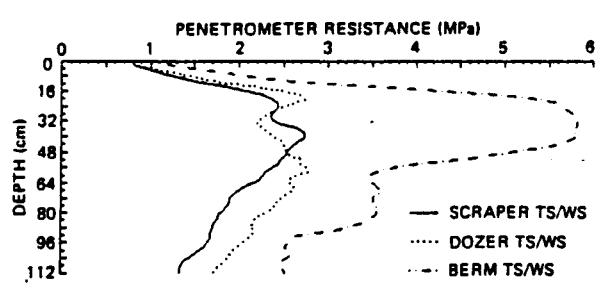

Figure 5 Profiles from the Fidelity site.

Table 5 Fidelity site penetrometer resistance

Treatment	Segment 2	Segment 3	Segment 4	Segment 5
	- - - Penetrometer Resistance,MPa - - -			
Berm TS/WS	6.029a	3.789a	3.452a	2.556a
Dozer TS/WS	2.356 b	2.642 b	2.321ab	1.953ab
Scraper TS/WS	2.543 b	2.334 b	1.816 b	1.525 b
LSD (0.05)	1.240	0.802	1.267	0.686

Conclusions

The methods that use only dozers on the freshly placed material and limit the amount of grading appear to leave the most favorable physical condition in the resulting soil. The use of some wheel traffic on the rooting media may increase soil strength and result in some drought susceptibility and yield reductions. Exclusive use of scrapers can increase soil strength further and leave a quite droughty soil. The practice of windrowing with scrapers can severely compact the soil quite deeply, under the windrow. This is due to both wheel traffic and the weight of topsoil in the berm.

Acknowledgments

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COMPACTION MEASUREMENT METHODS[1]

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Abstract

Current reclamation practices include a variety of methods to reconstruct soils. The methods of excavation transportation, and placement can affect the physical properties of the reconstmcted soil. This is a major factor affecting crop performance. The relationship of compacted subsoils and poor crop performance has been identified, and deep tillage is used when compaction is suspected. Illinois researchers have investigated several methods to detect and quantify soil physical problems. Experience has shown that soil strength, as collected with the deep profile penetrometer, is the most efficient and reliable measure for reconstructed soils. A three dimensional view of the soil can be rapidly generated when this information is collected with a GPS database. Some mine operators are currently using soil strength to more efficiently prescribe the deep tillage, where needed, at the proper depths.

Introduction

Current reclamation practices include a variety of methods to reconstruct soils. The methods of excavation, transportation, and placement can affect the physical properties of the reconstructed soil. This is a major factor affecting crop performance (Jansen et al. 1985). The relationship of compacted subsoils and poor crop performance has been identified with deep tillage to relieve subsoil compaction and improve productivity, becoming an accepted practice in the industry. Deep tillage is commonly used in Illinois as the final step in the reclamation process for row-crop acres. The yield effects of tillage depth, reclamation methods, and time have been studied (Dunker et al. 1995; Hooks et al. 1992). In general, it has been concluded that productivity success is directly related to the physical condition of the soil or the level and extent of compaction. In the early years of Illinois reclamation research, it became apparent that, in addition to long-term yield testing, a more efficient method for evaluation of these soils was needed. Several parameters were considered and have been tested in varying degrees. A discussion considering advantages and limitations is presented in this paper.

Parameters Considered

Crop Performance

Annual crop yields have been measured since 1978 by Illinois researchers on various test plots and whole fields. Differences in yields are most dramatic in years of high moisture stress. In years of little stress, moderate, if any, yield differences can be measured. Hence, yield tests over several years are necessary to reliably detect a minesoil problem. Figure 1 illustrates this with yield differences between years within treatment sometimes greater than the differences between the compacted (Scraper) and a favorable (Wheel-Conveyor) minesoil.

Whole field yield comparisons (grain elevator weight ticket measurement) are easily tabulated but are only useful for a field to field comparison. Specific within field problem areas cannot be identified GPS and yield monitors can be used to gather more specific information. Crop performance evaluations are subject to weather variability, and tests over time are required. Even then, it can be difficult to determine if yield differences are due to a soil problem, a management error, or a weather anomaly.

Visible Differences

Those who have been involved with monitoring crops during the growing season over time can attest to the fact that treatment or soil differences are easily detectable by plant moisture stress symptoms.

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[1]Paper presented at Prime Farmland Reclamation Workshop, August 11, 1998, at Southern Illinois University, Carbondale,Illinois.

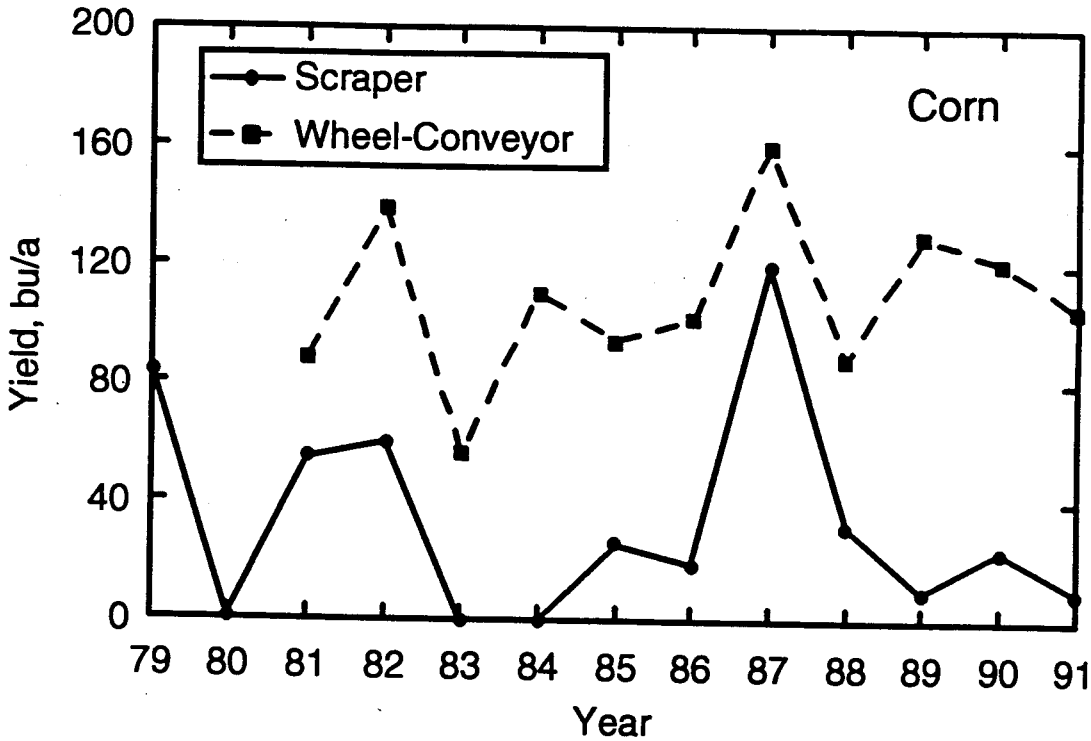

Figure 1. 1979 to 1991 Corn Yields: Compacted and Noncompacted Minesoils.

Signs of stress may occur for a long period of time or only a few days depending on the year. Symptoms may not be present in the early morning hours but are observable at midday. After long periods of stress, the symptoms remain through the night and are present in the morning. The plant response to soil differences is easily detected by those who frequent the fields but it is difficult to quantify. The year, the time of year, and the time of day are critical to capture these observable differences. Well-timed visual and infrared aerial photography has been used by researchers for this purpose. Through digitization, this information can be quantified. Though costly and time consuming, differences can be measured and compared statistically. Canopy temperatures also were measured with a hand-held infrared thermometer (Thompson et al. 1984). This also generated measurable differences, but again the timing and the year were critical. With considerable effort and critical timing, observable differences can be measured. The quantification of visible differences is possible but it is impractical for the mine operator.

Soil Characteristics

A constant rate penetrometer was developed to serve the need to quantify physical properties of reconstructed soils (Hooks and Jansen 1986). Thompson (1987) studied the relationship of bulk density and soil strength to corn root length density on reclaimed soils. That study concluded that while both bulk density and soil strength correlated well with corn root length density, soil strength data was easier to collect in the numbers required to accurately assess reconstructed soils. Bulk density sampling by the core method is questionable on reclaimed soils, especially deep tilled soils. In some cases, there is a resultant fluff in the soil that may be as much as 20 inches. With this dramatic increase in macroporosity, percolation increases and the subsoil can be easily compressed. Another possibility is that the tillage shatters the subsoil but large peds of compacted material remain with large fissures and macropores between them. Some minesoils with bulk density levels higher than acceptable for natural soils are productive. Bulk density has proven to be an unreliable test across several minesoils. Figure 2 shows that there is a lack of correlation between bulk density and yield across several depths of tillage.

The reliability of in situ soil strength measurements has been questioned (Mulqueen et al. 1977). Mulqueen also acknowledged the ease of sampling and suggested the measurement of moisture content. Perumpal (1983) presented a summary of many studies with the cone penetrometer. These studies relate the effects of moisture content, density, texture, and even organic matter to cone index. It appears that it is generally accepted that soil

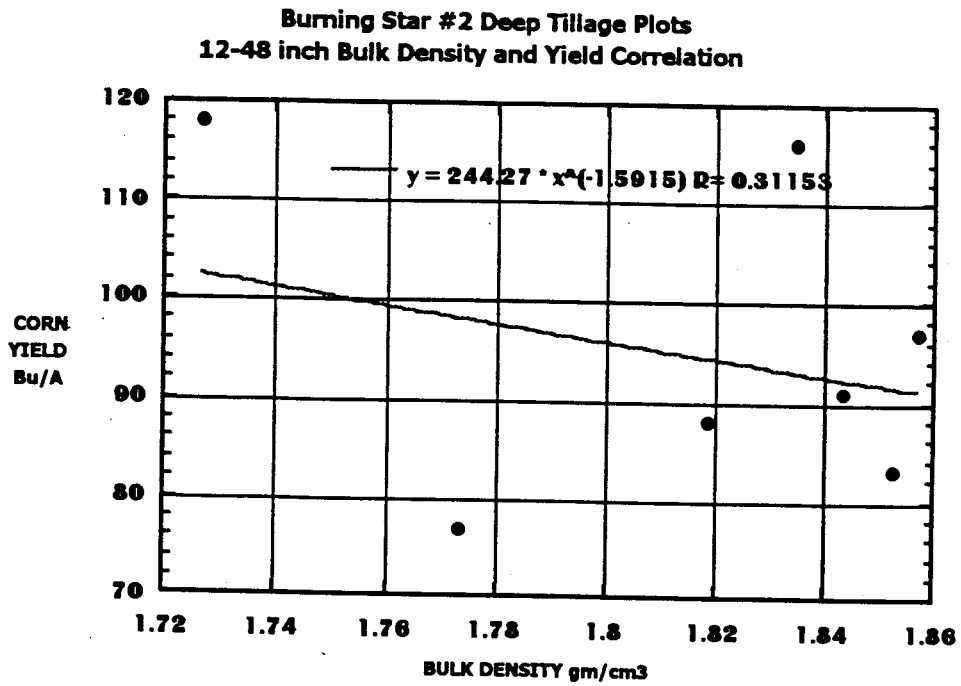

Figure 2. Subsoil Bulk Density vs 10 Year Corn Yield Means.

The correlation of soil strength and yield from the same data set is significant (Figure 3).

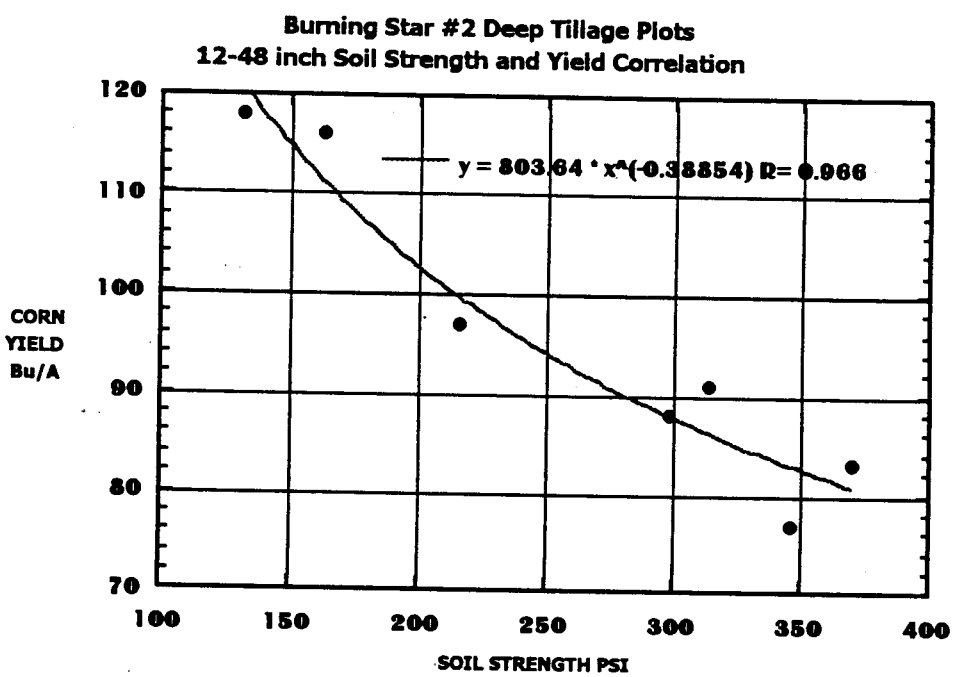

Figure 3. Subsoil Soil Strength vs 10 Year Corn Yield Means.

strength measurements are most reliable at or near field capacity. From an engineering or physical approach soil strength is a true value that should be predictable with given values of moisture content texture. density. etc. In this study, soil strength is approached as a relative value that is a composite of the effects of moisture content texture, density, etc. Moisture content is a major factor in soil strength when it is well below field capacity. However, when the data is collected in the spring, when soils are the most uniformly moist. minor differences in soil moisture between treatments are considered to be a reflection of the soil/enviromnent interaction and a valid part of the composite value "soil strength."

Minesoil productivity is related to the level and extent of compaction. Soil strength can determine the level of compaction in PSI, which can be related to plant root penetration. Soil strengths above 300 PSI are highly restrictive to root growth and are an indication that a soil physical problem exists. The depth to a root limiting zone also can be determined which relates to the available soil volume favorable for plant growth. When combined with a ground position database (GPS or surveyed) a three dimensional view of the reconstructed soil can be generated. . This allows the identification of critical compaction levels, their extent, location, and depth in a field. The data is collected in real time with the computer and data acquisition system. Minimal effort and data manipulation is required to generate a three dimensional field compaction map. Figure 4 is an example for a 24 acre field on topsoil over wheel spoil. Depth "slices" were generated with 6 inch segment means. The west half of this field was deep tilled to 32 inches and the east half was not tilled. The 12 to 18 inch segment is just below the topsoil and indicates that the west side is uniformly favorable for plant root growth with PSI levels below 300. The east side is highly compacted and few roots will penetrate below this depth. The 24 to 30 inch segment indicates a similar distribution of compaction but excessive levels still exist on the east side. The 36 to 42 inch segment is below the depth of excessive compaction with fairly uniform PSI levels at 300 or less. This is below the depth of tillage on the west side and is typical of wheel construction with compaction below the topsoil to the depth affected by spoil grading. Compaction can be efficiently managed with this information that indicates the east half of the field is a problem area needing tillage to a depth not exceeding 36 inches.

Summary

Soil strength as measured with the deep profile penetrometer has proven to be the most efficient and useful parameter for the detection and evaluation of compaction.

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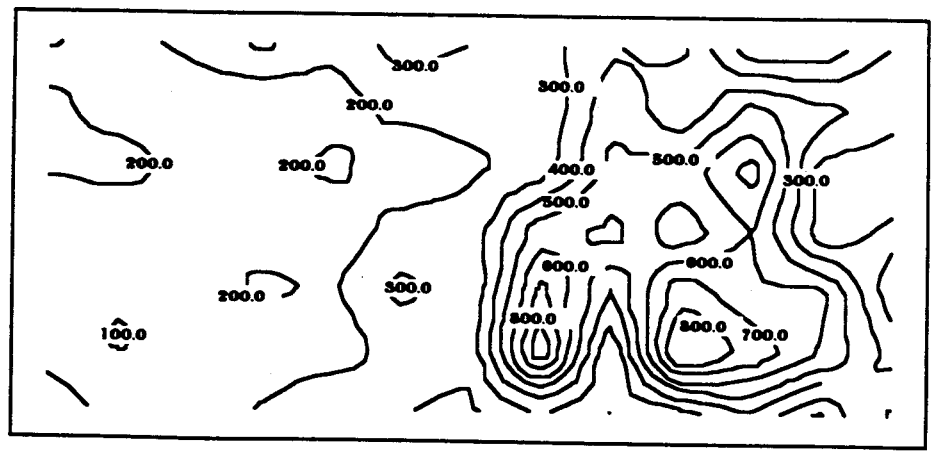
12 - 18 Inch Depth



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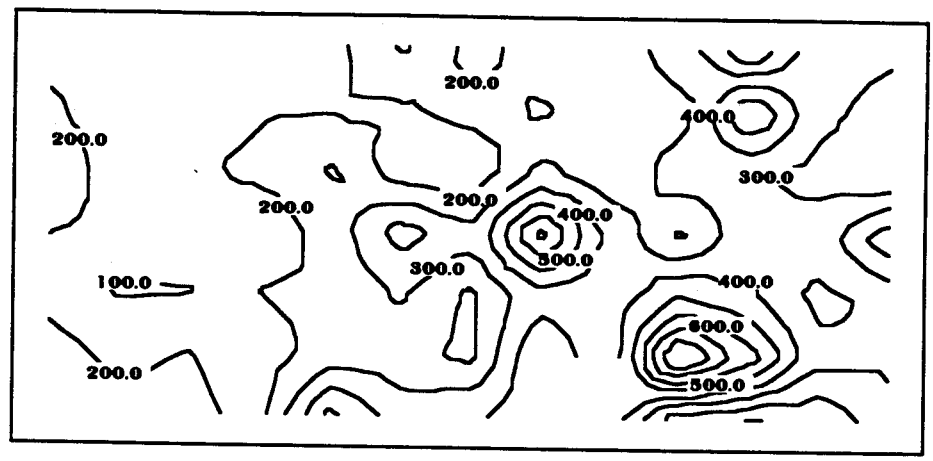
24 - 30 Inch Depth



36 - 42 Inch Depth

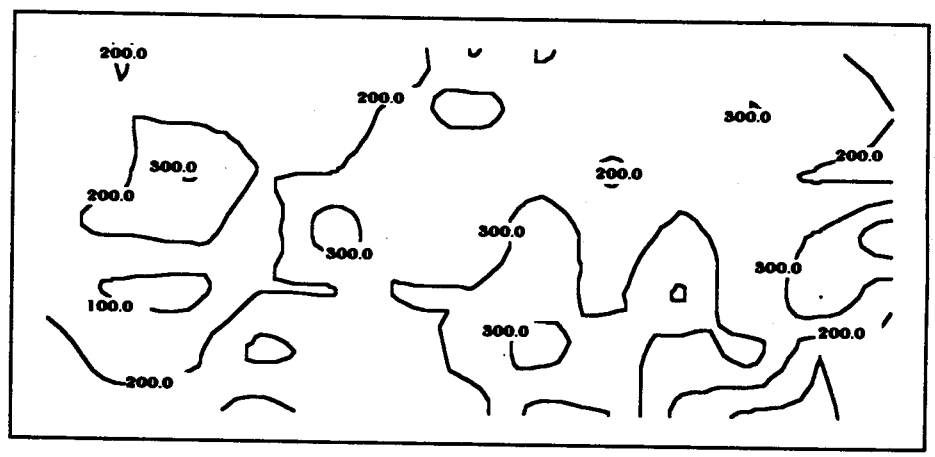


Figure 4. Soil Strength Depth Segment Contour Maps

Effects of Deep Tillage

COMPACTION ALLEVIATION METHODS COMPARISON

R E. Dunker, C. L. Hooks, S. L. Vance and R. G. Darmody

Introduction:

Poor soil physical condition has proven to be the most severe and difficult limiting factor in the reclamation of many prime farmland soils. The newly constructed soils commonly lack a continuous macropore network to provide for water movement, aeration, and root system extension. Also, the soil strength is commonly excessively high, so that plant root growth is severely inhibited.

There are two sources of the physical condition problem in man-made soils. One is the use of severely compacted, high strength materials from great depth without adequately disrupting that high in-place strength while moving the soil materials. Secondly, and more commonly, is compaction induced by earth moving equipment in the process of moving and placing the soil material.

It has been assumed by many that the physical condition problem can be solved by just including forage legumes in the crop rotation, or by an initial period under forage legumes. We have completed two experiments over the last ten years to evaluate their efficacy in solving this problem. The practice, though having some merit, has proven inadequate. Soil strengths are commonly just too high to get diffuse distribution of even alfalfa root systems. The roots tend to form mats in desiccation cracks and leave much of the soil volume largely unaffected. Physical improvement is slow and inadequate. Perhaps that should not be surprising, as severely compacted glacial till layers in some natural soils have also remained intact, even after one or two centuries of agriculture. Forage legumes would likely be much more effective in soil improvement if soil construction procedures could be modified so as to reduce the severity of the soil compaction problem.

It has been advocated that the problem can be solved by only moving soil materials when they are dry. This approach also has merit, but is also inadequate. First is the reality that the mines simply do not have that option. Secondly is the experience that, even though moving materials dry does help substantially, the finished product still has excessive soil strength and bulk density. Efforts should continue to find soil construction methods which will prevent the problem, but meanwhile, means for amelioration of deeply compacted soils must be investigated.

Compaction is particularly serious and the solution is particularly difficult in the heart of the corn belt, because of the need for deep soils there. Natural soils of the midwest are commonly 1.5 m or so deep. The predominate crops can effectively exploit soils of that depth. The rainfall is adequate to completely recharge a 1.5 m soil in most years. And, periods of drought stress during the growing season are sufficiently common as to require maximum available water storage capacity in soils for maximum yields.

There are many tillage options which have been proven effective to 30 cm or even 40 cm depth. A few methods are effective to 75 cm. Methods for effective physical improvement to depths beyond 100 cm in reclaimed prime farmland soils remain unproven.

Objective: Determine the effectiveness of each of several deep soil tillage methods for improving soils with poor physical condition.

Materials and Methods

The site: A site for this experiment was selected on Consolidation Coal Company's the Burning Star #2 Mine, east of Pinckneyville, Illinois. The soils on the site were constructed in 1983 by placing, with scrapers rooting medium with 15 cm of topsoil material, totaling 122 cm in thickness.

Consol took soil fertility samples of the area and seeded alfalfa in the fall of 1986. The first-year stand of legumes was mowed in mid-season 1987 to control weeds and to aid in the determination of surface drainage requirements. Minimal grading was then done between 21 and 23 July to eliminate minor depressions and to establish drainage outlets -at the north end and northwest corner of the site. The fertilizer requirement for a 30 cm plow layer was determined on the basis of Consol's fertility analysis of the previous fall. The required 0-170-260 fertilizer and 3 tons/acre of agricultural limestone were applied prior to application of the deep tillage treatments.

Experimental design and layout: A randomized complete block experimental design providing for six replications of seven treatments was prepared for the site. Four of the treatments were for planned deep tillage applications, one was for a control, and the remaining two were blanks for evaluation of any promising new methods which might become available later (Figure 1). The plots were surveyed and staked out on April 20, 1987. There are two rows of three blocks each, aligned in roughly a north-south direction. Each of the 42 plots is 15.2 m wide and 87 m long, to provide two 15.2 m by 30.2 m subplots for corn and soybeans, respectively, separated by a 15.2 m turn strip.

Pre-treatment evaluation of soil strength: The deep-profile penetrometer was used to measure soil strength to a depth of 112 cm prior to the application of any tillage treatments. The soil strength of this area was highly variable, but the pattern was such as'to not compromise the experiment The west half was much higher in soil strength than the east half, so that one row of three blocks will be in the high strength soils and the other three blocks in lower strength soils (Table 1).

The difference in soil strength between the east and west sides .is apparently due to time differences in grading. There was a one year delay in grading of the cast overburden, between the east and west sides, but all of the root medium and topsoil materials were placed during the June-August period of 1983.

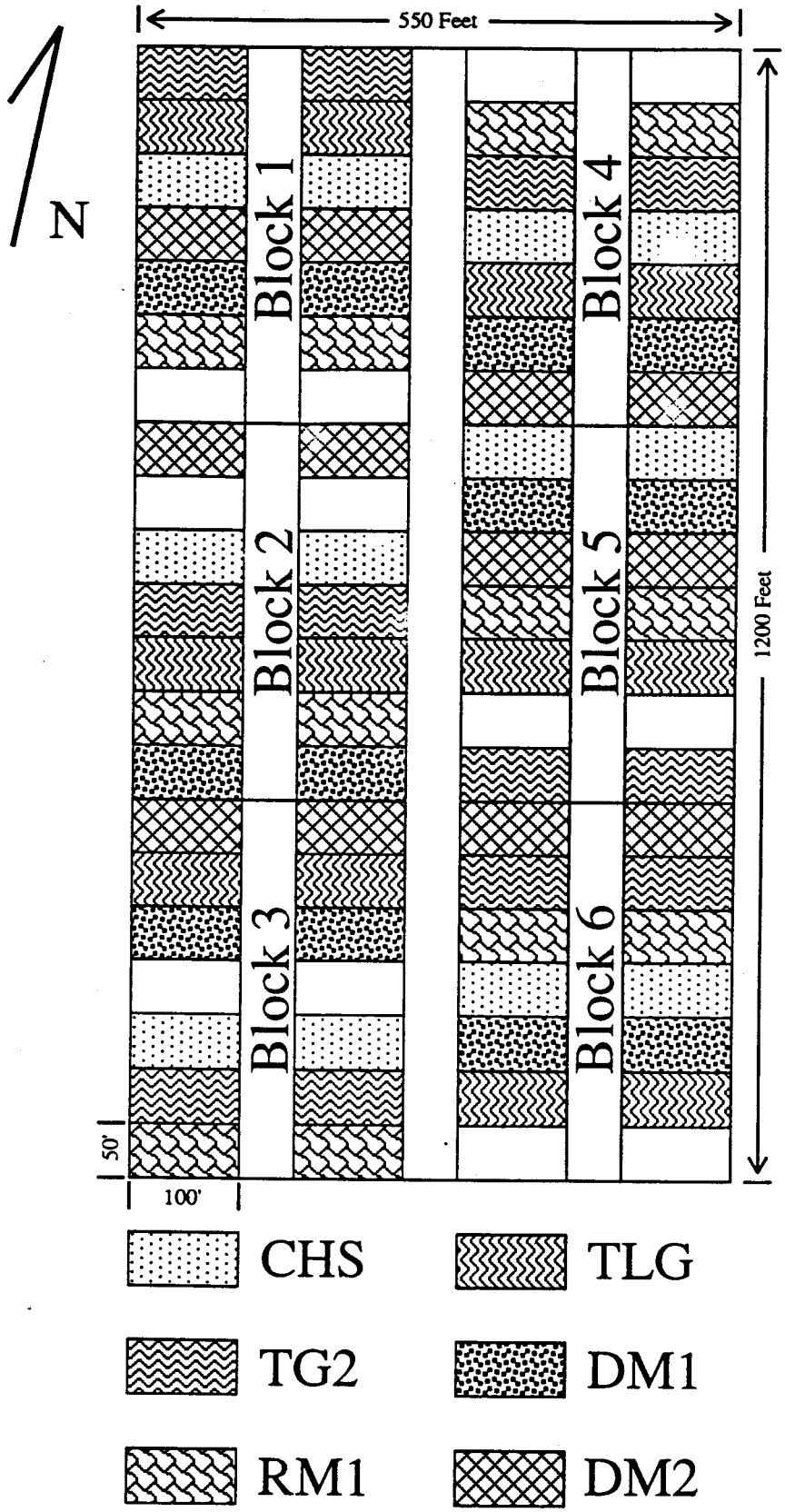


Figure 1. Deep Tillage Plots at Burning Star #2.

Aerial photography from early June on 1983 indicates a scraper haul road along the west side of the site. Soil texture analysis at each of the penetrometer test sites were performed in 1988 to determine whether there is any measurable differences in the soil materials between the east and west sides of the area.

Table 1. 1987 BS#2 penetrometer values before tillage.

Treatment	Seg 2 9 - 1 8 ”	Seg 3 18-27”	Seg 4 27-36”	Seg 5 36-44”
		Penetrometer Resistance, PSI		
1	332.5 a[1]	369.9 a	327.9 a	260.6 c
2	365.7 a	420.0 a	350.4 a	319.9 ab
3	358.6 a	391.8 a	335.5 a	314.2 ab
4	336.5 a	391.9 a	352.4 a	327.2 a
5	348.1 a	411.2 a	338.2 a	283.6 bc
6	316.0 a	386.3 a	350.5 a	322.3 ab
7	353.0 a	396.9 a	307.4 a	301.3 abc
LSD (0.05)	59.9	61.9	62.5	41.2

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

Application of the deep tillage treatments: The plot areas at the site were sprayed in early August, 1987 with one quart of Roundup and 1 pint of 2,4-D per acre kill the dense, foot-tall stand of legumes. This was done to reduce the amount of plugging with green trash during tillage and to reduce control problems in the row crops to be planted in 1988.

Five of the tillage treatments were completed during the next month (Table 2). Those treatments are as follows:

1) Kaelble Gmeinder TLG-12. The TLC uses a cut-lift operation to shatter the soil to a depth of about 90cm. A wide, moving foot is attached to each of the three shanks to cut and lift the soil as the machine moves forward.

2) RM1 Processor by Harry Jones. The RM1 Processor has four curved, vibrating shanks cut from 3.8 cm steel. The shanks do not have expanded points or wings. Two hydraulic vibrators are used; each operating two of the four shanks. It has an effective tillage depth of about 90 cm.

3) DM1 Deep Ripper (prototype). This machine is a two-lift, solid shank ripper. Two “Turbo” chisel shanks are used to fracture the soil to a 45cm depth ahead of the main shank. The main shank is cut from 10.2 cm steel. It is parabolic and has a winged point, 80cm wide with an 18cm lift. The point. of the main shank is designed to run 130cm deep. The machine

incorporates a hydraulic trip/reset mechanism to prevent breakage. Successive passes are separated by 122cm. Under favorable moisture/ tilth conditions the floor of the tilled zone shears nearly horizontally, yielding a minimum tilled depth of 122cm or more. Moisture content at that depth was a bit high at the time of treatment, and a pronounced ridge of unloosened material was left between shank passes.

4) Tiger-two chisel by DMI. This is a commercially available chisel used in commercial agriculture for tillage in the 30-45cm depth range. It is not really considered adequate for the needed loosening in reclaimed soils because of its depth limitations. It was included for comparison, to see just what could be accomplished with a conventional machine of this type.

5) Standard agricultural chisel plow with an effective depth of 22-25 cm. This treatment is considered the tillage control treatment.

Table 2 Tillage equipment description.

Treatment	Power Unit	Horsepower	Tillage Width	Depth of Tillage
DM1	Caterpillar D8LSA	440	48”	48”
DM2	caterpillar D10	530	48”	48”
RM1	John Deere 850 B	180	120”	32”
TLG	John Deere 850 B	180	90”	32”
Tiger II	Case	230	150”	14”
Chisel	Ford 6600	85	72”	9”

The DM1 Deep Ripper and the RM1 processor treatments were disced prior to tillage to reduce plugging of trash. The Tiger-two and the TLG were equipped with coulters to eliminate this problem. Immediately after tillage, each plot was leveled with a disc. The RM1 processor was used to rip the turn strips and border areas after all of the treatments had been applied.

An additional deep tillage treatment was applied in August, 1988 to the experiment utilizing one of the two blank treatments designed into the experiment. The new treatment, the DMI Super Tiger (DM2), is similar to the DM1 prototype previously used. It does, however, have a new point design and uses a larger power unit for more consistent depth and greater ground speed. One blank treatment remains in the design for a future tillage treatment if available.

Table 3. Plot management record for BS#2 experiment.

	1988	1989
	Corn:	
Hybrid	FR27xMo17 LH1l9xLH51	FR27xMo17 LH119xLH51
Planting date	May 11	May 11
Planting rate	23,200 / acre	24,200 / acre
Fertilizer	170 lb / a P 260 lb/a K 200 lb/a N	80lb / aP 190 lb/a K 200 lb/a N
Herbicide	4 lb Extrazine 2qt Lasso	2.5 lb Extrazine 1qt Lasso
Insecticide	Furadan 15G	Lorsban 15G
	Soybeans:	
Variety	Williams 82 Union	Williams 82 Union
Planting date	May 12	May 11
Planting rate	72 lb / a	62 lb / a
Fertilizer	170 lb / a P 260 lb/a K	80lb/a P 190 lb/a K
Herbicide	2 pt Prowl 2/3 pt Sceptor	2 pt Prowl 2/3 pt Sceptor

A nearby tract of Cisne silt loam (Mollic Albaqualf) is used as an unmined comparison. Management factors for the mined and unmined soils are the same and similar to practices followed by a typical farming operation (Table 3). Corn *(Zea mays* L.) and soybeans [*Glycine max* (L) Merr] are rotated each year within the experimental design. A minimum tillage management sys tern was used to minimize traffic and recompaction on the plots. Soil moisture is monitored during the growing season using a neutron probe.

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

Results and Discussion

Effects of deep tillage on soil strength: The deep-profile penetrometer was used to measure soil strength after tillage prior to planting in 1988 and 1989. Analysis of these evaluations are presented in Table 4. In summary, the Tiger II (TG2) was successful in lowering soil strength down to Segment 2 (9-18") when compared to the control at the 0.05 level of significance. . The TLG and RM1 significantly lowered soil strength to Segment 3 (18-27") in both years analysis. Soil strength values for these two treatments are numerically lower than the CHS treatment in both years but are not significantly different at the 0.05 level. Both the DM1 and DM2 deep plows were successful in lowering soil strength to the 44" depth. It is important to note that even though the magnitude of soil strength values are different for 1988 and' 1989 results, the significant groupings of treatments are essentially the same for both years. This is probably due to differences in soil moisture content: at the time data was collected.

Table 4. Penetrometer data from BS#2 plots after tillage.

Treatment	Seg 2 9-18"	Seg 3 18-27"	Seg 4 27-36"	Seg 5 36-44"
		Penetrometer resistance, PSI		
		1988		
Spare B[1]	804.1 a[2]	603.6 a	417.1 a	446.4 a
SpareC	768.8 a	584.4 a	415.8 a	432.8 ab
CHS	712.8 a	554.6 a	405.9 ab	434.55 ab
TG2	568.7 b	582.3 a	416.4 a	379.0 b
DM1	235.9 c	193.6 b	180.7 c	210.6 c
RM1	218.7 c	266.7 b	345.0 b	387.9 ab
TLG	193.4 c	219.1 b	338.9 b	390.2 ab
LSD (0.05)	99.5	123.9	67.1	61.5
		1989		
Spare B	521.9 a	515.8 a	419.7 a	381.6 a
CHS	457.4 ab	433.4 a	374.5 ab	350.5 a
TG2	400.4 b	457.7 a	394.5 ab	350.6 a
RMl	200.1 c	195.3 b	320.9 b	346.3 a
TLG	192.0 c	181.3 b	323.5 b	388.5 a
DM1	188.9 c	160.2 b	148.0 c	176.4 b
DM2	151.8 c	179.5 b	173.2 c	138.3 b
LSD (0.05)	71.0	135.6	87.3	62.9

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

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

Soil texture samples were collected and analyzed to determine in texture was a factor in the differences in pre-tillage soil strength on the east and west set of plots. Mechanical analysis of these samples showed that the root media texture fell into the loam category for both sides. No significant correlations occurred between texture differences observed at this location and differences in soil strength within a tillage treatment.

Rowcrop yields: Tillage treatments significantly affected corn and soybean yields in both 1988 and 1989 (Table 5). Corn hybrids were not a significant factor in either year. There was a soybean varietal response in 1988 but not in 1989. Significant block differences occurred for both corn and soybeans. In general, the three blocks on the west side of the experiment (Blocks l-3) yielded lower than the three blocks on the east side (Blocks 4-6).

Table 5. Mean squares and level of significance for the various effects in the analysis of variance for yield.

Source of Variation	df	Mean Square	
		Corn	
		1988	**1989**
Tillage Trt (T)	5,6	16113.25**	17023.79**
Block (B)	5	1519.83**	882.40**
Error (a)	25,30	316.45	119.75
Hybrid (H)	1	81.53	248.34
HxB	5	178.55*	200.23
HxT	5	124.81	154.30
Error (b)	25,30	64.69	99.17
		Soybeans	
Tillage Trt (T)	5.6	141.50**	586.66**
Block (B)	5	10.64*	290.58**
Error (a)	25,30	6.67	26.97
Variety (V)	1	31.82**	13.67
VxB	5	2.42	1.04
VxT	5	3.33	2.44
Error (b)	25,30	2.90	3.31

*** Statistically significant at the 0.01 level.

* Statistically significant at the 0.05 level.

Table 6. Mean yields for BS#2 deep tillage treatments and Cisne soil.

Soil treatment	1988	1989	Mean
		Yield, bu/a	
		Corn	
CHS[1]	37.5 e[2]	60.9d	39.2 d
TG2	42.7 de	52.5 d	47.6 d
RM1	55.6 cd	86.0 c	70.8 c
TLG	67.7 c	83.3 c	75.5 c
DMl	87.3 b	126.7 b	107.0 b
DM2		142.6 a	
Cisne	135.7 a	141.6 a	138.6 a
Target Yield-HCL3	95.6	95.6	95.6
Adjusted Target	68.6		
		Soybeans	
CHS	13.6 b	13.2 c	13.4 b
TG2	12.5 b	14.2 c	13.3 b
RM1	13.7 b	13.9 c	13.8 b
TLG	14.2 b	14.2 c	14.2 b
DMl	21.1 a	24.3 b	22.7 a
DM2		30.2 a	
Cisne	18.7 a	23.7 b	21.2 a
Target Yield-HCL3	31.1	31.1	31.1
Adjusted Target	23.2		

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

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

3/ Base target yields of high capability lands (HCL) for BS#2 permit area calculated by IL Dep of Agric . This base target yield is adjusted annually by a county success factor to adjust for weather variation.

Grain yields from the 1988 and 1989 growing seasons are presented in Table 6. The DMI deep plow treatments produced corn yields significantly higher than any of the other mine soil tillage treatments in both years studied. The TLG and RM1 were comparable in both years while the Tiger II (TG2) and conventional chisel treatments yielded the lowest. Corn yields for the first year on the DMI Super Tiger deep plow (DM2) treatment were significantly higher than any of the other tillage treatments in 1989 and were comparable to those obtained on the nearby tract of undisturbed Cisne soil. It will interesting to see if this yield advantage of the DM2 over the DMl treatment continues in future years. Penetrometer data indicates that soil strength levels for these two treatments are similar. This first year advantage may be due to increased water storage over winter by the DM2 treatment. Early season neutron probe data show that the DM2 had significantly higher volumetric water content in the 3-5 ft depths than the

Table 7. Correlations between yield and penetrometer resistance for treatment means.

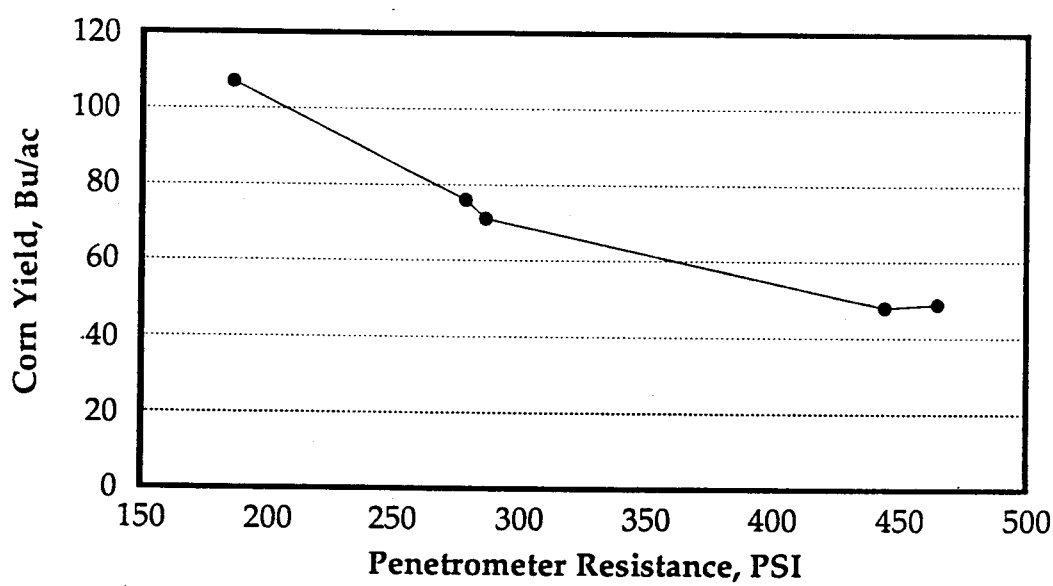
Segment Depth	1988	1989
	Corn	
9-18"	-0.7959+	-0.8018+
18-27"	-0.9181*	-0.7946+
27-36"	-0.9532**	-0.9723**
36-44	-0.8303+	-0.9018*
Ave 9-27"	-0.8625+	-0.8040+
Ave 9-36"	-0.9182*	-0.8975*
Ave 9-44"	-0.9541**	-0.9621**
	Soybeans	
9-18"	-0.4524	-0.6081
18-27"	-0.5600	-0.5654
27-36"	-0.9734**	-0.9217**
36-44"	-0.9423*	-0.9725**
Ave 9-27"	-0.5050	-0.5904
Ave 9-36"	-0.6129	-0.7203+
Ave 9-44"	-0.6926	-0.8340*

**, Statistically significant at the 0.01 level
*, Statistically significant at the 0.05 level
+, Statistically significant at the 0.10 level.

Soybean yields for the DMI deep plow treatments were significantly higher than the other mine soil tillage treatments in both 1988 and 1989 and were comparable to those obtained on the Cisne soil. No yield difference occurred on the other tillage treatments in either year. Soybean yields were poor in both 1988 and 1989 at this location due to adverse weather effects. Rainfall from August to mid-September was substantially below normal in both years.

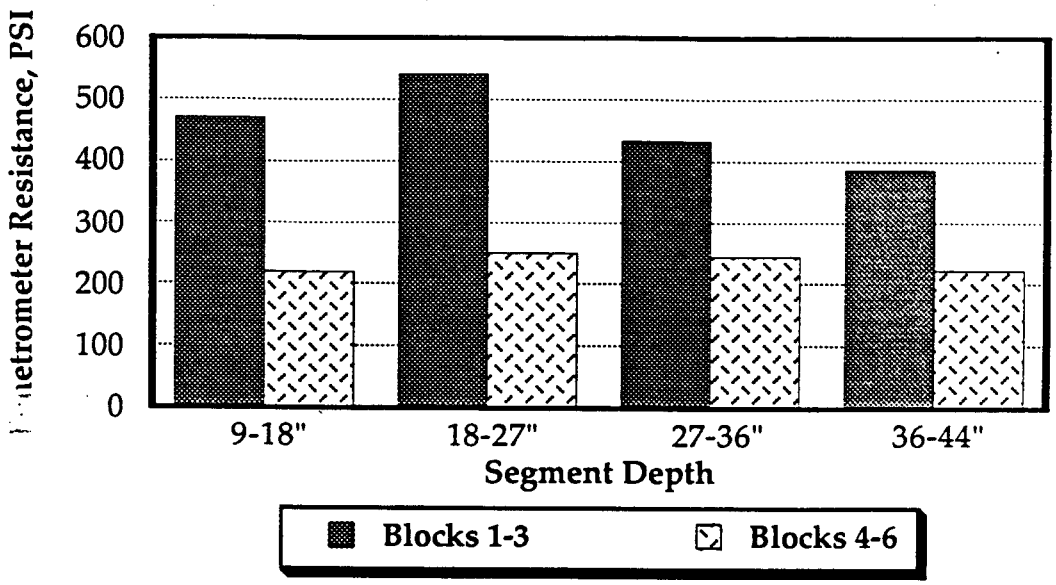
Soil strength effects on crop yield: Table 7 presents correlation data of soil strength vs yield for the 1988 and 1989 data. Consistent results for both years were observed. In general, soil strength was significantly correlated with corn yield in all segment depths. When soil strength was averaged over the 9-44" depth corn yields were highly correlated. Figure 2 graphically presents the relationship to 1988-89 mean corn yields to the two year mean soil strength values averaged over the 9-44" depth. Soybeans yields were highly correlated with soil strength levels at the 27-44" depth. 1989 soybean yields were also significantly correlated with soil strength when averaged over the 9-44" depth.

Figure 2. 9-44" mean soil strength effects vs. 1988-89 mean corn yields.



Significant differences in yields of the experimental blocks have occurred. Blocks 1-3 on the west side have yielded lower than blocks 4-5 on the east side. Pre-tillage evaluation with the cone penetrometer, has shown significant differences in soil strength between the east and west sides of the plots. These differences are graphically summarized in Figure 3 showing mean soil strength values for the east and west sides prior to tillage.

Figure 3. Pre-tillage Soil Strength.



1989 corn yield results comparing the east and west sides show various responses among tillage treatments (Table 8). Yields of the east and west blocks were not significantly different on the DM1, DM2 and chisel treatments. The DMI deep plow treatments were successful in ameliorating any soil strength differences between the east and west blocks. The chisel plow treatment is so shallow that initial soil strength values for both sides produced low yields. Yields were significantly higher on the east blocks for the TG2, RM1, and TLG treatments. This data suggests that the initial level of compaction , i.e. soil strength, will affect the depth of tillage needed to achieve productivity. The RM1 and TLG yield values of the east side (Blocks 4-6) are close to achieving the base target yield values of the permit area, while the west side yields are several bushels lower.

Table 8. 1989 corn yields comparing blocks 1-3 (west side) to blocks 4-6 (east side).

	Tillage Treatment					
Blocks	CHS	DM2	DM1	RM1	TG2	TLG
	Yield, bu/a					
West (1-3)	63.3 a	142.3 a	125.1 a	79.4 b	44.1 b	73.1 b
East (4-6)	58.4 a	142.9 a	128.4 a	92.7 a	61.0 a	93.5 a

Soil moisture data: Neutron access tubes were installed at the Burning Star #2 site for the 1988 and 1989 growing seasons. One access tube was installed in each corn plot of the six replications of each tillage treatment. Six tubes were also installed in the nearby undisturbed Cisne soil. Density data was collected in late August of each year by using a Gamma probe in the access tubes. This gamma density data is summarized in Table 9. These gamma density values appear high because the Gamma probe is sensitive to both soil and volumetric water content. In summary, gamma density of the TLG and RM1 are numerically lower than the Chisel treatment in-the 2-3 ft depth. The DMI treatments and the Cisne soil have significantly lower gamma densities at the 3-5 ft depths.

Figure 9. 1988-89 Burning Star #2 Gamma Density.

TRT	Depth, ft 1	2	3	4	5
	g soil and water/cm^3				
			1988		
CHS	1.290 ab	1.979 a	2.051 ab	2.025 a	2.053 ab
TG2	1.270 ab	1.903 ab	2.093 a	2.054 a	2.016 ab
RM1	1.257 ab	1.713 c	2.020 abc	2.097	2.061 ab
TLG	1.418 a	1.787 bc	1.900 bcd	2.107 a	2.092 a
DM1	1.140 b	1.753 bc	1.851 d	1.840 b	2.014 b
CIS	1.205 ab	1.641 c	1.872 cd	1.814 b	1.993 b
LSD(0.05)		0.218	0.180	0.168	0.119
			1989		
CHS	1.697 a	1.925 a	2.028 a	2.073 a	2.070 ab
TG2	1.659 ab	1.869 ab	2.012 a	2.079 a	2.079 ab
RM1	1.644 abc	1.726 c	1.986 ab	2.063 a	2.085 a
TLG	1.706 a	1.882 a	1.966 ab	2.064 a	2.078 ab
DM1	1.534 bcd	1.777 bc	1.832 c	1.878 b	2.056 b
DM2	1.508 cd	1.759 c	1.790 c	1.846 b	2.060 b
CIS	1.478 d	1.755 c	1.864 bc	1.847 b	1.990 c
LSD(0.05)	0.143	0.096	0.133	0.076	0.024

The net water extraction from June to August is summarized in Table 10. This net water extraction does not take into account any recharge that took place during this period. This data shows that corn extracted the most water from the Cisne and DMI deep plow treatments in the 3-5 ft depths in both 1988 and 1989. The chisel and Tiger II treatments extracted little water from these depths. The TLG and RM1 treatments released more water than the CHS and TG2 treatments at the 2-3 ft depths, with extraction tapering off below 3 feet.

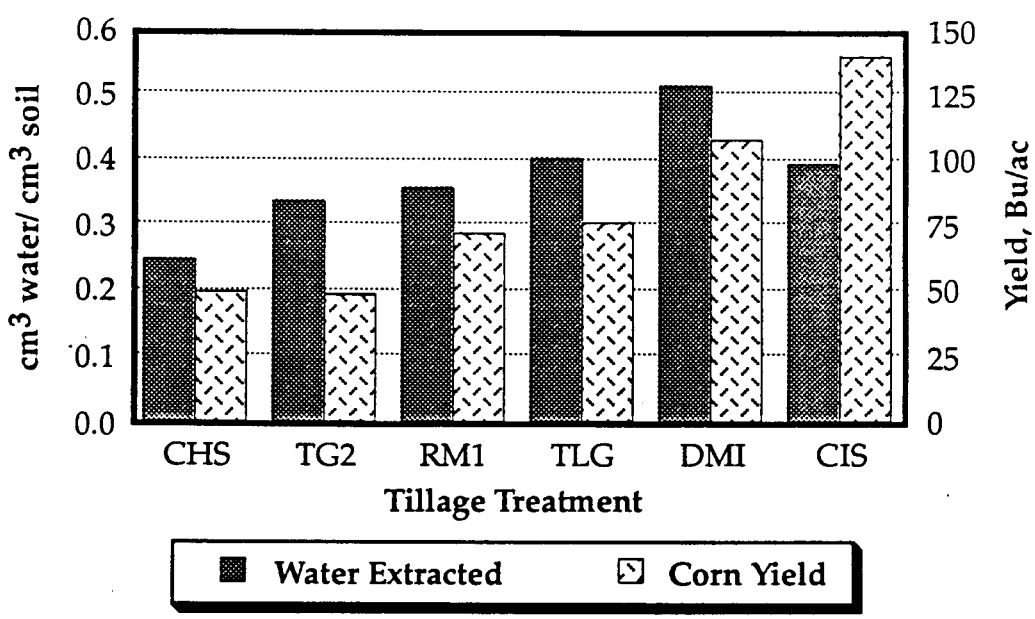
The water extraction trends of the tillage treatments tend to follow the same trends found in the yield and penetrometer data. The poorest extraction came from the shallow tillage and the deeper the tillage the greater the water extraction. Two

year mean water extraction values plotted with two year mean corn yields in Figure 4 show this relationship.

Table 10. 1988-89 Burning Star #2 Net Water Extraction June to August.

TRT	Depth, ft 1	2	3	4	5
	----------	----------	cm^3 water/cm^3 soil	----------	----------
			1988		
CHS	0.071 b	0.066 b	0.050 c	0.030 c	0.003 c
TG2	0.063 b	0.097 ab	0.098 ab	0.086 ab	0.068 a
RM1	0.085 ab	0.107 ab	0.062 bc	0.052 bc	0.037 abc
TLG	0.105 a	0.103 ab	0.088 abc	0.079 ab	0.046 ab
DM1	0.110 a	0.119 a	0.127 a	0.102 a	0.003 c
CIS	0.080 ab	0.135 a	0.097 ab	0.023 c	0.011 bc
LSD(0.05)	0.031	0.046	0.040	0.044	0.016
			1989		
CHS	0.135 b	0.077 b	0.042 c	0.011 cd	0.002 b
TG2	0.131 b	0.078 b	0.037 c	0.002 d	0.008 ab
RM1	0.168 a	0.106 ab	0.059 c	0.021 cd	0.010 ab
TLG	0.155 ab	0.114 ab	0.075 c	0.022 cd	0.009 ab
DM1	0.161 ab	0.138 a	0.126 b	0.076 ab	0.022 a
DM2	0.154 ab	0.150 a	0.180 a	0.104 a	0.009 ab
CIS	0.098 c	0.134 a	0.147 ab	0.048 bc	0.009 ab
LSD(0.05)	0.031	0.046	0.040	0.044	0.016

Figure 4. 1988-89 mean water extraction Jun-Aug vs. mean corn yield.



LONG TERM EFFECTS OF DEEP TILLAGE[1]

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Abstract

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

Introduction

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

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

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

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

There are many tillage options that have been proven effective to 12 to 15 inches depth for ameliorating wheel traffic effects of farm machinery on undisturbed soils. Standard agricultural tillage equipment cannot reach the depths of the compaction problem in reconstructed soils. A deep ripper, the Kaeble Gmeinder TLG-12, which has

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[1]Paper presented at Prime Farmland Reclamation Workshop, August 11, 1998, at Southern Illinois University, Carbondale, Illinois.

an effective depth of 32 inches, has been tested in prelimmary studies in southern Illinois (Hooks. et al. ,1987) and western Illinois (Dunker, et al., 1989). Results from both studies were very encouraging with significantly increased yields and reductions in soil strength to the depth of tillage. This experiment was designed to continue and expand the investigations of the effects of deep tillage.

Objective

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

Materials and Methods

The Site

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

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

Experimental Design and Layout

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

Pre-treatment Evaluation of Soil Strength

A deep-profile penetrometer (Hooks and Jansen, 1986) was used to measure soil strength to a depth of 44 inches prior to the application of tillage treatments (Table 1). Soil strength was highly variable, but the pattern did not compromise the experiment. Analysis of this pre-tillage penetrometer data revealed that while there was no soil strength difference between pre-treatment plot means, there were significant differences in soil strength between blocks. Soil strength levels of the west three blocks (l-3) are significantly higher (0.05 level) than soil strength levels of the three east blocks (46) for each depth segment of the soil profile.

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

Application of the Deep Tillage Treatments

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results and Discussion

Effects of Deep Tillage on Soil Strength

Soil strength measurements using the deep-profile penetrometer were taken prior to planting in 1988, 1989, 199 1, and 1993 to evaluate tillage effects. Analysis of these data are presented in Table 2. Soil strength measurements taken in April 1991 indicate that tillage effects remain consistent to initial post-tillage soil strengths 42 months after application of tillage treatments. In summary, using the chisel treatment (CHS) as the control treatment, the Tiger II (TG2) was successful in lowering soil strength down to Segment 2 (9 to 18 inches). The TLG and RM1 significantly lowered soil strength to Segment 3 (18 to 27 inches) and was numerically lower than the CHS or TG2 in Segment 4 (27 to 36 inches). Both the DMl and DM2 deep plows were successful in significantly lowering soil strength to the 44 inch depth. First year measurements of the DM3 treatment show it had similar effects to the RMl and TLG treatments.

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

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

Rowcrop Yields

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

Grain yields from 1988 through 1997 growing seasons indicate a consistent trend over time. The DMI deep plow treatments produced corn yields significantly higher than any of the other mine soil tillage treatments for the ten

years studied. The Dh43, TLG, and RMl corn yields were comparable, while the Tiger II (TG2) and conventional chisel (CHS) treatments yielded the lowest. Corn yields from the DMI Super Tiger deep plow (DM2) treatment were comparable to those obtained on the nearby tract of undisturbed Cisne soil in most years which indicates prime yield levels from reclaimed high capability soils. Significant differences have occured between treatments within and across years. Significant differences across treatments between years due to weather variations are also

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

Soil Strength (PSI) bv Deoth Segment

Treatment	Seg 2	Seg 3	Seg 4	Seg 5
	9-18"	18-27"	27-36"	36-44"
		1988		
SpareB1/	804.1 a2/	603.6 a	417.1 a	446.4 a
Spare C	768.8 a	584.4 a	415.8 a	432.8 ab
CHS	712.8 a	554.6 a	405.9 ab	434.5 ab
TG2	568.7 b	582.3 a	416.4 a	379.0 b
DM1	235.9 c	193.6 b	180.7 c	210.6 c
RM1	218.7 c	266.7 b	345.0 b	387.9 ab
TLG	193.4 c	219.1 b	338.9 b	390.2 ab
LSD (0.05)	99.5	123.9	67.1	61.5
		1989		
Spare B	521.9 a	515.8 a	419.7 a	381.6 a
CHS	457.4 ab	433.4 a	374.5 ab	350.5 a
TG2	400.4 b	457.7 a	394.5 ab	350.6 a
RM1	200.l c	195.3 b	320.9 b	346.3 a
TLG	192.0 c	181.3 b	323.5 b	388.5 a
DMl	188.9 c	160.2 b	148.0 c	176.4 b
DM2	151.8 c	179.5 b	173.2 c	138.3 b
LSD (0.05)	71.0	135.6	87.3	62.9
		1991		
CHS	402.5 a	459.5 a	423.6 a	369.4 a
TG2	343.6 b	448.9 a	411.0 ab	349.9 a
DM3	218.8 c	231.4 b	290.6 c	370.3 a
RM1	210.4 c	240.2 b	320.0 bc	355.2 a
TLG	203.7 c	189.5 b	382.8 abc	427.0 a
DMl	188.9 c	211.0 b	179.4 a	159.6 b
DM2	181.1 c	175.1 b	156.5 d	140.2 b
LSD (0.05)	56.3	109.0	96.3	91.6
		1993		
CHS	406.0 a	453.9 a	411.8 a	349.5 a
TG2	381.4 a	430.7 a	349.5 ab	311.8 a
DM3	216.1 b	184.2 b	262.5 b	329.2 a
RMl	194.3 b	255.2 b	375.6 ab	342.2 a
TLG	192.9 b	214.6 b	361.1 ab	311.8 a
DMl	152.3 b	146.5 b	130.5 c	146.5 b
DM2	114.6 b	114.5 b	129.1 c	146.4 b
LSD (0.05)	103.0	161.0	113.1	69.6

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

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

apparent. Soybean yields for the DMI deep plow treatments were significantly higher than the other mine soil tillage treatments in most years. Few soybean yield differences occurred on the other tillage treatments.

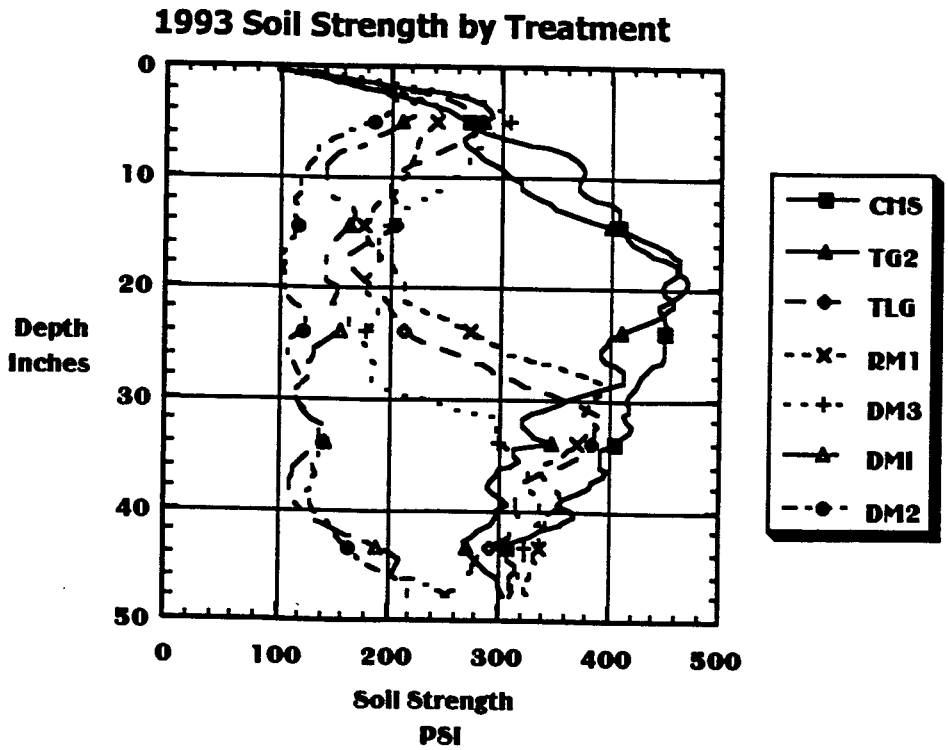

Figure 1. Soil Strength Profiles

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

Subsoil Differences and Productivity

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

Soil texture analysis reveals dramatic differences between the two sides (Table 4). The west side has higher sand, lower silt, and a high percentage of coarse fragments throughout the profile. This loamy subsoil is quite different than the silty material of the east side. The subsoil material of the west side can be identified as calcareous till while the subsoil materials of the east side are from Peorian loess and Roxana silt. The high soil strength of the

Table 3. 1988 - 1997 Yields

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

1/ Soil treatments are:CHS, conventional chisel plow, 9" tillage depth; TG2, DMI Tiger II, 14" depth; RM1, Harry Jones RM1 soil processor, 32" depth; TLG, Kaeble-Gmeinder TLG ripper, 32" depth; DM3, DMI prototype ripper, 36" depth; DM1, DMI deep plow (first design prototype), 48" depth; DM2, DMI Super Tiger, 48" depth.

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

3/ Soybeans were not harvested in 1990, 1991 and 1996 and not planted in 1994 and 1995.

4/ Cisne not included in 1995 or later comparisons.

Table 4. Soil Texture by Depth

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

west side is more a result of transported compacted till with minimal disturbance than equipment traffic, which is equal on both sides. The soil materials originated from different premine soils or from different depths of excavation.

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

Table 5. Tillage Treatment and Soil Effects on Productivity

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

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

Since the two sides are different soils regardless of tillage, productivity modeling has combined tillage and soils providing 14 treatments. Figure 2 is a logarithmic correlation of mean 12 to 48 inch soil strength and 1988-1997

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

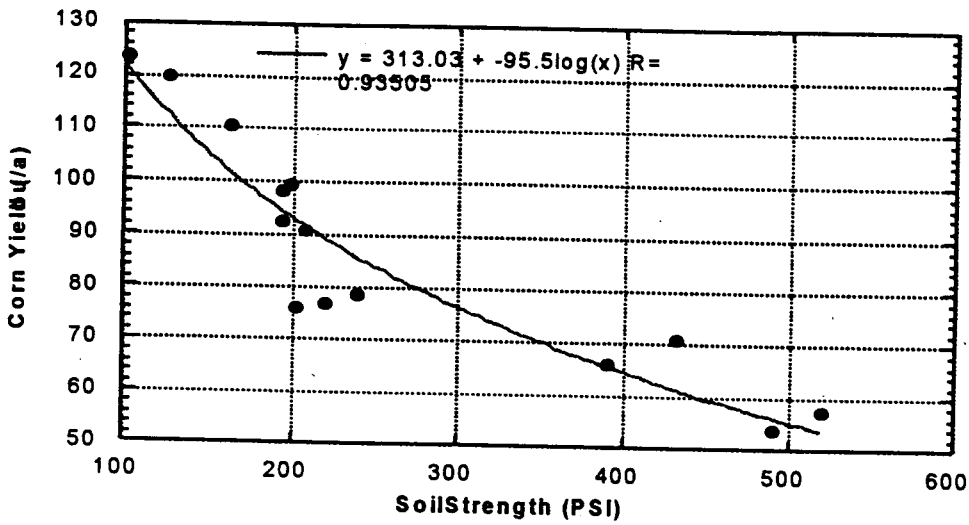

Figure 2. Soil Strength and Yield Correlation

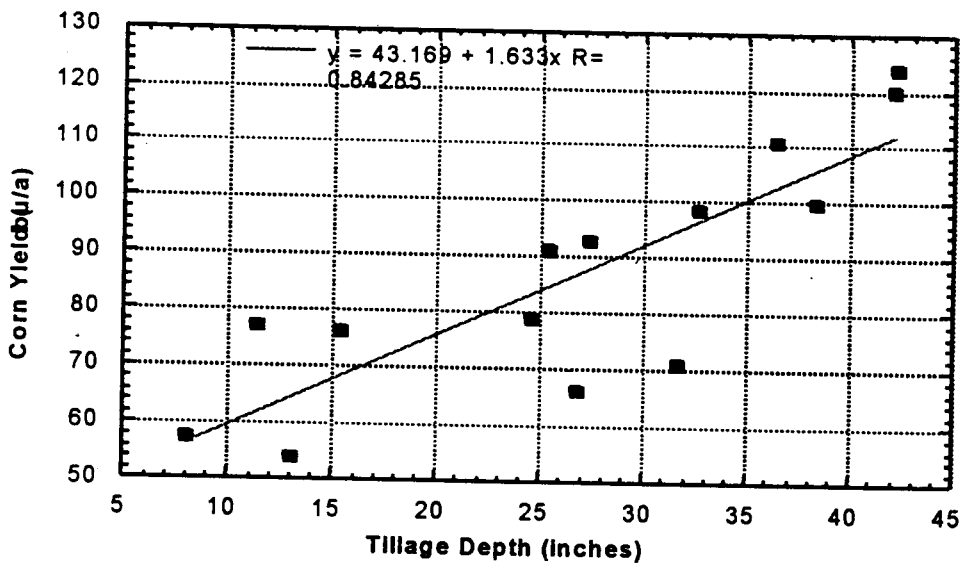

Figure 3. Tillage Depth and Yield Correlation

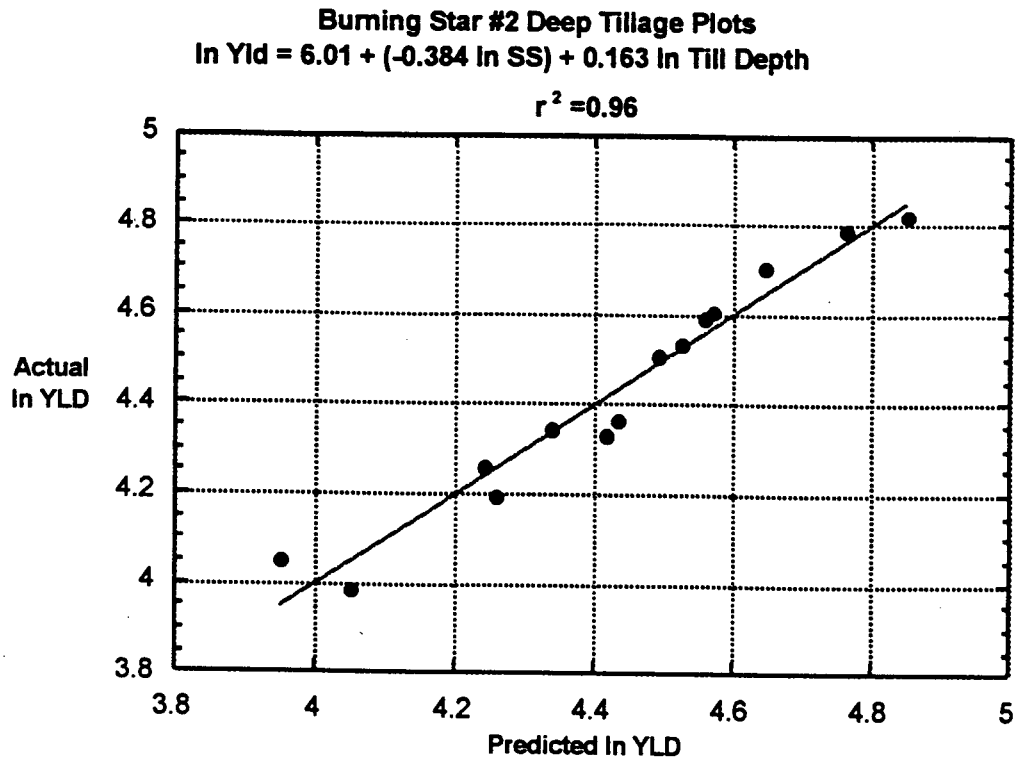

Figure 4. Soil Strength and Tillage Depth Correlation with Yield

Summary

Data from this study support the following general conclusions:

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

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

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

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

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

Acknowledgments

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

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Deep Tillage Effects on Mine Soils and Row Crop Yields

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Abstract. Effects of deep tillage to row crops grown on constructed mine soils were evaluated during the 1985 and 1986 growing seasons in southern Illinois. The test plots, which totaled approximately 60 acres were located in three adjacent areas with a ripped and non-ripped block located within each area. The mine soil consisted of 100 cm of scraper placed rooting medium and 20 cm of scraper placed topsoil. A Kaeble-Gmeinder TLG-12 deep ripper, which utilizes a moving shank and foot to effect tillage to a depth of approximately 80 cm, was used in July 1984 to augment 50 acres. Adjacent areas which were not deep-ripped were incorporated into the test area to evaluate the effectiveness of the tillage.

A constant rate recording cone penetrometer was used to measure soil strength to a depth of 112 cm between the ripped and non-ripped areas. Results show a wide range of soil strength values prior to augmentation. A significant reduction in soil strength occurred where values were high prior to tillage.

Corn and wheat were planted in 1985. Corn, soybeans and grain sorghum were planted in 1986. Yield results showed a significant positive response to the deep tillage treatment for all crops in both 1985 and 1986. Observations from this study indicate that careful management to avoid compaction after tillage is necessary.

Introduction

Prime farmland reclamation research has continued at the University of Illinois since 1977. Row crop yields have been monitored over time on research plots constructed by various soil placement methods. Alfisols are dominate as the pre-mine soil in southwestern Illinois location of this study. Yields comparable to those on pre-mine soils are being attained where soil placement methods minimize compaction, especially in the lower portion of the rooting media. Drought susceptibility due to compaction created during soil placement has been the major factor in crop failures and unacceptable yields[1].

Most mine soils affected by P.L. 95-87, due to practical or economic reasons, have been constructed in a manner which may not provide the necessary physical soil conditions for productivity[2]. Deep tillage to augment the physical condition of these soils has been incorporated into an existing set of University of Illinois research plots on a small scale for about three years. Deep tillage on a 40' wide lane across the plots provided a significant positive yield response for corn. A cooperative agreement with Arch of Illinois, Inc., Captain Mine allowed the assessment of the effects of deep tillage on a larger scale on areas treated for the mine by a commercial operator. A randomized design was not possible since the deep tillage had already been completed. Comparisons were made utilizing a students T-test.

Methods

Equipment

The Kaelble-Gmeinder TLG-12 used for deep tillage, was developed in West Germany. It utilizes a moving shank and foot to cut and lift to a depth of 30". Three shanks are spaced at 32" and operated by auxiliary hydraulics. The TLG-12 is currently mounted on an 850 John Deere Tractor and has a productivity of 1-1.5 acres/hour depending on soil conditions.

Plot Establishment

The plots were established on scraper placed mine soil of which 50 acres had been augmented with the TLG-12. The acres were divided into three areas (#1, #2, and #3) separated by a haul road and an incline pit. Adjacent non-tilled scraper placed soil was incorporated into the test plot in each of the three areas. This allowed side by side comparisons of "scraper" and "scraper/TLG" treatments. Each area was divided into 5 crop blocks to allow for rotation. Initial plans were to test deep tillage effects on several crops as well as develop management techniques to handle problems such as support of equipment, subsurface water movement, and susceptibility to compaction.

Management of Plots

Deep tillage was effected in July of 1984. The following spring brought above normal rainfall and wet soil conditions, limiting the corn planting to well drained areas. Even in these areas, soil strength was marginal for support of equipment. Corn was no-till planted and the existing grass-legume stand was sprayed in a one pass operation. The deep tilled soils were particularly wet due to water being trapped in the tilled material by the impermeable non-tilled material underneath. Land leveling and tiling were used to correct surface and subsurface drainage problems. These operations were conducted in mid-summer when soil moisture conditions allowed surface traffic. Wheat was planted in October of 1985.

Soil moisture conditions were more favorable in the spring of 1986. Fertilizer was custom spread with low ground pressure equipment. The plots were chisel plowed to relieve some of the effects of the traffic which occurred in the previous season. A conventional seedbed was prepared and herbicides were custom applied. Planting operations began on 1 May, 1986. All corn, soybean, and grain sorghum plots were planted without limitations due to excessive soil moisture.

Very little rainfall was received during June, 1986. Moisture stress symptoms were visible on the non-tilled portion of the corn plots early in the month. These signs did not appear on the scraper/TLG areas until the end of the month. During this period, the moisture stress symptoms on the scraper plots were variable. Non-tilled scraper plots in Areas #1 and #3 were exhibiting extreme moisture stress while Area #2 showed little or none. A height difference was the only observable response to the TLG for soybeans, grain sorghum, and wheat.

Wheat, soybean, and grain sorghum plots were harvested with a plot combine. Corn was sampled by hand harvest. The custom harvest of the remaining crops was limited to equipment with low ground pressure tires due to wet soil conditions.

The plot areas and surrounding deep-tilled land was custom planted to corn in 1987 to prove productivity for bond release.

Results and Discussion

Penetrometer Tests

A constant rate recording penetrometer was used to evaluate soil strength of deep tilled and non-tilled soils in the three areas of the test plots[3]. Sampling was done in early spring during a period of adequate subsoil moisture. Figure 1 represents the respective composite profiles for these areas. Areas #2 and #3 indicate a significant difference in the soil strength prior to deep tillage. Deep tillage had no significant effect, except for the 10-18 inch depth, in Area #2 where soil strength prior to tillage was relatively low. The relatively low soil strength observed in Area #2 is consistent with the previously mentioned lack of stress symptoms in June on corn in this area. The high soil strength in Area #3 was significantly reduced to the 35 inch depth by the deep tillage. Area #1 indicates a zone of high soil strength for both TLG and no-TLG in the 4-16 inch depth. This zone could have been created during the extensive land leveling work required in the area after deep tillage was effected.

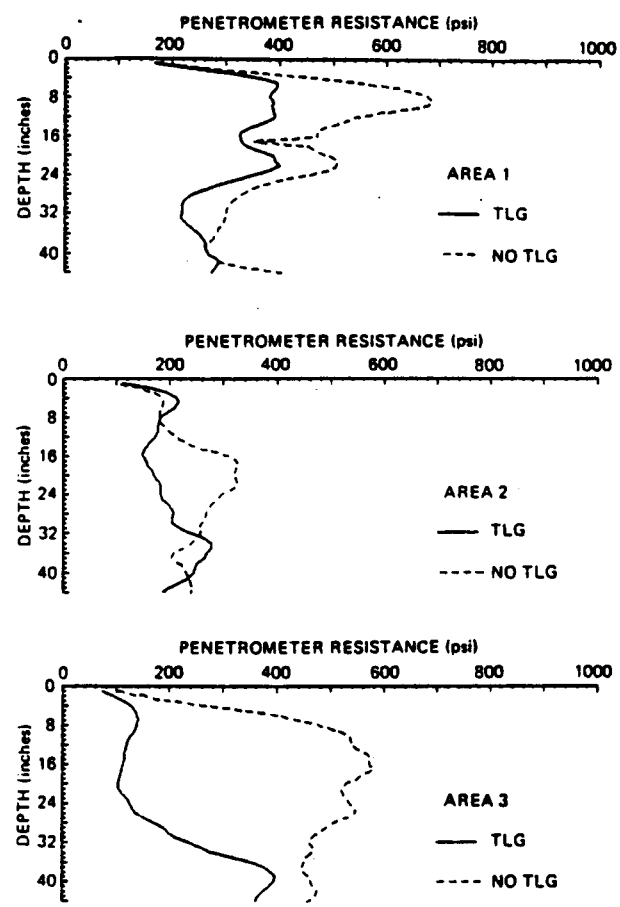

Figure 1. Penetrometer profiles.

The wide range of soil strength indicated prior to tillage in Scraper Areas #2 and #3 had not been detected on other, though smaller, research plots. Rooting media was placed during July and August of 1981 in Area #2 and October-December of 1981 in Area 3. Soil moisture may have been a factor in the resultant variation in soil strength although the summer of 1981 was above average in rainfall. The deep tillage operation did significantly reduce the soil strength where high values were measured in the non-tilled area of the plots.

Yield Results

Crop yields were compared using a Student's t-test on the scraper/TLG, scraper, and undisturbed treatments. The undisturbed site was a Stoy (fine-silty, mixed, mesic Aquic Hapludalf) which was planted on the same date and with similar management as the test plots.

Corn yields for 1985 (Table 1) represent a portion of Areas #2 and #3 which was suitable for planting with the equipment available that year. The yield from the scraper/TLG treatment was significantly higher than the scraper or undisturbed site. Yields from the undisturbed and scraper sites were similar. Yields from the scraper treatment of Area #3 were lowest. This is where the highest soil strength was detected.

Table 1. 1985 Corn Yields from Captain TLG Plots.

Treatment	Area #2	Area #3	Mean
	---------- yield, bu/a	---------	
Scraper/TLG	136	108	119 a*
Scraper	117	56	91 b
Undisturbed	94	94	94 b

* Yields within a column with a similar letter are not significantly different at the 0.05 level.

Corn, soybeans, and grain sorghum were planted in all areas in 1986 (Table 2). The scraper/TLG treatment yielded significantly higher than the scraper treatment on all crops when area yields were combined. The scraper/TLG treatment yields were equal to or greater than yields from the undisturbed site for all crops in all areas. The high soil strength in the scraper treatment of Area #3 is again reflected in the low corn yield. This area yielded significantly lower than the scraper/TLG or undisturbed site for all three crops. The scraper treatment in Areas #1 and #2 had a more favorable soil physical condition than Area #3. The scraper treatment in those areas performed equal to the undisturbed site for corn and grain sorghum.

The corn yield response to TLG seen in Area #3 is the most encouraging. A poor physical soil condition was augmented to produce an acceptable yield. The corn yield response to TLG in Area #2 is dramatic but may only be in part due to the physical augmentation of the soil.

Table 2. 1986 Crop Yields from Captain TLG Plots.

Treatment	Area #1	Area #2	Area #3	Mean
	-------- Corn yield, bu/a			---------
Scraper/TLG	100 a*	128 a	68 a	99 a
Scraper	73 b	62 b	16 b	50 b
Undisturbed	68 b	68 b	68 a	68 b
		Soybean yield, bu/a		
Scraper/TLG	29 a	34 a	31 a	31 a
Scraper	18 b	19 b	22 b	20 b
Undisturbed	30 a	30 a	30 a	30 a
		Sorghum yield, bu/a		
Scraper/TLG	83 a	95 a	69 a	82 a
Scraper	77 a	75 b	41 b	64 b
Undisturbed	76 a	76 b	76 a	76 ab
		Wheat yield, bu/a		
Scraper/TLG	56 a			
Scraper	49 b			
Undisturbed	49 b			

* Yields for a crop within a column followed by a similar letter are not significantly different at the 0.05 level.

Recommendations and Conclusion

The operating of the TLG test plots at the Captain Mine, though limited in statistical control and long term tests, has provided considerable insight into deep tillage augmentation practices. The plots were initiated to develop the necessary management techniques for row crop production on deep tilled reconstructed soils. The key to the management of deep tilled soils is management of compaction and water movement. A plan should be developed for each reclaimed field considering its inherent characteristics. It should begin well before any deep tillage is implemented. Planting and managing a legume stand for 2 or 3 years after reclamation may allow some initial settling to occur. It will also maintain a drier subsoil mid-summer to better effect deep tillage. Surface drainage may then be repaired and potassium, phosphate, and limestone applied as required for the planned cropping system in each area. The existing stand of legumes may harbor pathogens that would affect soybeans the following year. Corn or other non-legume crops would be recommended for the first year following an existing grass/legume stand.

Deep tillage can be effectively applied to a dry subsoil. The shattering effect will produce fluff of 6-8 inches. Water movement should be considered when applying deep tillage. Percolation will increase and subsurface water movement can occur. Subsurface water will be perched or even emerge to the surface unless the deep tillage is carried out through the toe of the slope.

Tiling has been used with limited success to relieve this where necessary. After deep tillage and prior to a significant rainfall, the soil should be disced to provide a level seedbed for planting the following year. The seeding of an easily controlled cover crop would be recommended to help dry the soil before spring planting.

Planting operations should consider the susceptibility of deep tilled soils to agricultural compaction. Plans may vary or change between fields due to existing conditions. Low ground pressure equipment, front wheel assist, and minimum pass planting is recommended. Both no-till and under-row till has been used at the Captain Mine, depending on field conditions. Agricultural practices of minimizing compaction and soil moisture conservation should be applied. These soils tend to be wetter than natural soils in the spring and fall. The support of equipment should be considered in both seasons. Once yield samples are obtained, it may be advisable to harvest at a higher grain moisture content while favorable soil conditions exist.

Smout[2] proposed some valid questions that should be addressed prior to a general acceptance of any compaction reduction method. Briefly they are: How deep should the soil profile be tilled? How long will it last? What management techniques will be necessary to enhance the effects?

The University of Illinois is establishing a statistically designed deep tillage test plot at the Consolidation Coal Co., Burning Star #2 Mine in southern Illinois. Data from these plots will be used to address the first two questions. What is economically and physically possible considering the depth to graded cast overburden is a question that should be added to the list. The question of management has been addressed but will continue to be a learning experience as new equipment evolves.

The development of a system to assess the physical conditions of a reclaimed soil will be necessary to determine the need and economic effectiveness of deep tillage.

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

Robert E. Dunker, Ivan J. Jansen and Scott L. Vance[2]

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

Introduction

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

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

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

Study Area and Methods

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

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

In August, 1984, under dry soil moisture conditions the Kaeble-Gmeinder TLG-12 was used as a deep tillage treatment. The TLG-12, which was developed in West Germany, utilizes a shank and moving foot to cut and lift to a depth of 76 cm. Three shanks are spaced at 81 cm and operated by auxillary hydraulics. The TLG-12 was mounted on a 750 John Deere tractor and has a productivity of 1 to 1.2 acres/ hour depending on soil conditions.

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

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

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

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

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

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

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

Results and Dlscussion

Yield and Agronomic Respone:

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

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

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

Soil Trt	1985	1986	Mean
	kg/ha		
TS TLG1	10346	11733	10968
TS CON	7370	11394	9160
SP TLG	8280	12368	10101
SP CON	8010	11175	9417
SABLE	11068	11545	11238
LSD(O.05)	2423	1098	1406

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

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

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

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

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

Two year average days after planting to 50 % pollen shed were significantly different for all soil treatments. Both topsoil replacement and tillage affected anthesis date. Topsoil replaced plots pollinated earlier than those plots without topsoil. Deep tillage also significantly reduced the number of days to pollen shed. These differences are believed to be due to reduced plant stress factors during the vegetative growth period. Seed emergence on the wheel spoil treatment was also generally 1 d later than on the topsoil or Sable. Early season vegetative growth was visibly greater on the topsoil and Sable. Within mine soils, those plots with the TLG-12 treatment also exhibited more vigorous vegetative growth.

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

Soil Trt	1985	1986	Mean
	----- % barren plants ------		
TS TLG	18.5	-1.9	9.4
TS CON	23.8	3.1	14.6
SP TLG	4.1	-11.8	-2.9
SP CON	0.2	4.2	2.0
SABLE	10.5	1.1	6.3
LSD(O.05)	11.7	15.4	9.0
	------ pollination, days ------		
TS TLG	71.6	74.7	73.1
TS CON	72.8	78.0	75.4
SP TLG	72.8	80.5	76.6
SP CON	74.4	83.2	78.8
SABLE	70.8	75.0	72.0
LSD(O.05)	1.1	1.6	0.9

Soil Strength

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

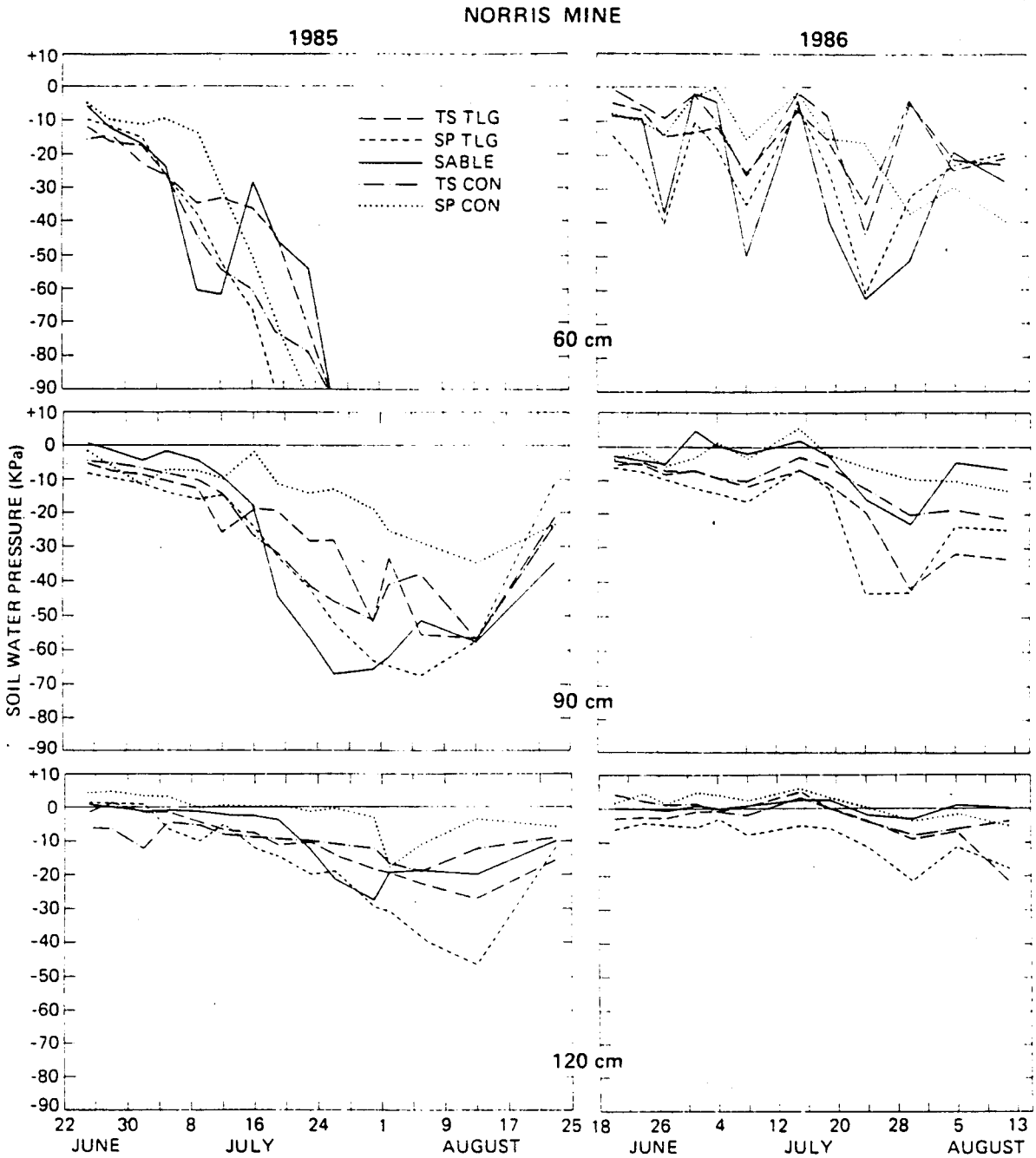

Figure 1. Soil moisture tension curves for 1985 and 1986 growing seasons at Norris Mine.

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

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

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

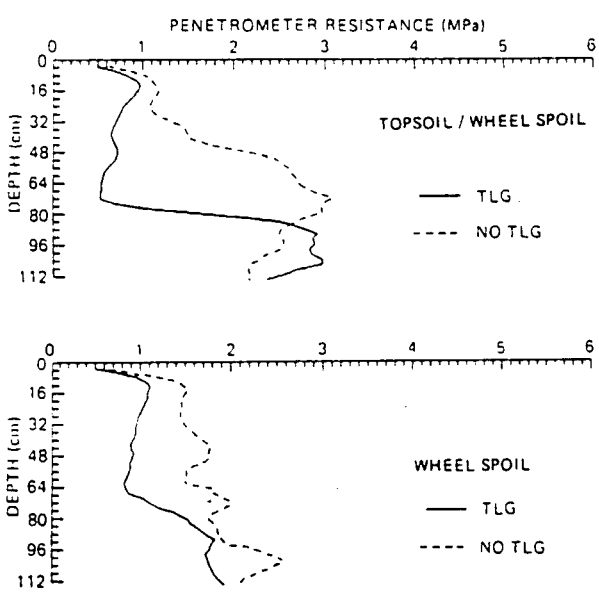

Figure 2. Penetrometer resistance curves for mined land treatments at Norris Mine, April, 1986.

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

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

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

Conclusions

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

Acknowledgment

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Prime Farmland Reclamation Standards

TITLE 62: MINING
CHAPTER I: DEPARTMENT OF MINES AND MINERALS

PART 1823
SPECIAL PROGRAM PERFORMANCE STANDARDS
OPERATIONS ON PRIME FARMLAND

Section

1823.1 Scope
1823.2 Objective
1823.11 Prime Farmland: Special Requirements
1823.12 Prime Farmland: Soil Removal
1823.13 Prime Farmland: Soil Stockpiling
1823.14 Prime Farmland: Soil Replacement
1823.15 Prime Farmland: Revegetetfon

AUTHORITY: Implementing and authorized by the Surface Coal Mining Land Conservation and Reclamation Act (Ill. Rev. Stat. 1985. ch. 96 l/2, pars. 7901.01 et seq.).

SOURCE: Adopted at 4 Ill. Reg. 37, p. 1. effective June 1, 1982; emergency amendment at 6 Ill. Reg. 8502. effective July 1, 1982. for a maximum of 150 days: amended at 6 Ill. Reg. 9987, effective September 3, 1982; codified at 8 Ill. Reg. 9361; amended at 10 Ill. Reg. 9631. effective July 1, 1986.

Section 1823.1 Scope

This Part sets forth special environmental protection performance, reclamation, and design standards for surface coal mining and reclamation operations, except this Part does not apply to any underground mining operations or activities, nor, except as expressly indicated or required by the Department in a permit, to the surface facilities and activities of surface mining that do not involve drilling, blasting, or mining.

Section 1823.2 Objective

The objective of this Part isto set forth those soil removal, stockpiling, and replacement operational requirements and revegetation and other. reclamation standards for prime farmland to ensure both that the land will have agricultural productive capacity which is equal after mining to premining levels and the land is not lost as an important national resource.

Section 1823.11 Prime Farmland: Special Requirements

Surface coal mining and reclamation operations conducted on prime farmland shall meet the following requirements:

a) A permit shall be obtained for those operations under 62 Ill. Adm. Code 1785.17; and

b) Soil materials to be used in the reconstruction of the prime farmland soil shall be removed before drilling, blasting, or mining, in accordance with Section 1823.12 and in a manner that prevents mixing or contaminating these materials with undesirable material. Where removal of soil materials results in erosion that may cause air and water pollution, the Department shall specify methods to control erosion of exposed overburden.

Section 1823.12 Prime Farmland: Soil Removal

a) Surface coal mining and reclamation operations on prime farmland shall be conducted to:

1) Separately remove the entire A horizon or other suitable soil materials which will create a final soil having an equal or greater productive capacity than that which existed prior to mining:

2) Separately remove, or assure proper placement during mining, the B horizon of the soil, a combination of B horizon and underlying C horizon, or other suitable soil material that will create a reconstructed soil of equal or greater productive capacity than which existed before mining: and

3) Separately remove, the underlying C horizons, other strata, or a combination of horizons or other strata, to be used instead of the B horizon. When replaced, these combinations shall be equal to or more favorable for plant growth than the B horizon.

b) The minimum depth of soil and soil material to be removed for use in reconstruction of prime farmland soils shall be sufficient to meet the soil replacement requirements of Section 1823.14(a).

Section 1823.13 Prime Farmland: Soil Stockpiling

If not utilized immediately, the A horizon or other suitable soil materials specified in Section 1823.12(a)(l) and the horizon or other suitable soil materials specified in Section 1823.12(a)(2) and (a)(3) shall be stored separately from each other and from spoil. These stockpiles shall be placed within the permit area where they are not disturbed or exposed to excessive water or wind erosion before the stockpiled horizons can be redistributed. Stockpiles in place for more than thirty (30) days shall meet the requirements of 62 Ill. Adm. Code 1816.22 or 62 Ill. Adm. Code 1817.23.

Section 1823.14 Prime Farmland: Soil Replacement

Surface coal mining and reclamation oporationa on prime farmland shall be conducted according to tha follwingr

a)

1) The minimum depth of soil and soil material to be reconstructed for prime farmland shall be forty-eight (48) inches except where a natural rock formation occurs at shallower depths. The Department shall specify a depth greater than forty-eight (48) inches wherever necessary to restore productive capacity due to uniquely favorable soil horizons at greater depths; and

2) Section 1823.14(a)(1) and (d) shall not apply to prime farmland and fragipan soils. Prime farmland fragipan soil shall be reconstructed in accordance with 62 Ill. Adm. Code 1825.14(a)(1), (a)(2), (a)(3), and (a)(5), For the purposes of this provision, prime farmland fragipan roils are specific soils classified as prime farmland that are underlain with a diagnostic subsurface horizon designated am a fragipan by the Soil Conservation Service of the U.S. Department of agriculture according to the criteria set in Soil Taxonomy, U.S.D.A. Handbook AH 436, including the following soils found in Illinois: Ava, Grantsburg, and Hosmer series as defined by the Soil Interpretation Sheets of the Soil Conservation Service.

b) Replace soil material only on land which has been first returned to final grade and scarified according to 62 Ill Adm. Code 1816.101 through 1816.105 or 62 Ill. Adm. Code 1817.101 through 1817.105, unless site-specific evidence is provided and approved by the Department showing that rcarffication will not enhance the capability of the recommended soil to achieve equivalent or higher levels of yield;

c) Replace the soil horizons or other suitable soil material in a manner that avoids excessive compaction;

d) Replace the B horizon or other suitable material specified in Section 1823.12(a)(2) and (a)(3) to the thicknerr needed to meet the requirements of paragraph (a) of this Section;

e) Replace the A horizon or other suitable soil materials specified in Section 1823.12(a)(l) as the final surface soil layer. This surface soil layer shall equal or exceed the thicknera of the original soil, as determined in 62 Ill. Adm. Code 1785.17(b)(l)(B) and be replaced in a manner that protects the surface layer from wind and water erosion before it is seeded or

planted: and

f) Apply nutrients and soil amendments as needed to quickly establish vegetative growth.

(Source: Amended at 6 Ill. Reg. 9987. effective September 3. 1982)

Section 1823.15 Prime Farmland: Revegetation

Each person who conducts surface coal mining and reclamation operations on prime farmland regardless of whether such land has been drilled, blasted, or mined, shall meet the following revegetation requirements during reclamation:

a) Following, soil rcplacement, that person shall establish a vegetative cover capable of stabilizing the soi1 surface with respect to erosion. All vegetation shall be in compliance with the plan approved by the Department under 62 Ill. Adm. Code 1785.17 and carried out in a manner that encourages prompt vegetative cover and recovery of productive capacity. The timing and mulching provisions of 62 Ill. Adm. Code 1816.113 and 1816.114 or 62 Ill. Adm. Code 1817.113 and 1817.114 shall be met.

b) Measurement of success of prime farmland revegetation shall be conducted in accordance with the following provisions:

1) Measurement of success of revegetation shall be initiated within ten (10) years after completion of backfilling and final grading of areas of prime farmland in accordance with the approved reclamation plan.

2) Success of revegetation shall be measured in accordance with 62 Ill. Adm. Code 1816.116(a)(4).

3) Revegetation shall be considered a success when crop production is equivalent to or exceeds the production required in 62 Ill. Adm. Code 1816.116(a)(4), with ninety (90) percent statistical confidence (i.e., one-sided t test with 0.10 alpha error) for a minimum of three (3) crop years of a ten (10) year period, provided that all three (3) crop years do not occur before the fourth year (inclusive) after augmented seeding, fertilizing, or other management practices, prior to release of the operator's performance bond. The level of management applied during the measurement period shall be the same as the level of management used on nonmined prime farmland in the surrounding area. The five (5) year period of extended responsibility shall begin after the last year of augmented seeding, fertilizing or soil treatment and at the time of the planting of the crop(s) to be grown for the productivity showing.

4) Compliance with this subsection shall not preclude a permittee from demonstrating the required soil productivity under the law by use of soil surveys or other techniques

approved consistent with future regulations.

(Source: Amended at 10 Ill. Reg. 9631. effective July 1, 1986)

TITLE 62: MINING
CHAPTER I: DEPARTMENT OF MINES AND MINERALS

PART 1825
SPECIAL PERMANENT PROGRAM PERFORMANCE STANDARDS--
OPERATIONS ON HIGH CAPABILITY LANDS

Section
1825.11 High Capability Lands: Special Requirements
1825.12 High Capability Lands: Soil Removal
1825.13 High Capability Lands: Soil Stockpiling
1825.14 High Capability Lands: Soil Replacement

AUTHORITY: Implementing and authorized by the Surface Coal Mining Land Conservation and Reclamation Act (Ill. Rev. Stat. 1985, ch. 96 1/2. pars. 7901.01 et seq.).

SOURCE: Adopted at 4 Ill. Reg. 37. p. 1, effective June 1, 1982; amended at 6 Ill. Reg. 1. effective June 1, 1982; emergency amendment at 6 Ill. Reg. 8502. effective July 1, 1982, for a maximum of 150 days; codified at 8 Ill. Reg. 9363: amended at 6 Ill. Reg. 9987, effective September 3, 1982; amended at 10 Ill. Reg. 9628, effective July 1. 1986: amended at 11 Ill. Reg. 8526, effective July 1, 1987.

Section 1825.11 High Capability Lands: Special Requirements

All high capability lands to be mined and reclaimed shall meet the following requirements, or meet the requirements of 62 Ill. Adm. Code 1816.133:

a) A permit shall be obtained for these operations as required by 62 Ill. Adm. Code 1173;

b) Darkened surface soil materials to be used in the reconstruction of high capability lands shall be removed before drilling for blasting or mining or other surface disturbances. in accordance with Section 1825.12 and in a manner that prevents mixing or contaminating these materials with undesirable material. Where removal of soil materials results in erosion that may cause air and water pollution, the Illinois Department of Mines and Minerals (Department) shall specify methods to control erosion of exposed overburden;

c) Revegetation success on high capability lands shall be measured in accordance with 62 111. Adm. Code 1816.116, except that the five (5) year period of responsibility for revegetation shall commence at the date of initial planting of the crop being grown only in case6 where the operator has chosen to show success of revegetation by using the land to grow crops; and

d) The requirements of this Part are in addition to the other requirements of these regulations.

(Source: Amended at 11 Ill. Reg. 8256. effective July 1. 1987)

Section 1825.12 High Capability Lands: Soil Removal

a) Surface mining operations on high capability lands shall be conducted as follows:

1) The darkened surface soil shall be removed and segregated, if not used immediately, from other materials. In no cases shall less than the top eight (8) inches of surface soil, darkened or not, be segregated for replacement; and

2) Darkened surface soil segregation and replacement requirements may be altered by the Department only if it has determined the provisions of 62 Ill. Adm. Code 1816.22(b) have been met.

b) The Department may require root medium stockpiling if necessary to meet the requirements of the Surface Mining Control and Reclamation Act of 1977 (30 U.S.C. 1201 et seq.), and these regulations.

(Source: Amended at 11 Ill. Reg. 8526, effective July 1, 1987)

Section 1825.13 High Capability Lands: Soil Stockpiling

If not used immediately, the darkened surface soil or its equivalent as approved by the Department and the root medium if the root medium is stockpiled in accordance with Section 1825.12 shall be stockpiled separately and these materials shall be stockpiled separately from other spoil, and provided needed protection from wind and water erosion or contamination by acid or toxic or non-soil material. Signs shall be erected to indicate the contents of each stockpile.

Section 1825.14 High Capability Lands: Soil Replacement

Surface mining operations on high capability lands shall be conducted according to the following:

a) The operator shall establish a suitable rooting medium.

1) Texture. In order to be of suitable texture, the materials under the darkened surface soil suitable as a root medium shall contain no more than twenty percent (20%) coarse material (greater than two (2)mm in size) by volume. No more than half of the coarse material may be between three (3) inches and ten (10) inches in the greatest dimension. No fragments shall be greater in size than ten (10) inches in the greatest dimension. In no case may clay material of less than two (2) microns be greater than forty percent (402) by weight of the soil size material nor shall the sand size material of greater than fifty (50) microns be greater than sixty percent (60%) by weight of the soil size material, when clay material content is less than twenty percent (20Z) by weight.

A) Rapid weathering coarse material, as determined by the Department, may be included in the root medium. If these fragments are allowed, they shall be included in the soil fraction for texture determination and shall not be included in the coarse fragment portion of texture evaluation.

B) These texture requirements do not apply if the soil conditions of the affected land prior to mining did not meet the standards included herein (i.e., if more than twenty percent (20%) coarse material by volume existed in the root medium below the darkened surface soil prior to mining, the same percentage or coarse material in the root medium will be allowed after mining; if more than one-half (l/2) of the coarse material consisted of rocks in the three (3) to ten (10) inch size category prior to mining, the same percentage will be permitted after mining; and if more than forty percent (40%) by weight of clay materials less than two (2) microns in size: and if more than sixty percent (60%) by weight of sand when clay material content is less than twenty percent (20%) by weight existed in the root medium below the darkened surface soil prior to mining, a like percentage by weight will be allowed after mining in the material under the darkened surface soil).

2) Chemical Properties. The materials under the darkened

surface soil must be chemically suitable as an agricultural root medium. Toxic material capable of producing chemically unsuitable conditions shall not be incorporated within the material used to create the root zone established for these lands.

3) Depth. The combined vertical thickness of the darkened surface soil and the agricultural root medium must be at least four (4) feet in all cases, except where a natural rock formation occurs at shallower depths. In such case, the operator shall create a root medium of equivalent thickness to its pre-mining condition.

4) The darkened surface soil shall be replaced as the final earth cover on high capability lands.

5) Location of texture compliance samples will be determined by random methods. Texture analysis shall be determined by methods specified by the Department.

b) The Department may alter the texture requirements under this Part oniy upon a clear and convincing showing that to vary such requirement would better effectuate the purposes of the Act than would enforcing the standards herein.

c) The affected land shall be graded to the approximate original contour of the land prior to mining. For the purpose of this Part, the slope classification of lands before mining are those lettered ranges developed by the U.S. Department of Agriculture, Soil Conservation Service for use in preparing a soil survey of the area.

d) Approximate original contour means grading of affected lands to a elope no greater than the maximum percent of the pre-mining slope range of the individual soil map units.

e)

1) The agricultural root medium described in Section 1825.14(a) shall be replaced and regraded to a uniform depth over the regraded spoil material in a manner that avoids excessive compaction or a compaction alleviation plan shall be provided. Excessive compaction is indicated by:

A) Very firm. massive soil physical condition in any layer above the rooting medium depth required by subsection (a)(3) that has one-half or more of the soil volume in masses ten (10) inches or more in diameter that are not exploited by the root system:

B) Roots restricted to a depth less than the required rooting meduim depth;

C) Confinement of roots to matrix desication cracks; or

D) Flattened roots.

2) Compaction alleviation is required unless the permittee can demonstrate that root system development at similar depths in undisturbed soils typical of the mined area is no better than that observed in the reconstructed soil. However, the requirements of 62 Ill. Adm. Code 1816.116 must still be met.

3) After approval of texture by the Department, the darkened surface soil shall be redistributed and graded to a uniform depth without excessive compaction over the replaced and regraded agricultural root medium.

f) High capability lands shall have a planned erosion control system if expected soil loss from row crop production will exceed the tolerable soil loss limits as defined by "Resource Conservation Planning Technical Material-IL-h' and subsequent revisions or modifications. Terrace systems, when utilized as part of a planned erosion control system, shall be constructed according to U.S. Department of Agriculture, Soil Conservation Service specifications. Erosion control plans in compliance with this subsection shall be submitted to and approved by the Department prior to the completion of the final grading of an areas, or on a time schedule approved by the Department after final grading based on seasonal factors, the extent of the area. and the sophistication of the erosion control plan.

g) Slopes of all affected lands shall be measured from the drainage divide to the base of the slope or to the intermittent water course at the lowest point. Abrupt slope changes between these points are not acceptable except for unusual conditions such as ditches, terraces, and roads.

h) The length of slope and contour of the restored surface shall be conducive to those farming operations normally associated with row crop production. Farming operations as used here shall include such measures or practices necessary to provide adequate drainage and erosion control for sustained row crop production.

(Source: Amended at 11 Ill. Reg. 8526. effective July 1, 1987)

Section 1816.APPENDIX A Agricultural Lands Productivity Formula

SOIL MASTER FILE

The Soil Master File of the Agricultural Lands Productivity Formula contains a comprehensive list of the soil mapping units currently recorded in Illinois. The Soil Master File provides the soil mapping unit number, common mapping name, and the high level of management yields for corn, soybeans, wheat, oats and mixed hay. Section 1816.Table E is the Soil Master File.

Additional components of the Soil Master File are as follows:

1. County number - identifies soils unique to a county. County number also distinquishes between soils with the same name in different counties but with unique soil properties and yields. County numbers are identified in Section 1816.Table C County Numbering System.

2. Variance code - physical conditions which would cause similar soil types to produce radically different yields. Variance code is explained in Section 1816.Table B Soil Variance Code.

3. Switch code - identifies a point at which a particular soil at a given slope and/or erosion category becomes either a new soil, a complex soil or moves from a favorable to unfavorable subsoil. The alphanumeric switch code is the new slope and erosion code.

4. Subsoil type - either #l favorable, or #2 unfavorable subsoil condition. Percent of adjustment that will be applied to both the high management yield in subsoil conditions provided in Section 1816.Table A - Subsoil Adjustments.

5. Slope and erosion - this category provides adjusted high management yields for slope and erosion groups for each soil series for each crop in the Agricultural Lands Productivity Formula.

COUNTY CROPPED ACREAGE FILE

The Agricultural Lands Productivity Formula requires that the number of cropped acres by soil mapping unit be calculated for each county. These calculations are generated by computer using the following formula:

Total acres per soil type per county	x	percent of total acreage - cropped	acres per soil type cropped

The percent of total acreage cropped per soil type will be provided by

County Soil and Water Conservation Districts. Any changes to these figures must be approved by the County Soil and Water Conservation District Board with a certified copy of all changes submitted by August 15 of each year to the Illinois Department of Agriculture.

Section 1816.Table F - County Cropped Acreage File reflects the total acres of each soil type per county. percent of acreage cropped. and the computed figure of total cropped acres by soil type in each county. The "total cropped acres" figures are carried forward to the County Average Yield File.

COUNTY AVERAGE YIELD FILE

The next procedure of the Agricultural Lands Productivity Formula is to equate annual county crop yield data to the soils derived in the "County Cropped Acreage File". Section 1816.Example A and the following paragraphs summarize the procedure for calculating the crop yield for each soil mapping unit.

Column A reflects the soil mapping units as they appear on a county by county basis.

Column B is the number of acres cropped in a county per soil type as recorded in the County Cropped Acreage File. These cropped acreage figures are then added together to give a.total number of acres cropped for the county.

Column C is the percent of the acreage represented by each soil type when compared with the total in Column B (Column B = total acres in soil mapping unit times the percent of acres cropped in the county by mapping unit).

The number of acres planted in grain (Column D) is calculated by multiplying the percent of each soil mapping unit in the county (Column C) by the total acres in the county harvested for corn, soybeans, wheat, oats, and mixed hay. (See asterisk in Section 1816.Example A). The purpose of this calculation is to estimate the number of acres harvested from each of the particular soil mapping units. It is assumed that 25% of the total corn, soybean, wheat, oat and mixed hay acreage was planted on that particular soil mapping unit. Therefore, the "grain acres" are distributed on the soil mapping units based upon the percent of acres in each soil mapping unit.

Column E is the adjusted yield information for each crop which comes from Section 1816.Table E - Soil Master File.

Column F is a derived high management production (Figure) obtained by multiplying the figures in Column D times the figures in Column E. This production figure will normally exceed actual production because the high

level management yield is used. The purpose of using the high management production is to derive a weighted average high management yield; which is, the total high management production (Column F) divided by the total grain acres in the county (Column D). The weighted high management yield figure will be used to derive a 'factor" as described below:

$$\text{Factor} = \frac{\text{Official County Crop Yield}}{\text{Weighted High Management Yield}}$$

Column G results from the multiplication of the above factor times the high level management yield of each soil mapping unit (Column E). The result is a yield which represents the average yield in either bushels per acre or tons per acre in the county for that year and crop.

PERMIT SPECIFICS
YIELD STANDARD

After completing calculations for the projected yield of the test year in question, a yield standard for each permit area must be calculated. The yield standard. which is also applicable to high capability standards of Section 1816.116(a)(3)(C) will be calculated in the following manner:

The number of prime farmland acres in each soil mapping unit will be divided by the total prime farmland acres in the mine permit area to obtain a weighted proportion for each soil type. The weighted proportion of each prime farmland soil mapping unit in the permit area, relative to the total prime farmland acres in the permit area, will be multiplied times the projected yield for the pre-mining soil types. The weighted final yield for each prime farmland soil type in a mining permit area will be added together and the total becomes the yield requirement for the permit area.

AGRICULTURAL LANDS PRODUCTIVITY FORMULA
SAMPLING METHOD

The sampling methodology that the Illinois Department of Agriculture or the Illinois Department of Mines and Minerals will use to gather the data" needed to determine if productivity has been returned to reclaimed mine land is summarized below for corn, soybeans, wheat, oats, sorghum, and mixed hay.

This sampling methodology requires an operator to submit by February 15 of each year, a scale drawing or aerial photo delineating specific field boundaries and type of crop which is to be sampled for proof of productivity for the current crop year. Each scale drawing and photo submitted shall include a field numbering scheme and the total acreage for each field on which sampling is being requested. In addition, the scaled drawing shall be no less than 1 inch equals 500 feet (1:500) or greater than 1 inch equals 100 feet (1:100). The February 15 annual submittal may be amended by the operator until July 15. Each such amendment shall contain a written explanation of changes from the original submittal and an aerial photograph

or scaled drawing reflecting the corrected sampling submittal.

The determination of sample points within a specific field will be made on the basis of a grid overlay scheme with the location of sample points on the grid randomly generated by computer. An intentional bias of fifty feet (50') will be introduced to all field boundaries to remove the potential that sampling points may fall in turn around areas, or areas where contiguous soil reconstruction may cause field boundaries to not be indicative of whole field productivity.

The minimum-acceptable number of samples to be taken relative to field size is shown in Section 1816.Table D sample points per crop acres, with fields of four acres or less to be sampled in their entirety with yields determined by harvest weight. Sample selections will take place using the following guidelines.

The Illinois Department of Agriculture may elect to increase the minimum number of acceptable sample points per field acres. Some factors which will be considered in determining whether to increase the number of sample points are as follows, but not limited to:

1. Operator requests additional sample points for specific fields.

2. The use of different hybrids in one field.

3. Contour changes within one field which would alter a yield.

4. A coefficient of variation greater than 15Z.

The Department shall request the operator to verify yields by harvest weight (e.g., scale tickets) for reasons, including but not limited to:

1. Verification of random sampling results.

2. Availability of sample enumerators.

3. Backlog of sample processing at the IDOA lab.

In each such case, the certified harvest yield adjusted, to optimum moisture content, will become the comparison yield for the Agricultural Lands Productivity Formula target yield.

CORN SAMPLING TECHNIQUE

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual sample locations.

Step 3 - After taking the last of the required paces to the first sampling point, place a stake immediately adjacent to the closest corn stalk to the toe of your shoe. Measure 15 feet of the corn row starting at the first stake and placing a second stake at the 15 foot mark, Move to the next adjacent corn row, measure and stake a second 15 foot section in the same manner as the first row. One sample unit will equal two fifteen foot corn row sections.

Step 4 - Determine the 3rd and 4th ears of the first row starting with the first stalk of corn. Tag these ears with a rubber band. If there are less than four ears in the first row, the last ear and the next to last ear should be tagged. In the case where a stalk has more than one ear, count the top ear first. (Note: An ear of corn is defined as a cob having at least one kernel.' The tagged ears will be used to determine the moisture content, and at least 250 grams of grain are needed. If it does not appear that the 3rd and 4th ears will supply 250 grams of grain for a moisture test, then the 5th. 6th and/or 7th ear should be included until at least 250 grams of corn is collected).

Step 5 - Husk all ears in Row 1 within the fifteen foot segment of the sample. Husk the ears and snap the skank off as cleanly as possible. Be sure to include any ears tagged for moisture testing.

Step 6 - Weigh the husked ears using a balance scale - obtain field weight in pounds.

Step 7 - After weighing, put ears tagged for moisture testing into polyethylene bags and seal. Mark the bag with the appropriate field number (as supplied by the mine operator), and sample identificaiton number .

Step 8 - Measure on a perpendicular line from the stalks in row one (1) to the stalks in row five (5). Divide this measured distance by four (4) to determine the average row width.

Step 9 - Repeat Steps 3 through 8 for each additional random sampling point coordinate.

Step 10 - Send or deliver to the Illinois Department of Agriculture any grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as 1A, 1B, 1C).

The following method will be used for determination of gross

yield of corn samples. Gross yield is determined by deducting the adjustment for moisture content of shelled corn from the harvest weight. Moisture content of the grain sample will be determined by lab analysis.

Gross Yield = Harvest Weight adjusted for moisture content

Included below for reference is the Gross Yield formula and an explanation of its components.

$$\text{Gross Yield Per Acre bu/ac} = \frac{A \times B \times C}{D} / (E \times 56 \text{ lbs/bu})$$

where: A = Field weight of husked ears of corn from 15 feet of row x 2 (2 Rows x 15 feet):

B = Weight of shelled grain at time of moisture test:

C = Percent moisture in grain corrected to 15.52:

$$= 1.0 - \frac{\text{(Moisture content of shelled corn)}}{100} / .845$$

D = Weight of ears of Corn used for moisture determination;

E = Row Factor

Area or percent of Acre Sampled with 30 feet of Row (2 rows x 15 feet)	30' = 0.001722
	36' = 0.002066
	38' = 0.002181
	40' = 0.002295

and .845 = The standard moisture content conversion factor of corn per bushel (1.0 - .155).

After calculation of the gross yield, the Harvest Loss will be substracted from the gross yield to obtain net yield per sample. Harvest Loss is the difference between actual grain yield and what is hauled from a field. The net yield determinations for each sample will be averaged together to obtain a yield figure for the entire field being evaluated for proof of productivity.

SOYBEAN SAMPLING TECHNIQUE BROADCAST BEANS

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual sample locations.

Step 3 - After taking the last of the required paces to the first sampling point, lay down a sampling frame so that it touches the toe of your shoe, crossing the crop rows at a right angle. Mark the two ends of the sampling frame with stakes just inside the 3.0 foot sampling tines. Continue to lay out the sample area in the direction of travel from where the last pace was counted. Rotate the sampling frame so that it is perpendicular to one corner of the stake (previously marked), and at a right angle to the original frame position. (Note: If at any time the point of a tine is restricted by a soybean plant, slide the soybean frame toward the starting point far enough for the point of the tine to clear the plant). Repeat this procedure to lay out the other two sides of the sampling square, using the opposite corner of the original frame position to find the other two sides.

Step 4 - Strip all the soybean pods from all the plants in the 9 square feet sampling area. Pick up any loose pods or beans found on the ground. Deposit all the pods, beans and blank pods, into a paper sack. Mark the sack with the appropriate field number (as provided by the mine operator), and sample identification number. Secure the sample sack to prevent any sample loss. (Note: If sample weigh: is below 250 grams for the moisture test, grain of known moisture content as is necessary to reach the test weight will be added to the sample so that moisture tests can be made).

Step 5 - Repeat steps 3 and 4 for each additional random sampling point coordinate.

Step 6 - Send or deliver to the Illinois Department of Agriculture any grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bag6 should be identified sequentially such as 1A, lB, 1C).

The following method will be used for determination of gross yield of soybean samples. Gross yield is determined by deducting the adjustment for moisture content of the soybean sample from the harvest weight. Moisture content of the grain sample will be determined by lab analysis.

Gross Yield = Harvest Weight adjusted for moisture Content

Included below for reference is the Cross Yield formula and an explanation of its components.

$$\text{Gross Yield Per Acre bu/ac} = \frac{\text{Total weight of all beans in 9 sq. ft. grid (in grams)} \times \text{Conversion Factor} \times 1.0 - (\%\ \text{moisture}/100)}{.875}$$

$$\text{Where the conversion factor} = \frac{43560\ \text{sq. ft./ac.}}{453.6\ \text{gms/lb} \times 60\ \text{lbs/bu} \times 9\ \text{sq. ft.}}$$

and .875 = The standard moisture content conversion factor of soybeans per bushel (l.0-(12.5%/100)).

After calculation of the gross yield, the Harvest Loss will be subtracted from the gross yield to obtain a net yield per sample. Harvest Loss is the difference between actual grain yield and what is hauled from the yield. The net yield determinations for each sample will be averaged together to: obtain a yield figure for the entire field being evaluated for proof of productivity.

SOYBEAN SAMPLING TECHNIQUE
DRILLED OR PLANTED BEANS

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual locations.

Step 3 - After taking the last of the required paces to the first sampling point, mark the closest plant to the toe of your foot. Place a flag at the point that you have just marked. From the point of this flag, and in the direction of travel from where the last pace was counted, measure a distance of six feet of plant row and place a flag at the six foot mark. Starting from the row just identified, measure the distance across five rows. This distance, from row one to row five, divided by four row spaces gives the average row width.

Step 4 - Strip all the soybean pods from all the plants in the 6 foot sample row. Pick up any loose pods or beans found on the ground at the base of these plants. Deposit all the pods, beans and blank pods, into a paper sack. Mark the sack with the appropriate field number (as provided by the mine operator), and sample identification number. Secure the sample sack to prevent any sample loss. (Note: If sample weight is too small for the moisture test, sufficient grain of known moisture content will be added to the sample so that moisture tests can be made).

Step 5 - Repeat steps 3 and 4 for each additonal random sampling point coordinate.

Step 6 - Send or deliver to the Illinois Department of Agriculture any grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as 1A, 1B, 1C).

The following method will be used for determination of gross yield of soybean samples. Gross yield is determined by deducting the adjustment of moisture content of the soybean sample from the harvest weight. Moisture content determinations will be made by the Illinois Cooperative Crop Reporting Service.

Gross Yield = Harvest Weight adjusted for moisture content

Included below for reference is the Gross Yield formula and an explanation of its components.

$$\text{Gross Yield Per Acre (bu/acre)} = \frac{A \times B}{C \times D \times E}$$

Where A = Weight of harvested grain from 6 feet of row

B - Percent moisture in grain corrected to 12.5% =

$$\frac{(1.0 - (\% \text{ moisture in shelled beans}/100\%))}{0.875}$$

C = Number of grams per pound = 453.6

D = Correction factor for row spacing on drilled or planted beans

$$= \frac{\text{Average row width across 5 rows (feet)} \times 6 \text{ feet of row}}{43560 \text{ sq. ft./acre}}$$

E = Standard weight of 1 bushel of soybeans = 60

After calculation of the gross yield, the Harvest Loss as calculated by Illinois Cooperative Crop Reporting Service will be subtracted from the gross yield to obtain a net yield per sample. The net yield determinations for each sample will be averaged together to obtain a yield figure for the entire field being evaluated for proof of productivity.

WHEAT SAMPLING TECHNIQUES

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual sample location

Step 3 - After taking the last of the required paces to the first sampling point, lay down a sampling frame so that it touches the toe of your shoe, crossing the crop rows at a right angle. Mark the two ends of the sampling frame with stakes just inside the 1.8 feet samples tines. Continue to lay out the sample area in the direction of travel from where the last pace was counted. Rotate the sampling frame so that it is perpendicular to one, corner of the stake (previously marked) and at a right angle to the original frame position. Repeat this procedure to lay out the other two sides of the sampling square using the opposite corner of the original frame position to find the other two sides.

Step 4 - Clip all wheat heads from within the square outlined by the sampling frame. The wheat heads should be clipped approximately 1/2 inch below the bottom of the head. Deposit all the collected wheat heads into a paper sample sack. Mark the sack with the approximate field number (as supplied by the mine operator), and sample identification number. Secure the sample sack to prevent any sample loss: (Note: If sample weight is below 250 grams for the moisture test, grain of known moisture content will be added to the sample so that moisture tests can be made).

Step 5 - Repeat steps 3 and 4 for each additional random sampling point coordinate.

Step 6 - Send or deliver to the Illinois Department of Agriculture grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as 1A, 1B, 1C).

The following method will be used for determination of gross yield of wheat samples. Gross yield is determined by deducting the adjustment for moisture content of the wheat sample from the harvest weight. Moisture content of the grain sample will be determined by lab analysis.

Gross Yield - Harvest Weight adjusted for moisture content

Included below for reference is the Gross Yield formula and an explanation of its components.

$$\text{Gross yield Per Acre bu/ac} = \frac{\text{Sample wt. of wheat (in grams)} \times 1.0-(\%\ \text{moisture}/100)}{.880} \times \text{conversion factor}$$

$$\text{Where the conversion factor} = \frac{43560\ \text{so. ft/ac}}{60\ \text{lbs/bu} \times 453.6\ \text{gms/lb} \times 3.24\ \text{sq. ft.}} = .4940\ \frac{\text{bu/am}}{\text{acre}}$$

and .88 = The standard moisture content conversion factor of wheat per bushel (l.0-(12%/100)).

After calculation of the gross yield, the Harvest Loss will be subtracted from the gross yield to obtain a net yield per sample. Harvest Loss is the difference between actual grain yield and what is hauled from a field. The net yield determinations for each sample will be averaged together to obtain a yield figure for the entire field being evaluated for proof of productivity.

OATS SAMPLING TECHNIQUE

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual sample location.

Step 3 - After taking the last of the required paces to the first sampling point, lay down a sampling frame so that it touches the toe of your shoe, crossing the crop rows at a right angle. Mark the two ends of the sampling frame with stakes just inside the 1.8 feet sampling tines. Continue to lay out the sample area in the direction of travel from where the last pace was counted. Rotate the sampling frame so that it is perpendicular to one corner of the stake (previously marked) and at a right angle to the original frame position. Repeat this procedure to lay out the other two sides of the sampling square using the opposite corner of the original frame position to find the other two sides.

Step 4 - Clip all oat heads from within the square outlined by the sampling frame. The oat heads should be clipped approximately l/2 inch below the bottom of the head.

Deposit all the collected oat heads into a paper sample sack.

Mark the sack with the appropriate field number (as supplied by the mine operator), and sample identification number. Secure the sample sack to prevent any sample loss. (Note: If sample weight is below 250 grams for the moisture test.. grain of known moisture content will be added to the sample so that moisture tests can be made).

Step 5 - Repeat steps 3 and 4 for each additional random sampling point coordinate.

Step 6 - Send or deliver to the Illinois Department of Agriculture any grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as 1A, 1B, 1C).

The following method will be used for determination of gross yield of oat samples. Gross yield is determined by deducting the harvest weight. Moisture content of the grain samples will be determined by lab analysis.

Gross Yield = Harvest Weight adjusted for moisture content

Included below for reference is the Gross Yield formula and an explanation of its components.

$$\text{Gross yield Per Acre bu/ac} = \frac{\text{Sample wt. of oats (in grams)} \times 1.0\text{-(\% moisture/100)} \times \text{conversion factor}}{0.850}$$

$$\text{Where the conversion factor} = \frac{43560 \text{ sq. ft/ac}}{32 \text{ lbs/bu} \times 453.6 \text{ gms/lb} \times 3.24 \text{ sq. ft.}} = .9262 \ \frac{\text{bu/gm}}{\text{acre}}$$

and .85 = The standard moisture content conversion factor of oats per bushel (1.0-(15%/100)).

After calculation of the gross yield, the Harvest Loss will be subtracted from the gross yield to obtain a net yield per sample. Harvest Loss is the difference between actual grain yield and what is hauled from a field. The net yield determinations for each sample will be averaged together to obtain a yield figure for the entire field being evaluated for proof of productivity.

SORGHUM SAMPLING TECHNIQUE

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinates in a sequential fashion to determine individual sample locations.

Step 3 - After taking the last of the required paces to the first sampling point, place a stake immediately adjacent to the closest sorghum plant to the toe of your shoe. Measure ten (10) feet of the plant row starting at the first stake and placing a second stake at the ten (10) foot mark. Move to the next adjacent plant row, measure and stake a second ten (10) foot section in the same manner as the first row. One sample unit will equal two (10) ten foot sorghum row sections.

Step 4 - Clip all grain heads in Row 1 within the ten (10) foot segment of the sample unit.

Step 5 - Weight the clipped grain heads using a balance scale - obtain field weight to the nearest tenth (0.1) of a pound.

Step 6 - Clip the first five grain heads and the last five grain heads in Row 2 to be used for moisture determination. Place any grain heads collected for moisture determination into sealed polyethylene bags. Mark the bags with the appropriate field number (as supplied by the mine operator), and sample identification number.

Step 7 - Measure on a perpendicular line from the plants in row one (1) to the plants in row five (5). Divide this measured distance by four (4) to determine the average row width.

Step 8 - Repeat Steps 3 through 7 for each additional random sampling point coordinate.

Step 9 - Send or deliver to the Illinois Department of Agriculture any grain sample collected for moisture content analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as lA, lB, 1C).

The following method will be used for determination of gross yield of sorghum samples. Gross yield is determined by deducting the adjustment for moisture content of the threshed grain from the harvest weight. Moisture content of the grain samples will be made by lab analysis.

Gross Yield = Harvest Weight adjusted for moisture content

Included below for reference is the Gross Yield formula and an explanation of its components.

$$\text{Gross Yield bu/ac} = \frac{A \times B \times C}{D} / E \times 56 \text{ lbs/bu}$$

Where: A = Field weight of grain heads of sorghum from ten (10) feet of row x 2 (2 rows x 10 feet);

B = Weight of threshed grain at time of moisture test;

C = Percent moisture in grain corrected to 13.01;

$$= 1.0 - \frac{\text{(Moisture content of threshed grain)}}{100} / 0.870$$

D = Weight of grain seeds used for moisture determination:

E = Row factor Area or percent of Acre Sampled with 20 feet of Row (2 rows x 10 feet)

28" =	.001070
30" =	.001148
36" =	.001377
38" =	.001455
40" =	.001529

and .870 = The standard moisture content conversion factor of sorghum per bushel (1.0 -.130)

MIXED RAY SAMPLING TECHNIQUE

Step 1 - Mark the starting corner of the field to be sampled with a large stake and attach a ribbon or flag to it.

Step 2 - Pace off predetermined sample point coordinate in a sequential fashion to determine individual sample locations.

Step 3 - After taking the last of the required paces to the first sampling point, lay down a sampling frame perpendicular to the toe of your shoe, where applicable, crossing crop rows at a right angle. Mark the two ends of the sampling frame with stakes just inside the 3 feet sampling tines. Continue to lay out the sample area in the direction of travel from where the last pace was counted. Rotate the sampling frame so that it is perpendicular to one corner of the stake (previously marked) and at a right angle to the original frame position. Repeat this procedure to lay out the other two sides of the sampling square using the opposite corner of the original frame position to locate the other two sides. In all cases, the layout of the sample area shall be consistent for each randomly identified sample point.

Step 4 - Clip all hay stalks from within the square outlined by the

sampling frame. The hay stalks should be uniformly clipped to an approximate height of two (2) inches above ground level.

Step 5 - Deposit all of the collected hay sample into a suitable sample sack/container. Mark the sack/container with the appropriate field number (as supplied by the mine operator). and sample identification number. Secure the sample sack/container to prevent any sample loss. (Note: If the sample weight is too large for handling by lab personnel, the sample may be quartered until an adequate representative sample for moisture testing is obtained.)

Step 6 - Repeat Steps 3 and 4 for each additional random sampling point coordinate.

Step 7 - Send or deliver to the Illinois Department of Agriculture any hay sample collected for moisture analysis. (Note: If any single sample requires more than one bag, additional bags should be identified sequentially such as 1A, lB, 1C).

* If a field moisture meter is used, steps 5 and 7 shall be eliminated and the following explanations for items A and D will be substituted.

A. Dry matter weight = harvest weight - percent moisture content determined by field moisture tests.

D. Percent moisture in hay at time of harvest determined by field moisture test.

The following method will be used for determination of gross yield of mixed hay samples. Gross yield is determined by deducting the adjustment for moisture content of the mixed hay sample frsm the harvest weight. Moisture content of mixed hay samples will be determined by lab analysis.

Gross Yield = Harvest weight adjusted for moisture content

$$\text{Gross yield (Tons/Acre)} = \left(A \times \frac{1}{B \times F}\right)$$
(C

Where : A = Oven dry weight of harvested hay.
B = Sample size (FT2) 43560 FT2/acre.
C = Conversion factor from lbs harvested to tons (i.e. 1 ton = 2000 lbs)
D = Percent moisture in hay at time of harvest
$= \frac{\text{Wet wt- oven dry wt}}{\text{Oven dry wt.}} \times 100 = \%\ H20$
E = Approximate % moisture in mixed baled hay = 15%

$$F = D/E = \frac{100\% - \%H_2O \text{ in Hay at Time of Harvest}}{15\%}$$

The net yield determinations for each sample will be averaged together to obtain a yield figure for the entire field being evaluated for proof of productivity. The annual harvest will be determined by the cumulative yields of each cutting.

SPECIAL PROBLEMS IN SAMPLE LAYOUT

1. It is possible for a sample grid coordinate to fall on areas within the field boundary which were not planted to crops (i.e.. grass waterway, roadway, etc.) When this situation occurs, stop the pace count at the start of such an area and resume the count on the other side of the area.

2. If a blank area is crossed which was planted to crops, the pace count should be continued through this area. Usually such areas are due to poor germination, insects, standing water, etc. (if the sample area falls in this planted area which is blank, then a zero yield is established).

3. If a sample coordinate falls partly in a blank area which was not planted for harvest, move the sample area ahead until it is wholly on acreage planted to the crop being sampled. The sample point should begin one pace from the edge of the blank area.

(Source: Added at 10 Ill. Reg. 8985, effective July 1. 1986)

Section 1816.EXHIBIT A COUNTY CROP YIELDS BY SOIL MAPPING UNIT

Column A Soil Mapping Unit	Column B County Cropped Acreage	Column C % of total acres cropped	Column D* Grain Acres by Soil Mapping Unit	Column E Adjusted High Mtg. Yield	Column F High Mgt. Produc-tion	Column G Yield by (Bu/A) (T/A)
	_____	_____	_____		_____	
	Total	Total	Total		Total	

County Acres in Corn _____
Soybeans _____
Wheat _____
oats _____
Mixed Hay _____
* Total Acres _____

(Source: Added at 10 Ill. Reg. 8985, effective July 1, 1986)

Section 1816.TABLE A SUBSOIL ADJUSTMENTS

Percentage Adjustments in Yields Under High Management for Common Slope Groups and Various Erosion Conditions

Favorable Subsoil

Slope Group*	(1) Uneroded	(2) Moderate Erosion %	(3) Severe Erosion
A (0 - 2%)	100	97	90
B (2 - 5%)	99	96	89
C (5 - 10%)	98	95	88
D (10 - 15%)	95	92	85
E (15 - 20%)	90	87	80
F (20 - 25%)	80	77	70
G (25% +)	71	68	61

Unfavorable Subsoil

Slope Group*	(1) Uneroded	(2) Moderate Erosion %	(3) Severe Erosion
A (0 - 2%)	100	95	80
B (2 - 5%)	99	94	79
c (5 - 10%)	97	92	77
D (10 - 15%	93	89	73
E (15 - 20%)	88	83	68
F (20 - 25%)	78	73	58
G (25% +)	69	64	49

* The slope range represents a lower upper limit. For example, a slope of B (2-5%) represents an overlap of A at 2%. This overlap is interpreted to mean A slope is 0 to 2% and B slope is any fraction greater than 2% to 5%.

(Source: Added at 10 Ill. Reg. 8985, effective July 1, 1986)

Section 1816.TABLE B SOIL VARIANCE CODES

Soil Variance Codes

Variance Code	Meaning
1	Soil Wet (Reduce yield by 30%)
2	Urbanized Soil (Reduce yield to zero)
3	Flooded Soil (Reduce Yield by 50%)
4	Ponded Soil (Yield Reduction Varies by County)
5	Sink Hole (Yield Reduction Varies by County)
6	Soil Variant (Yield Reduction Varies by County)
7	Mine Dump (Reduce yield to zero)
8	Quarry (Reduce yeild to zero)
9	Sewage Lagoon (Reduce yield to zero)
10	Water (Reduce yield to zero)
11	Borrow Pit (Reduce yield to zero)
12	Strip Mine (Reduce yeild to zero)
13	Sand Quarry/Pits (Reduce yield to zero)
14	Gravel Pit (Reduce yield to zero)
15	Made Land (Reduce yield to zero)
16	Miscellaneous non-cropped (Reduce yield to zero)

(Source: Added at 10 Ill. Reg. 8985, effective July 1, 1986)

Section 1816.TABLE C COUNTY NUMBERING SYSTEM

Assigned County Numbers for the
Agricultural Land Productivity Formula

County Number	County	County Number	County	County Number	County
1	Adams	69	Hardin	137	Morgan
3	Alexander	71	Henderson	139	Moultrie
5	Bond	73	Henry	141	Ogle
7	Boone	75	Iroquois	143	Peoria
9	Brown	77	Jackson	145	Perry
11	Bureau	79	Jasper	147	Piatt
13	Calhoun	81	Jefferson	149	Pike
15	Carroll	83	Jersey	151	Pope
17	Cass	85	Jo Daviess	153	Pulaski
19	Champaign	87	Johnson	155	Putnam
21	Christian	89	Kane	157	Randolph
23	Clark	91	Kankakee	159	Aichland
25	Clay	93	Kendall	161	Rock Island
27	Clinton	95	Knox	163	St. Clair
29	Coles	97	Lake	165	Saline
31	Cook	99	LaSalle	167	Sangamon
33	Crawford	101	Lawrence	169	Schuyler
35	Cumberland	103	Lee	171	Scott
37	DeKalb	105	Livingston	173	Shelby
39	Dewitt	107	Logan	175	Stark
41	Douglas	109	McDonough	177	Stephenson
43	DuPage	111	McHenry	179	Tazewell
45	Edgar	113	McLean	181	Union
47	Edwards	115	Macon	183	Vermilion
49	Effingham	117	Macoupin	185	Wabash
51	Fayette	119	Madison	187	Warren
53	Ford	121	Marion	189	Washington
5.5	Franklin	123	Marshall	191	Wayne
57	Fulton	125	Mason	193	White
59	Gallatin	127	Massac	195	Whiteside
61	Greene	129	Menard	197	Will
63	Grundy	131	Mercer	199	Williamson
65	Hamilton	133	Monroe	201	Winnebago
67	Hancock	135	Montgomery	203	Woodford

(Source: Added at 10 Ill. Reg. 8985. effective July 1, 1986)

Section 1816.TABLE D SAMPLE POINTS PER CROP ACRES

CORN

Size of Bond Release Field	Minimum Number Of Samples
4 - 39 acres	8
40 - 279 acres	12
280 - 639 acres	16
640 acres or more	28

SOYBEANS

Size of Bond Release Field	Minimum Number Of Samples
4 - 39 acres	10
40 - 279 acres	12
280 - 639 acres	16
640 acres or more	26

WHEAT - OATS

Size of Bond Release of Field	Minimum Number Of Samples
4 - 39 acres	6
40 - 279 acres	8
280 - 639 acres	10
640 acres or more	14

SORGHUM

Size of Bond Release Field	Minimum Number Of Samples
4 - 39 acres	10
40 - 279 acres	16
280 - 639 acres	28
640 acres or more	40

MIXED HAY

Size of Bond Release Field	Minimum Number Of Samples
4 - 39 acres	5
40 - 279 acres	10
280 639 acres	20

640 acres or more requires one (1) sample for each additional 35 acres

(Source: Added at 10 Ill. Reg. 8985, effective July 1, 1986)

PAPER NO. 86-2614

RESTORATION OF AGRICULTURAL PRODUCTIVITY ON MINED LAND

by

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SUMMARY:
The Federal Surface Mining Act of 1977 introduced a new concept of productivity restoration compared to revegetation reclamation of surface-mined land. Methods of measuring productivity and assessing the problems affecting production (soil compaction) have had to be developed to address this new issue. Illinois has adopted productivity measurement regulations. Compaction regulations are still under study.

KEYWORDS:

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Restoration of Agricultural Productivity on Hined Land

Dean Spindler and Douglas Downing[1]

ABSTRACT

The Federal Surface Mining Act of 1977 introduced a new concept of productivity restoration compared to revegetation reclamation of surface mined 1 and. Methods of measuring productivity and assessing the problems affecting production (soil compaction) have had to be developed to address this new issue. Illinois has adopted productivity measurement regulations. Compaction regulations are still under study.

INTRODUCTION

PL 95-87, the Surface Mining Control & Reclamation Act of 1977, introduced many new controls on the coal industry. One of these was the reauirement to reestablish equivalent (pre-mining vs. post-mining) crop productivity. Illinois contains approximately 21 million acres of prime farmland with an estimated 490,000 acres underlain by strippable coal reserves (IDMM, 1985). Many additional acres have the potential to be disturbed by surface activities from underground mines. This reclamation law has a significant impact on restoring and measuring crop productivity on reclaimed lands.

Regulatory authorities, as well as coal operators, must now consider not only how to remove and replace the soil layers to the approximate original contour, they must also evaluate:

(1) The impact of different technologies of soil handling.
(2) The impact of subsoil mixing on chemical and textural quality.
(3) The structural condition of the replaced soil.
(4) Management of the replaced soils to meet the productivity yield tests to prove productivity, and
(5) The interrelationship of the four (4) previous considerations.

Prior to 1977, cropland reclamation restoration in Illinois consisted primarily of replacing the topsoil over a root medium with a set standard of no more than 40% clay and no more than 20% coarse fragments (none of which could be greater than ten inches). Total replacement thickness was 48” of soil medium. Reveeetation was typically a grass legume mix with an easily achievable 85% ground cover standard. No standards for actual crop yield or soil structure (compaction) were set.

After 1977, regulations were promulgated requiring coal mine operators to:

(1) Identify pre-mining soil productivity.
(2) Explain how the soils were to be handled -- either horizon by horizon, or by horizon mixes (if demonstrated to be equal or better than replacement of individual horizons), and
(3) Achieve pre-mining yields after reclamation.

Even if the soils were handled according to the mining and reclamation plan, failure to achieve the required yields would result in performance

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bond forfeiture and prohibition of future mining. Specific regulations covering: (1) the requirement to actually grow crops, (2) to prove restored productivity, (3) methods of determining crop yields, and (4) soil compaction standards have been hotly debated and also litigated.

METHODS OF EVALUATING PRODUCTIVITY

As a result of the interim and permanent progrw regulations and subsequent litigation, it became apparent there were several different ideas being considered for ways to measure productivity of reclaimed land. These included:

(1) Assessing the return of each field to its pre-mining yield, i.e. pre-mining yield comparisons to post-mining yields.
(2) Soil survey comparisons which would measure and compare soil characteristics of the mined prime farmland to unmined prime farmland.
(3) Use of an unmined reference area to compare with the mined area.
(4) Soil Conservation Service yields assigned to prime farmland soils in the county.
(5) Countywide average yield figures for individual crops.
(6) The one adopted. by Illinois (the Illinois Agricultural Productivity Formula) which is a comparison of yields established by county average to the reclaimed permit area, tied to the ratio of productivity indexes (established by the University of Illinois for each prime farmland map unit in the county) to the permit area.

Measurement of post-mining productivity can be rrparated into two primary methods : (1) Use of a soil survey, and (2) Actual crop production. (Doll, et al., 1985) endorse the use of the soil survey. Other writers (Smith, 1983; Office of Technology Assessment, 1985; Vories, 1985) endorse the concept of use of the soil survey for productivity determination after further research is done.

Each of the above references, including (Lohse, et al., 1985) discusses the problems inherent with the different methods of measuring, productivity. Al though prime farmlands are classified by the Soil Conservation Service according to soil characteristic criteria rather than vield values, there is concern that individual parameters may or may not be interpreted the same way on disturbed soil as compared to undisturbed soils. Reconstructed soils will probably have entirely different texture, chemistry or structure than unmined soils. Methods of measurement and determining critical values of various soil parameters remain as major issues yet to be established for mined soils. It is hoped research will establish a useable soil survey method for measuring productivity to replace or become part of a crop production measurement system. Specific discussions concerning soil compaction are addressed later in this paper.

Employment of the actual crop production system has advantages; however, there also are several problems or concerns. These include:

(1) Tillage exposes the soil to erosion which increases operator liability to control rill and gully development and to meet effluent limits.
(2) Establishing fair yield targets for comparisons.
(3) Increased monitoring to check for aupmentative management..

(4) Establishing equivalent management practice standards.
(5) Increased amount of time and personnel involved in crop harvesting.

Experience has shown that site specific pre-mining yield is generally not available and that which exists may not be representative of the surrouading area. Reference areas are not always available and may not be adequately representative of the permit area. Monitoring and responsibility for management are additional problems with the reference area concept. SCS-established yields and county-average yields have inherent problems with year to year variability induced by weather and pests, and do not have a mechanism for assessing crop yields from variable quality soils.

As a result of federal court decisions regarding the requirement for actual cropping of reclaimed cropland and current uncertainty in the use of the soil survey and public comment, the Department has adopted the Illinois Agricultural Land Productivity Formula (ALPF) to: (1) determine target yield values, and (2) to measure yields obtained.

THE AGRICULTURAL LANDS PRODUCTIVITY FORMULA

The ALPF was designed and developed by the Illinois Department of Agriculture (IDOA) over a period of approximately five years. The ALPF is a comparison of reclaimed prime farmland crop yields to yields achieved in the county as a whole, based on a ratio of the quality of prime farmland soils in the permit area and the quality of the same soils being cropped in the county as a whole.

The quality of the soils in a permit area is determined by soil map 'unit. Each map unit is assigned a productivity yield value (Fehrenbacher, et al., 1978). Map units for the county are determined from the county soil survey, if completed, or from soil survey information gathered for the Conservation Needs Inventory and summarized (Runge, et al., 1969). Further refinement of the county-wide soil acreage is accomplished by the estimation of the acreage of each soil map unit actually cropped each year. This is done by the respective county Soil & Water Conservation District (SWCD)(Table 1). This establishes a relative amount of soils by mapping unit which are cropped in the county by crop year.

Table 1. County Cropped Acreage File 1984

Soil Mapping Unit	Soil Name	Total Acres	SWCD % Cropped	Total Cropped Acres
2A	Cisne	19,986	95	18,987
3B	Hoyleton	4,785	95	4,546
14B	Ava	7,622	90	6,860
214C3	Ho smer	5,707	85	3,110.
5C3	Blair	11,786	60	7,072
				40,575

Table 2. County Crop Yields by Soil Map Unit 1984

Column A Soil Mapping Unit	Column B County Cropped Acreage	Column C % County in Soil Mapping Unit	Column D* Grain Acres by Soil Mapping Unit	Column E Adjusted High Mgt. Yield	Column F High Mgt. Product-ion Yield	Column G County Yield by Soil Map-ping Unit
2A	18,987	46.8	18,720	115	2,152,800	89
3B	4,546	11.2	4,480	115	515,200	89
14B	6,860	16.9	6,760	97	655,720	75
214C3	3,110	7.7	3,080	79	243,320	61
5C3	7,072	17.4	6,960	81	563,760	63
	40,575	100.0	40,000		4,130,800	

*County Acres in Corn - 12,000 ac. Soybeans - 10,000 Total
(By CRS) Wheat - 10,000 ac. Hay - 8,000 Acres =
1984 County Average Yield Corn - 80 bu/ac Soybeans - 35 bu/ac 40,000
(By CRS) Wheat - 35 bu/ac Hay - 3.0 tons/ac

Weighted High Management Yield $\frac{4{,}130{,}800 \text{ bu}}{40{,}000 \text{ ac}}$ = 103.27 bu/ac

Factor Value = $\frac{80 \text{ bu/ac}}{103.27}$ = .775

Annual county crop yield averages are determined by the Illinois Cooperative Crop Reporting Service (Table 2). Yield averages become available from the Cooperative Crop Reporting Service the spring following the actual crop year. The county cropped acreage by soil map unit is inserted into the equation in Column C as a percentage of the total county cropped acreage. Further refinement of the acreages actually cropped in a given crop year is determined by multiplying the total acreage cropped according to the Crop Reporting Service (CRS) times Column C to establish grain acres by soil mapping unit (Column D).

For uni formity , it is presumed each map unit cropped has an eaual chance of being planted to any one crop; therefore, total cropped acreage has been inserted into the equation at Column B. Also, acreages in minor crops have been eliminated.

Column E represents the High Management Yield, adjusted by map unit, determined from University of Illinois Circular 1156 (Fehrenbacher, et al., 1978).

Column F is mathematically derived by multiplying Column D by Column E to project a high management production yield. High management product ion yields are then totaled (Column F) and divided by total grain acres (Column D) to establish a weighted high management yield for a particular crop year. The actual county crop acreage yield determined by the Crop Reporting Service is divided by weighted high management yield to create the factor value.

County yield by soil mapping unit (Column G) is established by multiplying the factor value by Column E. This gives a yield value by map unit which represents the yield target for a permittee with reclaimed prime farmland of that soil type for that year.

Table 3. Permit Area Target Mine A 1984

Soil Map Unit	Projected Yield	Mapping Unit Acres	% of Permit	Weighted Final Yield
2A	89	100	50	44.5
3B	89	50	25	22.25
14B	75	50	25	18.75
Total		200 ac.	100%	85.5 bu/ac

1984 Required Yield 85.5 bu. Corn

Table 3 provides an example of the formula applied to a hypothetical permit area. Map unit acreages are recorded and calculated in terms of a percentage of the whole permit area. The projected yields are multiplied times these percentages. The cumulative total represents the projected yield for the permit area in a given year.

Crop fields are to be established on the reclaimed ground and must be planted to approved crops. Crops commonly grown on the surrounding mined cropland such as corn, soybeans, hay, wheat or oats are currently approvab le crops. Prime farmland areas must include a minimum of one successful year of corn, and a maximum of one successful year of a hay crop may be used to demonstrate the three-year proof of productivity, if included in an approved crop rotation.

Once field boundaries are established, they till be fixed areas to be individually tested for proof of productivity.

Prime farmland requires productivity testing to commence within a maximum of ten years after topsoil replacement. Successful yields are to be demonstrated within a ten-year period after the first year of successful yields.

As more and more productivity research information is published, the operator and regulatory agencies will probably be able to assess the soils potential for meeting the required productivity by comparing research results to the soil replacement technology used.

SOIL COMPACTION

Soil compaction during the soil replacement process is currently identified as the primary obstacle to restoring productivity. Methods of measuring soil compaction for unmined land and the relationships of the measurements to crop yields have been thoroughly researched. Measurement values and techniques for compaction for reclaimed land are not well understood. Research is underway to develop adequate measuring techniques (Hooks, et al., 1986), as well as compaction alleviation techniques (Ralston, D., 1984). Compaction avoidance or minimization is preferred. Visual observations indicate this can be achieved by bucket-wheel excavators with minimal grading . These machines, however, are not adaptable to all mines. Trucks and scrapers, which are the most common type of soil replacement technology, appear to create a more compact soil. This is a result of the high ground pressure traffic over the soil during replacement. Preliminary results and observations of soil structure

modification by deep tillage equipment is encouraging and promises achievement of fully restored productivity. However, none of the deep tillage equipment being tested will alleviate compaction below 36 inches. Currently the Office of Surface Mining, USDA-Soil Conservation' Service, Illinois Department of Mines & Minerals, and several state universities are working to measure and evaluate the issue of soil compaction.

SUMMARY

Much has been learned concerning restoring mined cropland since the enactment of PL 95-87 in 1977. Testing for productivity restorat'ion by actual crop production is recommended until soil parameter relationships to crop production are fully understood, particularly on the area of soil compactions. Even with the present state of knowledge, successful restoration is being achieved where there are no obvious soil structural problems in reclaimed areas. Additional research is needed on compaction alleviation equipment and the long and short term effects on crop productivity .

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University of Illinois at Urbana-Champaign
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Cooperative Extension Service
Circular 1156

Soil Productivity in Illinois

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INTRODUCTION

The good soils and humid, temperate climate of Illinois are particularly conducive to the production of high yields of corn and soybeans, the state's two major crops. Crop yields in Illinois have increased over a long period of time with the application of improved soil and crop management. There is every reason to believe that yield trends will continue upward with the development of even better crop varieties and the application of improved soil and crop management practices to more and more of the cropland in the state.

It is the purpose of this publication to show the average yields of various grain, forage, and tree crops obtainable on the various soil types in Illinois under basic and high levels of management. Productivity indexes are given for the various soils, and a simplified method of adjusting both yields and productivity indexes for slope and erosion is provided for the two levels of management. In addition, an estimation is made of how average management, as reflected in average state yields, may fit in the scale from a basic to high level of management. Prime agricultural land classes based upon grain-crop productivity indexes at the high level of management are assigned to the various soils.

The impact of improved technology on crop production is reflected in the continuing upward trend of yields obtained by Illinois farmers. Data collected by the Illinois Cooperative Crop Reporting Service (Fig. 1) show that average yields of corn nearly tripled and average yields of wheat more than doubled in the 39 years from 1939 to 1977. Average yields of oats and soybeans increased more than 50 percent during the same period.

Tables of estimated crop yields under basic and high levels of management previously published by the University of Illinois Department of Agronomy were based on the agricultural technology available in the late 1960's. The development and increased use of pesticides, fertilizers, improved crop varieties, narrower rows, more efficient machinery, etc. during the last decade have resulted in a 15-percent increase in average corn yields. Substantial increases have also occurred in average yields of soybeans (10 percent), wheat (15 percent), and oats (10 percent). The yield estimates given in this publication reflect these increases, and are consistent with the agricultural technology available in 1978.

ESTIMATED CROP YIELDS IN ILLINOIS

Estimated yields under basic and high levels of management for the four major grain crops (corn, soybeans, wheat, and oats), hay and pasture, and tree crops in Illinois are shown in Table 2 (pages 10-16). Nearly all of the soils for which yields are given have been correlated in the soil survey of the state. Yields are not given for some crops on soils where these crops are not well adapted, including oats yields on certain soils restricted to southern Illinois (where little oats are grown); oats, wheat, hay, and deciduous and conifer timber yields for the organic soils; and conifer timber yields for the bottomland soils.

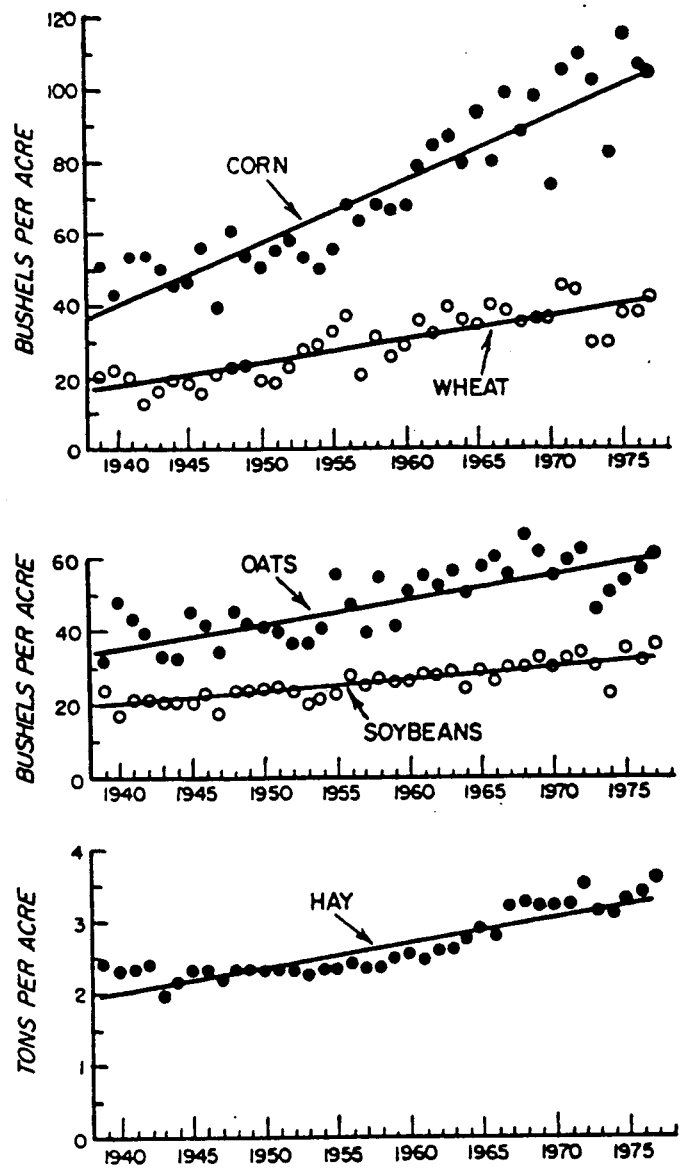

Figure 1. Trends of grain-crop yields in Illinois, 1939-1977. Data from Illinois Cooperative Crop Reporting Service. (X = years since 1939; Corn: Y = 38.4 + 1.77X; Wheat: Y = 16.6 + 0.68X; Oats: Y = 35.7 + 0.67X; Soybeans: Y = 19.5 + 0.37X; Hay: Y = 2.0 + 0.035X)

It is often desirable to compare the yields of different crops. Corn is a useful standard for these comparisons because it is both the principal and the highest yielding grain crop grown in Illinois. Based on the estimated yields given in Table 2, the yields of small grains, soy-

beans, and forage crops can be converted to their approximate equivalent in bushels of corn per acre by using the following factors:

Soybeans (bu. per acre) X 3 = Corn (bu. per acre)
Wheat (bu. per acre) X 2.5 = Corn (bu. per acre)
Oats (bu. per acre) X 1.7 = Corn (bu. per acre)
Hay (tons per acre] X 25 = Corn (bu. per acre)

These conversion factors are merely "rules of thumb," and do not account for differences in adaptation of the crops to specific soil conditions.

Basic and High levels of Management

Crop yields produced by any soil under a given climate depend upon the technological inputs used and the capacity of the soil and crop to respond. Management is the selection and application of crop-production technology. Continuing increases in average crop yields result from improved management.

Because the impact of management on crop yields is so great, the level of management must be defined in order for measures of soil productivity to have any meaning. Table 2 shows estimated yields and productivity indexes under both basic and high levels of management. Some representative characteristics of the two management levels are given below.

Management factor	Basic management	High management
Drainage	Partial — more needed	Optimum for soil conditions
Soil pH	6.0 to 6.5	6.0 for grain; 6.5 for alfalfa and clover
Available phosphorus (P-1 test)	10-15 pounds per acre	40-50 pounds per acre
Available potassium	150-200 pounds per acre	240+ pounds per acre
Nitrogen rates per year for corn (or legume equivalent)	50-75 pounds per acre	125-175 pounds per acre
Plant population (corn)	12,000-14,000 plants per acre	20,000-24,000 plants per acre
Crop residues	Returned to sail	Returned to soil
Weed and insect control	Inadequate — often untimely	Adequate and timely
Tillage, planting, and harvesting operations	Often untimely - equipment poorlv adiusted	Timely and fitted to soil and crop conditions
Soil erosion	Exceeds sail-loss tolerances	Within soil-loss tolerances

The basic level of management includes the minimum inputs considered necessary for crop production to be feasible. Some drainage, for example, is required before crops can be grown on naturally poorly drained soils. Limestone must be applied to highly acid soils. Nitrogen from fertilizers or legumes is essential for corn production. Requirements like these are met by basic management, but the inputs are far below those required for optimum production.

The high level of management includes inputs that are near those required for maximum profit with current technology. Estimated yields under a high level of management are attained and often surpassed by top farmers over a period of years.

Average Yields and Average Management

Average annual yield estimates of grain and hay crops in Illinois are available from the Illinois Cooperative Crop Reporting Service, Statistical Reporting Service, Springfield, Illinois. Average yields are given for the state, crop reporting districts, and counties. (The state average yields of selected crops from 1939 to 1977 are shown in Fig. 1.)

Average soil and crop management is difficult to define for a diversified area such as the State of Illinois. One might consider an average of the yields under basic and high management as a reflection of more or less average management. It is not known, however, how this "average" management might compare with the actual average management under which crops are produced in the state.

An approximation of how average management in Illinois compares with the basic and high levels of management was arrived at by comparing the state average yields given by the Illinois Cooperative Crop Reporting Service in recent years with the weighted state average yield estimates of each crop given in this publication. The weighted state average yields at the two management levels were calculated by weighting the yields for most of the soils in Illinois given in Table 2 by the percentage that each soil occupies in the state.

The percentages of each soil in the state were taken from the Conservation Needs Inventory, as summarized in Illinois Agricultural Experiment Station Bulletin 735. Soils occupying less than 0.1 percent of the state and steep soils, which are poorly suited to corn production, were excluded in these calculations. About 11 percent of the area of the state was excluded for corn, soybeans, wheat, and hay, and about 29 percent was excluded for oats.

The state weighted average yields of each crop at the basic and high management levels were then plotted against the weighted state average productivity indexes

of Illinois soils (Fig. 2). The weighted state average productivity indexes at the two management levels were calculated in the same manner as the weighted state average yields. The weighted state average soil productivity index of Illinois is 80 under a basic management level and 130 under a high management level (Fig. 2). (See pages 3-5 for a detailed discussion of productivity indexes.)

Average state yields for the last three, five, and ten years reported by the Crop Reporting Service for each crop were then calculated and plotted on the yield versus productivity index trend lines between basic and high management levels (Fig. 2). A straight-line relationship of yields to productivity indexes was assumed between the basic and high management levels.

State average corn, soybean, and wheat yields given by the Illinois Crop Reporting Service correspond to productivity indexes of about 95 to 105. Average hay yields for the state correspond to a productivity index of about 87, and average oat yields to a productivity index of about 82. Although these calculations do not define average management, they do indicate that management of oats and hay production in the state may be near the basic management level, and that management of corn, soybeans, and wheat is somewhat less than halfway between the basic and high management levels. There is also a strong indication' that state average yields can be increased significantly by practicing better management on more of the cropland in Illinois.

Forage Yields of Illinois Soils

In addition to grain crop yields, Table 2 (pages 10-16) gives estimated yields of mixed grass-legume hay and animal days of mixed pasture. Yields are given for mixtures rather than for individual grasses and legumes. Mixtures with alfalfa tend to produce about the same yields as alfalfa alone, and are better suited for grazing and erosion control. Pasture yields are based on the assumption that one ton of hay or its pasture equivalr- will support one cow for 50 days. Because fewer data are available, the estimated forage yields in Table 2 are less reliable than the estimated yields of grain crops.

Timber Yields of Illinois Soils

The annual timber growth estimates shown in Table 2 are based on the experience and judgment of professional foresters and soil scientists. Timber yields are not given for soils with a grain-crop productivity index of 85 or higher under the basic level of management because these soils are generally used for the production of grain and forage crops.

Crop Adaptation to Various Soils

Crops vary in their adaptation to various soils and climatic conditions. Oats, for example, is a cool-season crop that usually yields poorly in the relatively warm climate of southern Illinois. Corn and soybeans are better adapted than wheat and oats to naturally poorly drained soils. Forage crops, such as alfalfa, clovers, bromegrass, and orchardgrass, are better suited than corn and soybeans to well-drained, steep, or easily eroded soils.

Tree species also differ in their adaptation to specific soil conditions. Most conifers, such as pine, grow best on well-drained or even excessively drained soils but are not suited to wet, poorly drained sites. Some deciduous trees, such as upland oak, also do well on well-drained soils. Poorly drained bottomland soils will support water-loving trees such as cottonwood, silver maple, and ash.

Adaptation of a crop or timber group to a particular soil is reflected in the estimated yields. The yields of wheat and oats, for example, are not given for the organic soils because these crops are not well suited to the extreme wetness, low spring temperatures, and frost-heaving characteristics of organic soils. A range in timber growth is given for deciduous species on bottomland soils to indicate the rapid growth of trees such as cottonwood as opposed to slower growing trees such as the oaks. Conifer growth rates are not given for the bottomland soils because these trees are not generally well adapted to most of the bottomland soils.

PRODUCTIVITY INDEXES OF ILLINOIS SOILS

Soil productivity is strongly influenced by the capacity of a soil to supply the nutrient and soil-stored water needs of a growing crop in a given climate. Productivity also depends in part upon the adaptation of a particular crop to specific growing conditions and level of management. It is often necessary to compare soils that differ in suitability for particular crops or in response to management. Estimated crop yields are not suitable for these comparisons because yields fluctuate from year to year, and absolute yields mean little when comparing different crops. Productivity indexes provide a single scale on which soils may be rated according to their suitability for several major crops under specified levels of management.

Calculation of Productivity Indexes for Grain Crops

Productivity indexes for grain crops express the estimated yields of the major grain crops grown in Illinois as a single percentage of the average yields obtained

under basic management from several of the more productive soils in the state. This group of soils is composed of the Muscatine, Ipava, Sable, Lisbon, Drummer, Flanagan, Littleton, Elbum, and Joy soils. Under basic management, the average yields or base yields used to calculate productivity indexes for this group of soils are as follows: corn, 103 bushels; soybeans, 33 bushels; wheat, 34 bushels; and oats, 66 bushels per acre.

For example, the productivity index for Fayette silt loam under a high level of management is calculated as follows. (All productivity indexes are rounded to the nearest multiple of 5.)

Line number		Fayefte silt loam (No. 280) (Norhern and Central Illinois)			
		Corn	Soy-beans	Wheat	oats
1	Estimated yield under high level of management, bushelsperacre	129	39	53	73
2	Base yield (index = 100).	103	33	34	66
3	Relative yield (line 1 ÷ line 2 x 100)	125.2	118.2	155.9	110.6
4	Fraction of total grain crop acreage	.55	.35	.06	.04
5	Weighted relative yield (line 3 X line 4). . .	68.9	41.4	9.4	4.4
6	Productivity index (sum of line 5 data)	124.1			
	Rounded to the nearest multiple of 5 = 125				

Wheat and oats are relatively minor crops in northern and central Illinois, where Fayette soils occur. According to the Illinois Cooperative Crop Reporting Service, corn is grown on 55 percent, soybeans on 35 percent, wheat on 6 percent, and oats on 4 percent of the total grain crop acreage in northern and central Illinois. These percentages or fractions are used to weight the relative yields of the four grain crops (line 4 above). In southern Illinois, the relative acreages are as follows: corn, 35 percent; soybeans, 45 percent; wheat, 20 percent; and oats, 0 percent (virtually no oats are grown in southem Illinois). As used here, the term "southern Illinois" means the 36 southernmost counties of the state, bounded on the north by Madison, Bond, Fayette, Effingham, Cumberland, and Clark counties.

Another example of calculating productivity indexe is given below for Ava silt loam.

line number		Ava silt loam (No. 14) (Southern Illinois)			
		Corn	Soy-beans	Wheat	Oats
1	Estimated yield under high level of management, bushels per acre	98	33	48	0
2	Base yield (index = 100)..	103	33	34	66
3	Relative yield (line 1 ÷ line 2 x 100)	95.1	100.0	141.2	0
4	Fraction of total grain crop acreage	.35	.45	.20	0
5	Weighted relative yield [line 3 X line 41. . . .	33.3	45.0	28.2	0
6	Productivity index (sum of line 5 data)	106.5			
	Rounded to the nearest multiple of 5 = 105				

Productivity indexes have no units because they are relative rather than absolute measures of productive capacity. A productivity index of 150 is not the same as 150 bushels per acre of corn. The relationship between high-management productivity indexes and the yields of each of the major grain crops (Fig. 3) does show, however, that the average yield corresponds to a particular productivity index. For example, a soil that has a productivity index of 160 should produce approximately 163 bushels of corn, 94 bushels of oats, 67 bushels of wheat, and 52 bushels of soybeans per acre under a high level of management.

The capacity of a soil to respond to improved management is indicated by the difference between productivity indexes for basic and high levels of management. Flanagan silt loam (No. 154) and Drummer silty clay loam (No. 152) both have a basic level productivity index of 100 (see Table 2, page 11), but the differences between high and basic indexes are 60 and 50, respectively. Because thick, permeable, somewhat poorly drained Flanagan soils are less likely to have ponded water and slow

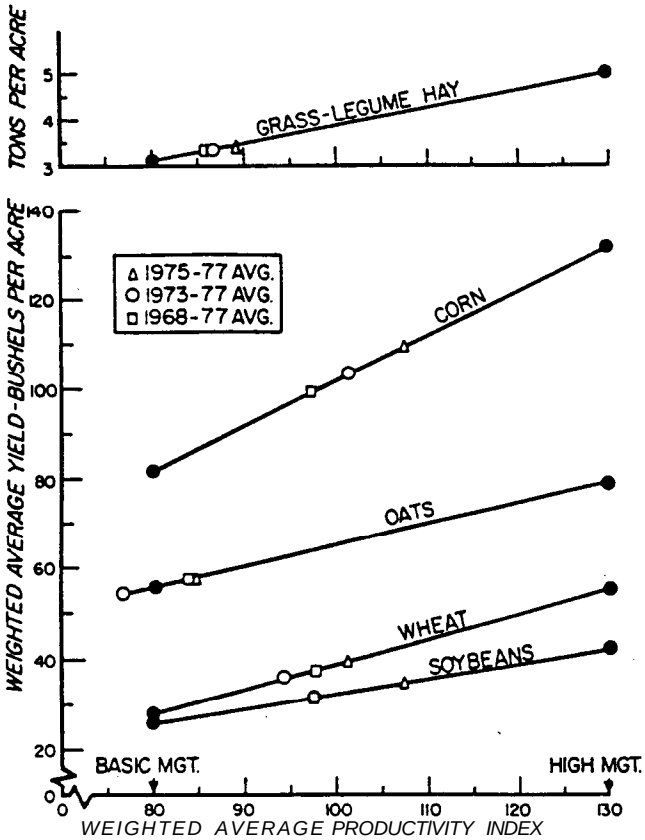

Figure 2. Comparison between Cooperative Crop Reporting Service state averoge yields and weighted average yields and productivity indexes under high and basic levels of management.

soil warming in the spring than the associated poorly drained Drummer soils, they are somewhat better able to respond to improved management practices.

Inputs required to achieve a similar response to management may differ widely for various soils. For example, both Tama silt loam (No. 36) and Ava silt loam (No. 14) have a difference of 50 units between basic- and high-management productivity indexes. Management inputs required to achieve that difference, however, are greater on the Ava soil, which has a root-restricting siltpan in the lower subsoil, than on the permeable Tama soil, which has no root-restricting layer.

Comparison Between Current and Previous Productivity Indexes for Grain Crops

Productivity indexes for many of the soils listed in Table 2 are the same as those published by the University of Illinois Department of Agronomy in 1970. Although crop yields have increased since that time, the relative differences in yields between soils have changed very little. Productivity indexes, which indicate relative differences between soils, have remained essentially the same, although indexes for a few soils have been changed to reflect new or more accurate knowledge of crop yields and responses to management.

Because many users in Illinois are familiar with the productivity indexes associated with various soils in the state, it seemed desirable to keep the productivity indexes essentially the same as those given in 1970, although crop yields have increased. For this reason, the base yields used in this publication are 15 percent higher for corn and wheat and 10 percent higher for soybeans, oats, and hay than the base yields published in Illinois Cooperative Extension Circular 1016, "Productivity of Illinois Soils."

The percentage increases in the base yields are the same as the increases in the state average yield of each of the four major grain crops and hay since 1968. The base yields used in Circular 1016 were obtained from the RL (residue and limestone) plots on representative Illinois agronomy fields. Since these treatments were discontinued after 1967 yields are no longer available.

Productivity Indexes for Forage Crops

Productivity indexes are not given for forage crops. Forage productivity indexes, calculated in a manner comparable to that for grain crops (using 3.8 tons per acre as a base yield) are similar to the grain-crops productivity indexes (Fig. 4). Since the two indexes are parallel and express nearly the same relationships between soils, the grain-crops productivity index can be used for comparing the productivities of various soils for forage crops.

ADJUSTMENTS IN CROP YIELDS AND PRODUCTIVITY INDEXES

It is necessary to make adjustments in crop yield estimates and productivity indexes for conditions other than those used in Table 2 (0- to 2-percent slopes, uneroded). Grain crop yields, for example, decrease as slope increases and erosion becomes more severe. Some adjustments, such as for flood damage, may be extremely variable and require local knowledge for a reasonable assessment of the situation.

Adjustments for Increasing Slope and Erosion

The yield estimates and productivity indexes given in Table 2 are for 0- to 2-percent slopes and uneroded conditions. It should be emphasized that relatively few Illinois soils occur on slopes that are not partially within the 0- to 2-percent slope class. The term "uneroded" is meant to include a range from no erosion to slight erosion. Since yields were estimated and productivity

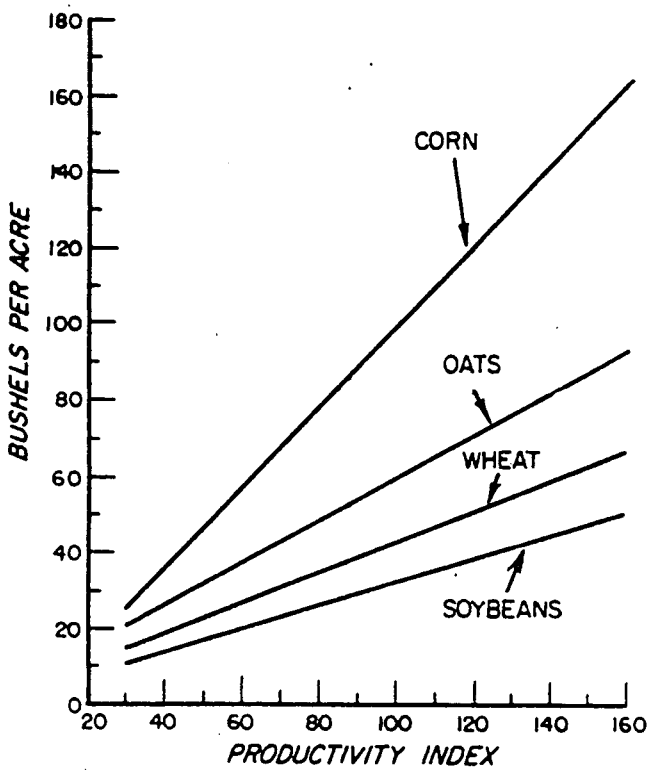

Figure 3. Relationship between yields and productivity indexes under high level of management. (Corn Yield = (1.06) PI − 6.28; Oats Yield = (0.565) PI + 3.38; Wheat Yield = (0.400) PI + 2.97; Soybeans Yield = (0.312) PI + 2.01)

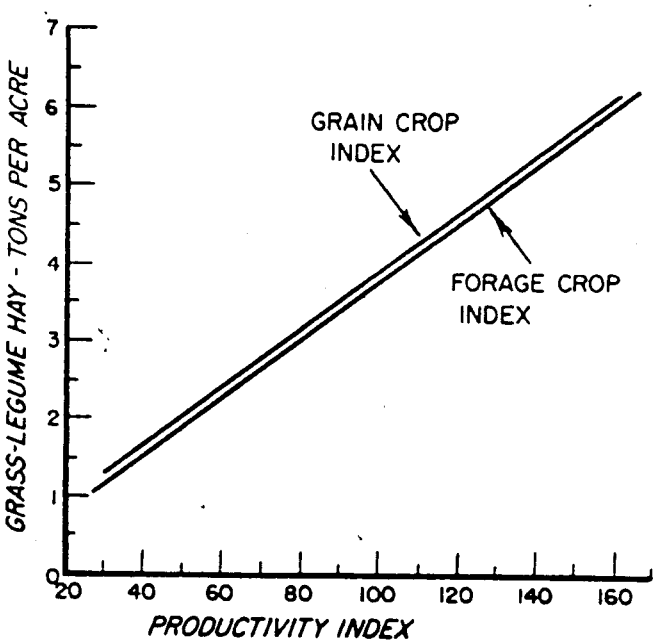

Figure 4. Relationship between hay yields and grain-crop and forage-crop productivity indexes. (Grain-Crop Index (hay, tons per acre) = (0.0376) grain PI + 0.156; Forage-Crop Index (hay, tons per acre) = (0.0381) forage PI − 0.0032)

indexes were calculated for these conditions on all soils, however, adjustments for slope and erosion are always reductions in the values given in Table 2. The range in slope gradients for all soils in the state are given in the alphabetical index to Illinois soils in the back of this publication (pages 17-21).

The two erosion classes for which adjustments are suggested here are *moderate erosion* and *severe erosion*. Moderate erosion is defined as significant erosion. Subsoil is evident in the plow layer in much of the moderately eroded areas that have been freshly plowed. Enough subsoil has been mixed with the surface soil to change the behavior of the plow layer from that occurring in uneroded or slightly eroded areas. Severe erosion is defined as extreme erosion, a condition in which all or nearly all of the surface soil (or A horizon) and probably some of the subsoil has been lost. Management problems are usually severe, depending upon the nature of the exposed subsoil.

Table 1 shows percentage adjustments for common slope groups and erosion conditions. Adjustments for steeper slopes and greater erosion are given as percentages of yields and productivity indexes for the base conditions (0- to 2-percent slopes, uneroded) under high and basic levels of management.

On sloping soils that are subject to erosion, greater reductions for slope and erosion are made on those soils that have unfavorable subsoils for root growth. Unfavorable subsoils or other shallow subsurface layers include those with high clay content, poor structure, high gravel content, dense pans (fragipan horizons), high sodium content, and massive bedrock. The sloping soils with unfavorable subsoils that are subject to erosion are indicated in Table 2 by footnote e.

The adjustment percentages given in Table 1 for various slope groups and erosion conditions with favorable or unfavorable subsoils under high and basic levels of management are plotted in Fig. 5. Fig. 5 can be used to obtain the percentage adjustment in yields and productivity indexes on all soils for any slope group and erosion combination.

For example, to calculate the grain yields and productivity index under a high level of management for soil type No. 36, Tama silt loam, 7- to 12-percent slopes, severely eroded, obtain the yields for Tama given in Table 2 for 0- to 2-percent slopes, uneroded conditions: 155 for corn, 46 for soybeans, 62 for wheat, and 89 bushels per acre for oats. The productivity index is 150. Place the midpoint of the 7- to 12-percent slope group, 9½ percent, on the horizontal axis of Fig. 5 (high management) and follow straight down to the curved line for severe erosion and favorable subsoil; then follow horizontally to the left and read on the vertical axis the

Table 1. Percentage Adjustments in Yields Under High and Basic Levels of Management for Common Slope Groups and Various Erosion Conditions

Slope	High management, favorable subsoil			High management, unfavorable subsoil			Basic management, favorable subsoil			Boric management, unfavorable subsoil		
	Un-eroded	Moderate erosion	Severe erosion	Un-eroded	Moderate erosion	Severe erosion	Un-eroded	Moderate erosion	Severe erosion	Un-eroded	Moderate erosion	Severe erosion
(percent)	(percent)			(percent)			(percent)			(percent)		
0-2	100	97	90	100	95	80	100	95	85	100	90	75
2-5	99	96	89	99	94	79	98	93	83	98	88	73
5-10	97	94	97	96	91	76	95	90	85	94	84	69
10-15	93	90	83	91	86	71	90	85	75	88	78	63
15-20	97	84	77	85	80	65	a4	79	69	82	72	57
20-25	80	77	70	78	73	58	77	72	62	74	64	49
25-30	71	68	61	69	64	49	68	63	53	65	55	40
30-35	60	57	50	58	53	38	57	52	42	54	44	29
35-40	52	49	42	50	45	30	49	44	34	46	36	21
45-	48	45	38	46	41	26	45	40	30	42	32	17

percentage by which the base yields and productivity index in Table 2 should be multiplied to make the adjustment. In this example, the yields and productivity index in Table 2 should be multiplied by.86 percent to make the adjustment. The yields and productivity index for Tama silt loam, 7- to 12-percent slopes, severely eroded, are 133 bushels per acre for corn, 40 for soybeans, 53 for wheat, and 77 for oats, and the grain-crop productivity index is 129 (130 when rounded to the nearest multiple of 5).

The curves in Fig. 5 include adjustments for slopes to 48 percent. Yields of the grain crops are seldom given for slopes greater than about 15 to 20 percent because of the problems of controlling erosion and othenvise obtaining good yields on the steeper slopes. The portion of the curves from about 20- to about 45 percent slope is useful mainly for adjusting productivity indexes on steep land for land valuation purposes. The shape of the curves indicates that yields and productivity indexes decrease slowly on gentle slopes up to about 6- to 8-percent slope, decrease sharply to about 35-percent slope, and then begin to level off with little change beyond about 40-percent slope. In most cases, it is likely that slopes much greater than 45 percent do not affect productivity indexes much differently from those slopes near 45 percent. For this reason, it is suggested that the percentage adjustments in Fig. 5 for 45 percent slopes be used for all slope groups having a midpoint (average slope) greater than 45 percent.

Adjustment for Flooding

Estimated yields and productivity indexes given in Table 2 for bottomland soils apply to soils that are protected from flooding or a prolonged high water table during the cropping season because of high water in stream valleys. Soils that are subject to flooding are less productive than soils that are protected by levees, etc. The frequency and severity of flooding is often governed by landscape characteristics and management of the watershed in which a soil occurs. For this reason, factors used to adjust productivity indexes for flooding must be based upon knowledge of the characteristics and history of the specific site. Wide variation in the flood hazard, sometimes within short distances in a given valley, require that each situation be assessed locally.

If the history of flooding in a valley is known to have caused three years of essentially total crop failures out of ten years, for example, the estimated yields and productivity indexes of the bottomland soils could be reduced to 70 percent of those given in Table 2. Estimated crop yields and productivity indexes of upland soils subject to crop damage from ponding have been reduced accordingly in Table 2.

Adjustment for Soil Complexes and Soil Associations

A soil complex consists of two or more soils occurring together in a pattern that is too intricate for the individual soils to be delineated on the soil maps at the scale being used. Yield estimates and productivity indexes of a soil-complex area is an average of the yields and indexes of the component soils. For example, Huey silt loam (No. a high-sodium soil, often occurs within some areas of Cisne silt loam (No. 2) in south central Illinois. These areas are delineated as a Cisne-I-Iuey complex (No. 991) when the two soils cannot be separated at the scale used in mapping. The productivity index of the complex under a high management level when the two soils are present in equal amounts is 95,

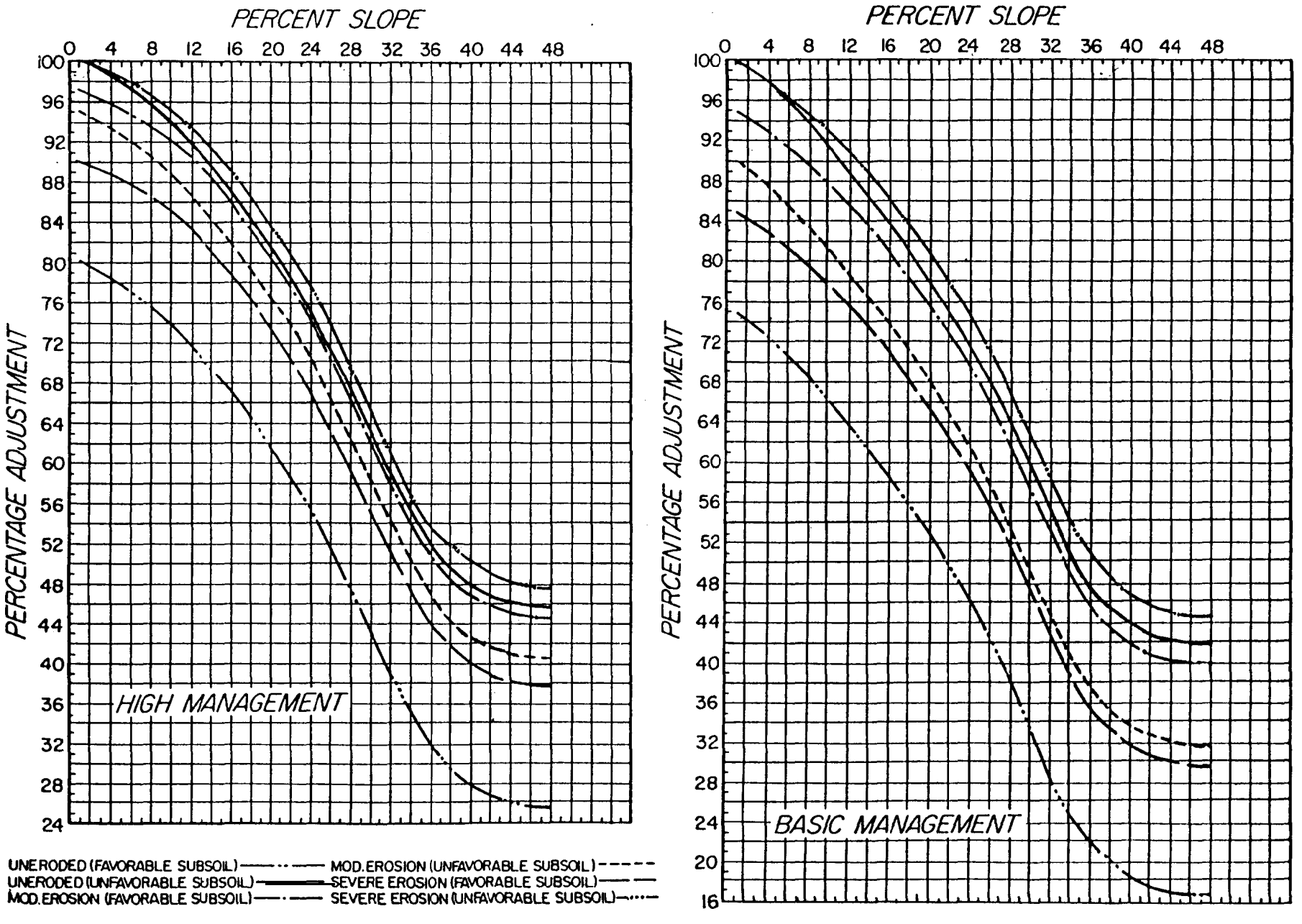

Figure 5. Percentage adjustments in yields and productivity indexes for various slope groups and erosion conditions with favorable and unfavorable subsoils under high and basic levels of management.

the average of the productivity indexes of Cisne (PI = 115) and Huey (PI = 75) soils. Weighted productivity indexes can be calculated if the percentage of each soil in the complex is known.

Soil associations are similar to soil complexes in many respects, but are usually used on general rather than on detailed soil maps. Like soil complexes, soil associations are geographic mixtures of two or more soils. When the percentages of the various soils are known, yield estimates and productivity indexes of soil associations are calculated in the same manner as for soil complexes.

PRIME AGRICULTURAL LAND CLASSES

As mentioned earlier, prime agricultural land classes based on grain-crop productivity indexes under the high level of management on 0- to 2-percent slopes, uncroded, were assigned to the various soils. These prime land classes are designated A, B, and C, and are shown in the next-to-last column in Table 2. Soils that do not have a land-class designation in this'column have high-management productivity indexes below the minimum required for class C (PI = 105). Some of the soils not classed as prime agricultural land can be used for grain production, but others are best suited for hay, pasture, woodland, wildlife, or recreation.

The terms "prime agricultural land" and "prime farmland" have different meanings to different people. We have chosen to define prime agricultural land classes on the basis of the grain-crop productivity index at the high level of management. These indexes, which are based upon the grain-crop producing capacity of the soils, integrate all of the factors -crops, soils, and climate — involved in grain production at the high level of management under Illinois conditions.

The three prime agricultural land classes are actually three grades or subdivisions of prime agricultural land, and are defined as having high-level-of-management grain-crop productivity indexes of 145 to 160 for Class A, 125 to 140 for Class B, and 105 to 120 for Class C. These three grades of prime agricultural land have also been designated as Class A (excellent), Class B (very good), and Class C (good).

The minimum productivity index of 105 required for Class C prime agricultural land in the system used here corresponds fairly well with the cutoff point of prime farmland as defined by the USDA, Soil Conservation Service. A few Illinois soils with production capacities near the minimum required for Class C may be classified as prime agricultural land or prime farmland in one system and not in the other. The USDA system is a national system, and makes no distinction in soil quality within the broad class of prime farmland.

It should be noted that the prime agricultural land class of any uneroded soil in Illinois on slopes less than about 5 percent will not change from that given in Table 2, which lists the land class for 0- to 2-percent slopes, uneroded. On soils that have a wide slope range or are eroded, however, that portion of the soil having greater slope and erosion will tend to drop to a lower land class or perhaps entirely out of prime agricultural land. Generally speaking, soils having slopes greater than about 8 to 10 percent are not considered prime agricultural land or prime farmland in Illinois because of the erosion hazard and other difficulties in maintaining high production on steeper slopes.

Table 2. Productivity of Illinois Soils, Uneroded Conditions, 0- to 2-Percent Slopes

Soil type		Estimated crop yields per acre[a]												Timber yield per acre[b]		Productivity indexes			Prime agr. land	Soil type
		Basic level of management						High level of management								Grain crops				
No.	Name	Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Deciduous	Conifer	Basic mgt.	High mgt.	Difference	class[d]	No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
2	Cisne silt loam	63	20	23	0	2.3	115	115	35	52	0	4.5	225	200	1.0	60	115	55	C	2
3	Hoyleton silt loam	63	19	23	0	2.4	120	116	34	53	0	4.7	235	250	1.3	60	115	55	C	3
4	Richview silt loam	62	19	23	0	2.4	120	110	33	50	0	4.6	230	300	1.6	60	110	50	C	4
5	Blair silt loam	49	17	22	0	2.2	110	95	33	44	0	3.7	185	200	1.2	55	105	50	C	5
6	Fishhook silt loam[e]	41	11	17	26	1.7	85	76	22	24	46	2.6	130	125	.8	40	70	30		6
7	Atlas silt loam[e]	29	11	13	22	1.2	60	57	18	21	48	2.4	120	100	.6	30	55	25		7
8	Hickory loam	36	13	13	23	1.4	70	80	26	29	55	3.0	150	225	1.2	35	80	45		8
12	Wynoose silt loam	51	18	18	0	2.1	105	96	33	46	0	3.9	195	175	.9	50	105	55	C	12
13	Bluford silt loam	57	18	21	0	2.2	110	103	33	49	0	4.1	205	225	1.2	55	110	55	C	13
14	Ava silt loam[e]	49	17	22	0	2.2	110	98	33	48	0	4.3	215	275	1.5	55	105	50	C	14
15	Parke silt loam	63	19	23	0	2.3	115	112	35	53	0	4.5	225	300	1.5	60	115	55	C	15
16	Rushville silt loam	64	20	23	39	2.2	110	114	36	47	64	4.2	210	250	1.1	60	110	50	C	16
17	Keomah silt loam	82	24	28	53	3.0	150	129	39	52	72	5.1	255	300	1.4	75	125	50	B	17
18	Clinton silt loam	79	23	26	51	3.2	160	129	39	53	73	5.2	260	350	1.7	75	125	50	B	18
19	Sylvan silt loam	63	19	22	37	2.4	120	112	35	53	66	5.0	250	325	1.6	60	110	50	C	19
21	Pecatonica silt loam	75	22	25	46	2.8	140	118	35	49	65	4.7	235	350	1.7	70	115	45	C	21
22	Westville silt loam	66	22	25	43	2.5	125	114	35	47	64	4.2	210	325	1.5	65	110	45	C	22
23	Blount silt loam	60	20	22	36	2.3	115	106	35	48	64	4.3	215	225	1.2	60	105	45	C	23
24	Dodge silt loam	76	24	26	47	3.1	155	126	41	54	70	5.1	255	350	1.7	75	125	50	B	24
25	Hennepin loam[e]	30	12	13	22	1.4	70	63	19	22	37	2.5	125	175	.9	30	60	30		25
26	Wagner silt loam	60	20	20	32	2.0	100	106	35	49	65	3.9	195	200	1.1	60	105	45	C	26
27	Miami silt loam	70	22	24	43	2.8	140	121	40	51	68	4.8	240	300	1.4	70	120	50	C	27
28	Jules silt loam	74	22	24	42	3.0	150	129	41	53	73	5.2	260	350-500	0	70	125	55	B	28
29	Dubuque silt loam	43	15	20	32	2.0	100	83	25	36	53	3.4	170	250	1.1	45	80	35		29
30	Hamburg silt	35	13	13	23	1.5	75	67	22	32	45	3.2	160	125	.5	35	65	30		30
34	Tallula silt loam	75	21	24	42	2.8	140	121	40	52	72	4.8	240	250	1.1	70	120	50	C	34
35	Bold silt loam	43	13	17	30	1.9	95	74	22	34	45	3.3	165	175	.7	40	70	30		35
36	Tama silt loam	100	32	36	66	4.0	200	155	46	62	89	5.9	295			100	150	50	A	36
37	Worthen silt loam	99	32	36	65	3.9	195	151	46	62	88	5.9	295			95	145	50	A	37
40	Dodgeville silt loam	66	22	25	43	2.5	125	98	36	48	66	4.1	205	275	1.2	65	105	40	C	40
41	Muscatine silt loam	104	33	34	68	4.0	200	167	51	64	95	6.2	310			100	160	60	A	41
42	Papineau fine sandy loam	56	18	18	31	2.1	105	98	31	40	57	3.7	185	200	1.3	55	95	40		42
43	Ipava silt loam	103	33	35	67	4.0	200	163	52	66	91	6.1	305			100	160	60	A	43
45	Denny silt loam	70	23	23	39	2.3	115	113	37	46	62	4.0	200	225	1.0	70	110	40	C	45
46	Herrick silt loam	89	30	33	64	3.4	170	141	45	61	78	5.5	275			90	140	50	B	46
47	Virden silt loam	92	31	30	63	3.3	165	144	46	60	75	5.3	265			90	140	50	B	47
48	Ebbert silt loam	83	28	29	0	3.0	150	130	42	54	0	5.0	250			85	135	50	B	48
49	Watseka loamy fine sand	59	18	20	34	2.1	105	92	31	43	62	3.7	185	125	1.2	55	95	40		49
50	Virden silty clay loam	91	30	30	61	3.2	160	138	46	57	72	5.2	260			90	135	45	B	50
53	Bloomfield fine sand	49	13	15	28	1.7	85	79	31	41	51	3.2	160	100	1.2	45	85	40		53
54	Plainfield sand	37	11	13	24	1.4	70	57	20	28	40	2.4	120	75	1.0	35	60	25		54
55	Sidell silt loam	89	25	29	57	3.4	170	138	45	58	80	5.5	275			85	135	50	B	55
56	Dana silt loam	92	28	31	64	3.4	170	143	45	60	85	5.5	275			90	140	50	B	56
57	Montmorenci silt loam	78	24	26	47	3.1	155	126	42	54	77	5.1	255	350	1.6	75	125	50	B	57
59	Lisbon silt loam	102	32	34	66	3.8	190	155	51	63	92	5.9	295			100	155	55	A	59
60	LaRose silt loam	80	23	25	50	3.2	160	123	41	52	74	4.8	240	325	1.5	75	125	50	B	60
61	Atterberry silt loam	94	30	32	63	3.5	175	149	44	60	85	5.6	280			90	140	50	B	61
62	Herbert silt loam	87	28	30	59	3.3	165	140	44	56	81	5.4	270			85	135	50	B	62
67	Harpster silty clay loam	89	26	26	57	3.0	150	136	44	52	74	5.0	250			85	135	50	B	67
68	Sable silty clay loam	103	34	32	64	3.5	175	156	51	61	85	5.6	280			100	155	55	A	68
69	Milford silty clay loam	91	29	28	53	3.1	155	131	48	56	81	5.2	260			90	135	45	B	69
70	Beaucoup silty clay loam	94	30	30	57	3.3	165	138	46	55	75	5.1	255			90	135	45	B	70
71	Darwin silty clay	64	22	20	33	2.0	100	99	35	47	63	3.5	175	350-500	0	65	100	35		71
72	Sharon silt loam	71	24	26	41	2.9	145	132	40	55	72	5.0	250	450-600	0	70	125	55	B	72
73	Ross loam	94	31	32	65	3.5	175	145	46	60	80	5.5	275			95	140	45	B	73
74	Radford silt loam	95	32	32	65	3.6	180	143	46	61	84	5.6	280			95	140	45	B	74
75	Drury silt loam	89	26	29	51	3.4	170	126	40	57	77	5.0	250			85	125	40	B	75
76	Otter silt loam	92	31	32	64	3.4	170	143	46	49	69	4.7	235			90	140	50	B	76
77	Huntsville silt loam	100	33	36	68	4.0	200	152	48	64	86	5.8	290			100	150	50	A	77
78	Arenzville silt loam	89	28	30	62	3.4	170	138	42	56	79	5.4	270			85	135	50	B	78
81	Littleton silt loam	103	33	35	66	3.8	190	159	50	63	90	6.1	305			100	155	55	A	81
82	Millington loam	86	26	24	46	2.9	145	133	41	52	68	4.6	230	425-575	0	80	130	50	B	82
83	Wabash silty clay	74	24	22	36	2.3	115	106	35	43	55	3.7	185	375-525	0	70	105	35	C	83
84	Okaw silt loam	47	17	16	24	1.5	75	84	28	41	54	3.1	155	175	.9	45	85	40		84
85	Jacob clay	36	13	13	23	1.1	55	66	26	29	37	2.3	115	350-450	0	35	70	35		85

(Footnotes on page 16)

Table 2. — continued

Soil type No.	Name	Estimated crop yields per acre[a] Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b] Deciduous	Conifer	Productivity indexes Grain crops Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
87	Dickinson sandy loam	63	19	22	41	2.3	115	99	37	45	77	3.9	195	150	1.5	60	105	45	C	87
88	Sparta loamy sand	53	17	18	31	1.9	95	85	29	37	53	3.3	165	100	1.3	50	85	35		88
89	Maumee fine sandy loam	62	19	21	33	2.1	105	103	37	41	58	3.7	185	150	1.1	60	105	45	C	89
91	Swygert silty clay loam[e]	67	22	24	42	2.5	125	114	39	51	73	4.5	225	250	1.3	65	115	50	C	91
92	Sarpy sand	46	13	15	28	1.7	85	71	26	34	47	3.0	150	225-375	0	45	75	30		92
93	Rodman gravelly loam[e]	30	11	11	20	1.3	65	54	22	24	33	2.4	120	50	.5	30	60	30		93
97	Houghton peat	80	23	0	0	0	125	120	37	0	0	0	195	0	0	75	115	40	C	97
98	Ade loamy fine sand	59	18	21	36	2.1	105	91	31	41	57	3.7	185	125	1.4	55	90	35		98
100	Palms muck	78	22	0	0	0	115	115	36	0	0	0	180	0	0	70	110	40	C	100
102	LaHogue loam	85	26	31	58	3.3	165	129	43	56	80	5.2	260	250	1.3	80	130	50	B	102
103	Houghton muck	86	28	0	0	0	155	129	44	0	0	0	220	0	0	85	125	40	B	103
104	Virgil silt loam	95	30	31	64	3.5	175	148	45	60	84	5.6	280			90	140	50	B	104
105	Batavia silt loam	89	28	29	62	3.4	170	138	43	55	81	5.4	270			85	135	50	B	105
107	Sawmill silty clay loam	100	34	33	63	3.9	195	147	47	54	76	5.5	275			100	140	40	B	107
108	Bonnie silt loam	60	22	22	32	2.1	105	113	37	46	62	4.0	200	400-550	0	60	110	50	C	108
109	Racoon silt loam	61	21	22	0	2.2	110	108	35	48	0	4.1	205	200	1.1	60	115	55	C	109
112	Cowden silt loam	72	23	26	0	2.6	130	120	37	53	0	4.8	240	225	1.1	70	120	50	C	112
113	Oconee silt loam	69	22	25	0	2.9	145	120	36	54	0	5.0	250	300	1.4	70	120	50	C	113
116	Whitson silt loam	72	23	23	46	2.5	125	122	36	45	65	4.3	215	250	1.1	70	115	45	C	116
119	Elco silt loam	66	22	25	43	2.5	125	112	37	47	64	4.4	220	250	1.4	65	110	45	C	119
120	Huey silt loam	41	13	15	0	1.5	75	64	23	33	0	2.6	130	100	.5	40	75	35		120
122	Colp silt loam[e]	49	14	17	26	1.9	95	86	32	43	57	3.6	180	225	1.4	45	90	45		122
125	Selma loam	87	29	32	62	3.1	155	136	44	53	76	5.0	250			85	135	50	B	125
127	Harrison silt loam	80	26	29	55	3.2	160	136	42	59	76	5.3	265	400	1.9	80	130	50	B	127
128	Douglas silt loam	79	24	28	50	3.2	160	135	42	59	76	5.3	265	400	1.9	75	130	55	B	128
130	Pittwood fine sandy loam	78	25	24	52	2.8	140	120	41	49	73	4.5	225	275	1.3	75	120	45	C	130
131	Alvin fine sandy loam	68	21	23	37	2.5	125	99	37	47	67	4.1	205	175	1.5	65	105	40	C	131
132	Starks silt loam	79	24	25	53	3.1	155	129	40	55	72	5.1	255	300	1.4	75	125	50	B	132
134	Camden silt loam	74	22	24	47	3.0	150	125	39	55	72	5.0	250	325	1.7	70	120	50	B	134
136	Brooklyn silt loam	64	20	22	39	2.0	100	108	35	44	58	3.7	185	200	.9	60	105	45	C	136
137	Ellison silt loam	62	19	21	34	2.3	115	98	36	48	67	4.1	205	225	1.5	60	105	45	C	137
138	Shiloh silty clay loam	90	32	31	54	3.2	160	139	46	56	70	5.0	250			90	135	45	B	138
141	Wesley fine sandy loam	68	21	22	42	2.4	120	112	36	48	74	4.4	220	250	1.4	65	110	45	C	141
142	Patton silty clay loam	99	33	32	56	3.5	175	148	48	56	78	5.6	280			95	145	50	A	142
145	Saybrook silt loam	93	28	30	61	3.4	170	139	46	60	84	5.6	280			90	140	50	B	145
146	Elliott silt loam	78	25	28	51	3.1	155	128	45	55	79	5.1	255	275	1.4	75	130	55	B	146
147	Clarence silty clay loam[e]	55	19	21	32	2.1	105	100	35	47	66	4.1	205	225	1.3	55	105	50	C	147
148	Proctor silt loam	93	30	33	65	3.4	170	144	44	59	88	5.5	275			90	140	50	B	148
149	Brenton silt loam	101	33	35	66	3.9	195	160	47	62	91	5.9	295			100	150	50	A	149
150	Onarga sandy loam	69	22	24	44	2.6	130	110	36	48	74	4.2	210	200	1.6	65	110	45	C	150
151	Ridgeville fine sandy loam	76	24	25	52	3.1	155	115	40	53	75	4.6	230	250	1.6	75	120	45	C	151
152	Drummer silty clay loam	103	34	32	63	3.5	175	154	51	61	83	5.5	275			100	150	50	A	152
153	Pella silty clay loam	91	31	30	58	3.2	160	140	48	56	78	5.2	260			90	140	50	B	153
154	Flanagan silt loam	103	33	35	66	3.8	190	162	52	67	92	6.1	305			100	160	60	A	154
155	Stockland loam[e]	54	17	20	33	2.0	100	83	28	43	61	3.7	185	225	1.4	50	85	35		155
159	Pillot silt loam	74	22	25	44	2.8	140	112	36	49	75	4.3	215	325	1.6	70	110	40	C	159
162	Gorham silty clay loam	86	31	33	57	3.2	160	141	46	56	77	5.1	255			90	140	50	B	162
164	Stoy silt loam	69	20	23	0	2.5	125	112	35	52	0	4.5	225	275	1.3	65	115	50	C	164
165	Weir silt loam	57	19	21	0	2.1	105	103	34	45	0	3.9	195	200	1.0	60	110	50	C	165
167	Lukin silt loam	67	21	24	0	2.5	125	121	36	54	0	4.8	240	275	1.4	65	120	55	C	167
171	Catlin silt loam	98	30	33	65	3.7	185	150	46	61	87	5.8	290			95	145	50	A	171
172	Hoopeston sandy loam	71	21	24	44	2.5	125	105	33	47	70	4.1	205	175	1.3	65	105	40	C	172
173	McGary silt loam[e]	52	17	18	30	2.0	100	91	34	48	65	3.6	180	175	1.1	50	95	45		173
175	Lamont fine sandy loam	60	19	20	35	2.1	105	97	36	45	77	3.7	185	125	1.3	60	105	45	C	175
176	Marissa silt loam	87	29	32	57	3.3	165	137	44	57	77	5.3	265			85	135	50	B	176
178	Ruark fine sandy loam	61	18	22	35	2.1	105	100	35	44	73	3.5	175	225	1.1	60	105	45	C	178
180	Dupo silt loam	85	28	30	57	3.3	165	132	43	55	76	5.2	260			85	130	45	B	180
184	Roby fine sandy loam	66	21	23	39	2.5	125	98	36	45	73	4.0	200	200	1.4	65	105	40	C	184
187	Milroy sandy loam	62	18	18	35	2.0	100	91	32	40	55	3.4	170	200	1.0	55	95	40		187
188	Beardstown loam	75	25	26	54	3.0	150	116	37	52	66	4.5	225	300	1.4	75	115	40	C	188
189	Martinton silt loam	87	29	30	59	3.3	165	135	45	57	84	5.3	265			85	135	50	B	189
191	Knight silt loam	75	24	24	50	2.6	130	118	42	49	68	4.4	220	225	1.0	75	120	45	C	191
192	Del Rey silt loam	72	22	24	44	2.6	130	115	37	49	69	4.5	225	250	1.3	70	115	45	C	192
194	Morley silt loam	56	19	20	32	2.1	105	103	35	47	64	4.3	215	275	1.3	55	105	50	C	194
197	Troxel silt loam	99	32	33	64	3.6	180	148	45	55	79	5.4	270			95	140	45	B	197

(Footnotes on page 16)

Table 2. — continued

Soil type No.	Soil type Name	Estimated crop yields per acre[a] — Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b]: Deciduous	Conifer	Productivity indexes Grain crops: Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
198	Elburn silt loam	103	33	34	67	3.9	195	161	50	63	94	6.1	305			100	155	55	A	198
199	Plano silt loam	99	32	36	66	3.9	195	151	45	60	90	5.8	290			95	145	50	A	199
200	Orio sandy loam	78	23	24	46	2.6	130	112	37	47	64	4.1	205	250	1.2	75	110	35	C	200
201	Gilford fine sandy loam	75	23	24	47	2.5	125	110	39	46	68	4.1	205	200	1.2	70	110	40	C	201
204	Ayr sandy loam	76	24	26	53	2.9	145	118	39	52	70	4.5	225	250	1.7	75	120	45	C	204
205	Metea sandy loam	63	19	21	35	2.3	115	103	35	46	63	4.0	200	225	1.6	60	105	45	C	205
206	Thorp silt loam	76	25	25	53	2.8	140	126	42	51	69	4.6	230	275	1.3	75	125	50	B	206
208	Sexton silt loam	71	23	23	44	2.4	120	120	37	48	65	4.3	215	250	1.1	70	115	45	C	208
210	Lena muck	83	25	0	0	0	140	125	41	0	0	0	200	0	0	80	120	40	C	210
212	Thebes silt loam	66	21	23	38	2.4	120	100	35	46	73	4.0	200	300	1.5	65	105	40	C	212
214	Hosmer silt loam[e]	61	20	23	0	2.5	125	108	35	51	0	4.6	230	325	1.6	60	115	55	C	214
215	Wartrace silt loam	69	20	25	0	2.6	130	115	36	52	0	4.7	235	350	1.7	65	120	55	C	215
218	Newberry silt loam	68	22	24	0	2.4	120	118	37	53	0	4.5	225	175	.9	65	120	55	C	218
219	Millbrook silt loam	90	29	32	57	3.3	165	144	43	59	81	5.4	270			90	140	50	B	219
221	Parr silt loam	91	24	26	57	3.3	165	129	44	57	78	5.3	265	350	1.6	80	130	50	B	221
223	Varna silt loam	72	22	24	46	2.6	130	123	41	53	75	4.8	240	300	1.5	70	125	55	B	223
224	Strawn silt loam	60	19	20	35	2.2	110	109	32	43	59	4.0	200	250	1.2	60	105	45	C	224
227	Argyle silt loam	79	23	26	51	3.1	155	124	39	54	72	4.8	240	375	1.8	75	120	45	C	227
228	Nappanee silt loam[e]	46	14	16	29	1.8	90	87	31	40	55	3.4	170	175	1.0	45	90	45		228
229	Monee silt loam	51	17	16	28	1.7	85	87	32	41	55	3.3	165	125	.6	50	90	40		229
230	Rowe silty clay	64	21	21	34	2.2	110	108	40	45	63	4.0	200	200	1.0	60	110	50	C	230
232	Ashkum silty clay loam	87	29	28	51	3.1	155	130	47	54	79	5.0	250			85	135	50	B	232
233	Birkbeck silt loam	76	23	26	51	3.0	150	123	41	55	70	5.0	250	375	1.8	75	125	50	B	233
234	Sunbury silt loam	95	30	32	62	3.5	175	147	45	62	84	5.6	280			90	140	50	B	234
235	Bryce silty clay	76	25	24	43	2.6	130	120	43	48	70	4.4	220	225	1.1	75	120	45	C	235
236	Sabina silt loam	84	25	29	55	3.2	160	133	42	56	75	5.2	260	325	1.5	80	130	50	B	236
238	Rantoul silty clay	61	20	16	28	1.8	90	99	35	36	50	3.2	160	150	0	60	100	40		238
239	Dorchester silt loam	84	24	25	52	3.1	155	132	43	54	76	5.3	265	450-600	0	80	130	50	B	239
240	Plattville silt loam	75	25	28	54	3.0	150	117	42	53	75	4.6	230	300	1.4	75	120	45	C	240
241	Chatsworth silt loam[c]	29	11	13	22	1.2	60	46	16	22	33	2.1	105	75	.5	30	45	15		241
242	Kendall silt loam	84	25	28	56	3.2	160	135	41	55	75	5.2	260	325	1.5	80	130	50	B	242
243	St. Charles silt loam	77	23	26	52	3.0	150	127	40	56	73	5.1	255	375	1.8	75	125	50	B	243
244	Hartsburg silty clay loam	97	31	30	58	3.3	165	145	47	56	79	5.3	265			95	140	45	B	244
248	McFain silty clay	77	26	25	41	2.6	130	114	36	48	65	4.2	210	400-500	0	75	110	35	C	248
249	Edinburg silty clay loam	86	28	28	52	2.9	145	132	43	55	72	4.6	230			85	130	45	B	249
250	Velma loam	68	21	24	36	2.5	125	118	39	51	72	4.6	230	275	1.5	65	120	55	C	250
252	Harvel silty clay loam	91	30	30	54	3.1	155	138	45	52	70	5.1	255			90	135	45	B	252
253	Stonington loam[e]	49	14	18	32	1.9	95	76	25	36	55	3.4	170	200	1.2	45	75	30		253
256	Pana silt loam	68	21	24	36	2.5	125	108	35	45	62	4.2	210	275	1.5	65	105	40	C	256
257	Clarksdale silt loam	94	30	31	61	3.5	175	140	43	57	79	5.3	265			90	135	45	B	257
259	Assumption silt loam	78	22	25	46	2.9	145	128	39	56	77	5.0	250	300	1.6	70	125	55	B	259
261	Niota silt loam	51	17	17	30	1.9	95	86	30	39	53	3.3	165	175	1.0	50	90	40		261
262	Denrock silt loam	66	20	21	39	2.3	115	108	37	46	63	4.1	205	225	1.3	65	110	45	C	262
264	El Dara sandy loam	59	17	20	35	2.2	110	87	31	40	55	3.5	175	175	1.5	55	90	35		264
265	Lomax loam	75	22	25	46	2.8	140	110	36	45	66	4.4	220	250	1.7	70	110	40	C	265
266	Disco sandy loam	66	20	23	37	2.3	115	103	35	44	65	4.0	200	175	1.5	65	105	40	C	266
268	Mt. Carroll silt loam	89	26	31	55	3.4	170	137	43	57	84	5.4	270			85	135	50	B	268
271	Timula silt loam	63	19	21	35	2.3	115	103	35	46	63	4.2	210	225	1.0	60	105	45	C	271
272	Edgington silt loam	79	25	25	46	2.8	140	122	42	51	68	4.5	225	250	1.1	75	125	50	B	272
274	Seaton silt loam	70	21	24	45	2.8	140	118	35	49	69	4.8	240	375	1.7	65	115	50	C	274
275	Joy silt loam	103	32	35	67	3.9	195	161	48	63	92	6.1	305			100	155	55	A	275
277	Port Byron silt loam	98	31	34	66	3.9	195	150	45	61	88	5.6	280			95	145	50	A	277
278	Stronghurst silt loam	85	25	29	56	3.2	160	138	42	55	76	5.3	265	350	1.5	80	135	55	B	278
279	Rozetta silt loam	82	23	26	51	3.2	160	131	40	54	73	5.2	260	400	1.8	75	125	50	B	279
280	Fayette silt loam	79	23	26	51	3.2	160	129	39	53	73	5.2	260	400	1.8	75	125	50	B	280
282	Chute fine sand	30	11	11	20	1.4	70	55	22	24	33	2.4	120	85	.7	30	60	30		282
284	Tice silty clay loam	98	33	37	65	3.9	195	153	47	61	84	5.7	285			100	145	45	A	284
286	Carmi Sandy Loam	77	20	25	45	2.8	140	103	33	53	69	4.3	215	250	1.6	70	105	35	C	286
287	Chauncey silt loam	69	22	25	0	2.4	120	120	37	53	0	4.7	235	225	1.1	70	120	50	C	287
288	Petrolia silty clay loam	79	25	25	50	2.6	130	132	43	49	66	4.5	225	375-525	0	75	130	55	B	288
289	Omaha loam	86	24	29	58	3.1	155	115	41	56	75	4.6	230	275	1.5	80	120	40	C	289
290	Warsaw silt loam	86	23	28	58	3.1	155	115	40	53	74	4.6	230	325	1.5	80	120	40	C	290
291	Xenia silt loam	76	22	25	48	2.8	140	126	41	55	72	4.8	240	350	1.7	70	125	55	B	291
292	Wallkill silt loam	82	23	23	50	2.6	130	126	42	41	65	4.3	215	375-525	0	75	125	50	B	292
293	Andres silt loam	95	31	32	61	3.6	180	145	48	61	88	5.5	275			95	145	50	A	293

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Table 2. — continued

Soil type No.	Name	Estimated crop yields per acre[a] Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b]: Deciduous	Conifer	Productivity indexes Grain crops: Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
294	Symerton silt loam	92	28	30	59	3.3	165	136	44	59	83	5.4	270			90	135	45	B	294
295	Mokena silt loam	78	24	25	51	2.9	145	126	41	55	77	4.7	235	275	1.4	75	125	50	B	295
296	Washtenaw silt loam	85	26	26	53	3.0	150	136	45	45	68	4.5	225	425-575	0	80	130	50	B	296
297	Ringwood silt loam	86	25	29	62	3.3	165	128	44	59	80	5.2	260	375	1.8	80	130	50	B	297
298	Beecher silt loam	69	22	24	44	2.6	130	116	39	51	72	4.5	225	250	1.3	65	115	50	C	298
300	Westland clay loam	91	28	31	61	3.1	155	126	47	54	75	4.8	240			85	130	45	B	300
301	Grantsburg silt loam[e]	49	17	22	0	2.1	105	95	33	46	0	4.1	205	250	1.4	55	105	50	C	301
302	Ambraw clay loam	83	26	26	55	2.9	145	132	43	52	70	4.6	230	425-575	0	80	130	50	B	302
304	Landes fine sandy loam	60	21	23	35	2.2	110	99	34	45	62	3.7	185	375-525	0	60	100	40		304
306	Allison silty clay loam	97	33	35	66	3.9	195	149	48	61	81	5.7	285			95	145	50	A	306
307	Iona silt loam	76	23	25	47	2.9	145	123	37	51	68	5.0	250	350	1.7	70	120	50	C	307
308	Alford silt loam	77	23	27	0	3.2	160	127	38	55	0	5.2	260	400	2.0	75	125	50	B	308
309	Keytesville silt loam[e]	37	12	14	25	1.5	75	66	23	30	42	2.6	130	150	.7	35	65	30		309
310	McHenry silt loam	67	21	24	41	2.5	125	116	37	52	72	4.6	230	325	1.6	65	115	50	C	310
311	Ritchey silt loam[e]	36	14	16	28	1.5	75	70	25	36	48	3.0	150	200	.9	40	75	35		311
312	Edwards muck	63	20	0	0	0	130	98	33	0	0	0	175	0	0	60	95	35		312
314	Joliet silty clay loam	47	18	17	30	1.8	90	83	32	39	54	3.3	165	200	.9	50	90	40		314
315	Channahon silt loam[e]	43	17	18	31	1.7	85	75	29	40	55	3.2	160	225	1.0	45	80	35		315
316	Romeo silt loam	10	8	10	15	.8	40	30	12	13	22	1.0	50	200-300	0	15	30	15		316
317	Millsdale silty clay loam	69	25	23	42	2.5	125	113	41	47	65	4.4	220	275	1.2	70	115	45	C	317
318	Lorenzo loam[e]	67	18	21	40	2.2	110	92	30	44	61	3.6	180	225	1.2	60	90	30		318
320	Frankfort silt loam[e]	53	18	20	31	1.9	95	95	33	45	59	3.7	185	200	1.1	55	95	40		320
321	DuPage silt loam	79	26	24	51	3.0	150	132	40	53	70	5.0	250	475-625	0	75	125	50	B	321
322	Russell silt loam	74	22	25	47	2.8	140	125	41	55	69	4.8	240	350	1.7	70	125	55	B	322
323	Casco silt loam[e]	57	17	20	32	2.0	100	89	28	41	55	3.5	175	175	1.0	55	90	35		323
324	Ripon silt loam	69	22	25	55	3.1	155	106	39	46	72	4.4	220	250	1.1	70	110	40	C	324
325	Dresden silt loam	71	21	24	46	2.8	140	110	36	49	69	4.5	225	300	1.4	65	110	45	C	325
326	Homer silt loam	74	21	23	44	2.6	130	115	37	48	67	4.4	220	275	1.1	70	115	45	C	326
327	Fox silt loam	63	20	22	37	2.3	115	106	33	46	64	4.3	215	275	1.3	60	105	45	C	327
329	Will silty clay loam	89	25	29	57	3.1	155	117	43	53	73	4.7	235			85	120	35	C	329
330	Peotone silty clay loam	80	26	25	50	2.8	140	123	42	43	58	4.2	210	200	0	80	120	40	C	330
331	Raymond silt loam	88	26	31	57	3.3	165	140	45	60	77	5.3	265			85	140	55	B	331
332	Billett sandy loam	56	18	20	35	2.1	105	90	31	41	58	3.7	185	150	1.5	55	90	35		332
333	Wakeland silt loam	83	26	29	54	3.1	155	135	45	57	74	5.2	260	500-650	0	80	135	55	B	333
334	Birds silt loam	77	24	26	46	2.5	125	122	42	52	72	4.4	220	450-600	0	75	125	50	B	334
335	Robbs silt loam	54	17	20	0	2.0	100	96	33	47	0	4.0	200	200	1.1	55	105	50	C	335
337	Creal silt loam	61	20	22	0	2.3	115	109	35	51	0	4.3	215	250	1.3	60	115	55	C	337
338	Hurst silt loam[e]	52	18	18	28	1.9	95	87	32	45	62	3.6	180	200	1.2	50	90	40		338
339	Wellston silt loam[e]	30	11	11	20	1.4	70	70	23	25	35	2.5	125	175	1.0	30	70	40		339
340	Zanesville silt loam[e]	46	13	15	28	1.7	85	85	29	37	53	3.4	170	225	1.2	45	85	40		340
342	Matherton silt loam	80	22	28	46	2.9	145	118	40	52	73	4.6	230	275	1.3	75	120	45	C	342
343	Kane silt loam	87	24	30	59	3.1	155	122	43	55	76	4.8	240	300	1.4	80	125	45	B	343
344	Harvard silt loam	83	25	29	53	3.2	160	133	41	54	78	5.2	260	325	1.7	80	130	50	B	344
346	Dowagiac silt loam	70	21	23	39	2.4	120	102	35	45	63	4.2	210	250	1.6	65	105	40	C	346
347	Canisteo silt loam	87	25	28	61	3.3	165	132	44	53	77	5.3	265	225	0	80	130	50	B	347
348	Wingate silt loam	80	25	29	52	3.1	155	133	42	56	79	5.1	255	375	1.8	80	130	50	B	348
353	Toronto silt loam	85	28	31	55	3.3	165	141	44	59	80	5.4	270			85	135	50	B	353
354	Hononegah loamy coarse sand	46	14	16	29	1.7	85	78	25	34	51	3.1	155	75	1.1	45	75	30		354
361	Kidder silt loam	63	19	20	36	2.3	115	101	35	45	67	4.1	205	275	1.3	60	105	45	C	361
363	Griswold loam	78	22	25	48	2.9	145	112	41	56	76	4.8	240	325	1.5	70	120	50	C	363
365	Aptakisic silt loam	76	23	24	50	2.9	145	115	39	51	70	4.8	240	275	1.3	70	115	45	C	365
369	Waupecon silt loam	103	33	34	65	3.5	175	149	50	62	81	5.3	265			100	150	50	A	369
370	Saylesville silt loam	66	23	25	44	2.5	125	107	35	46	66	4.3	215	300	1.5	65	105	40	C	370
375	Rutland silt loam	92	29	30	63	3.4	170	132	45	59	84	5.3	265			90	135	45	B	375
379	Dakota silt loam	75	22	25	42	2.6	130	107	36	51	67	4.5	225	275	1.7	70	110	40	C	379
380	Fieldon loam	48	18	20	55	2.8	140	80	28	37	72	3.9	195	175	1.5	50	85	35		380
382	Belknap silt loam	67	24	24	36	2.5	125	124	39	54	66	4.6	230	400-500	0	70	120	50	C	382
386	Downs silt loam	92	31	33	64	3.6	180	148	43	59	83	5.6	280			90	140	50	B	386
387	Ockley silt loam	84	28	29	51	3.0	150	126	42	51	75	5.0	250			85	125	40	B	387
388	Wenona silt loam	86	26	29	61	3.3	165	124	42	55	79	5.1	255	325	1.7	80	125	45	B	388
389	Hesch, thin to sandstone[e]	31	9	10	20	1.1	55	48	17	22	30	1.8	90	100	.8	30	50	20		389
390	Hesch fine sandy loam[e]	61	17	20	39	2.1	105	97	33	43	58	3.6	180	125	1.3	55	100	45		390
393	Marseilles, gray subsoil[e]	49	17	17	32	1.9	95	84	29	39	53	3.3	165	150	.7	50	85	35		393
394	Longlois silt loam	98	30	32	58	3.3	165	132	44	56	77	5.3	265			95	130	35	B	394
397	Boone loamy fine sand[e]	35	10	11	21	1.3	65	50	18	25	37	2.5	125	100	1.1	35	50	15		397

(Footnotes on page 16)

Table 2. — continued

Soil type No.	Soil type Name	Estimated crop yields per acre[a] — Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b]: Deciduous	Conifer	Productivity indexes — Grain crops: Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
398	Wea silt loam	101	31	33	65	3.4	170	144	47	61	80	5.5	275			95	140	45	B	398
400	Calco silty clay loam	84	28	28	52	2.9	145	132	44	52	72	4.7	235			85	130	45	B	400
402	Colo silty clay loam	98	32	31	57	2.8	140	149	48	53	74	5.3	265			95	145	50	A	402
404	Titus silty clay	78	26	26	46	2.8	140	125	42	52	68	4.3	215	400-500	0	75	125	50	B	404
410	Woodbine silt loam	57	20	22	34	2.2	110	102	35	45	60	3.9	195	300	1.3	60	105	45	C	410
411	Ashdale silt loam	82	24	26	57	3.2	160	116	39	53	74	5.0	250	375	1.6	75	115	40	C	411
412	Ogle silt loam	90	28	32	64	3.4	170	140	44	58	79	5.3	265			85	135	50	B	412
413	Gale silt loam	52	17	18	30	1.9	95	85	28	31	55	3.3	165	225	1.1	50	85	35		413
414	Myrtle silt loam	83	24	25	55	3.1	155	125	41	53	74	4.9	245	395	1.9	80	125	45	B	414
415	Orion silt loam	82	28	28	52	3.0	150	135	43	52	72	4.7	235	425-575	0	80	130	50	B	415
416	Durand silt loam	80	26	29	57	3.1	155	130	43	56	77	5.2	260	400	1.9	80	130	50	B	416
417	Derinda silt loam[e]	47	14	17	28	1.6	80	81	28	35	50	3.2	160	175	.9	45	80	35		417
418	Schapville silt loam[e]	54	18	19	33	2.1	105	88	33	39	55	3.6	180	225	1.1	55	90	35		418
419	Flagg silt loam	79	23	27	51	3.1	155	121	39	52	72	4.8	240	375	1.8	75	120	45	C	419
420	Piopolis silty clay loam	66	23	24	36	2.2	110	115	39	45	59	4.0	200	350-500	0	65	115	50	C	420
422	Cape silty clay loam	57	21	22	31	1.9	95	108	36	43	54	3.4	170	325-475	0	60	105	45	C	422
424	Shoals silt loam	97	32	34	62	3.7	185	145	46	61	77	5.0	250			95	140	45	B	424
425	Muskingum stony silt loam[e]	21	9	10	15	.9	45	34	13	15	27	1.7	85	125	.8	25	35	10		425
426	Karnak silty clay	55	21	20	28	1.8	90	99	33	40	52	3.2	160	325-425	0	55	100	45		426
427	Burnside silt loam	54	19	21	31	2.0	100	103	35	45	54	3.7	185	325-475	0	55	105	50	C	427
428	Coffeen silt loam	94	30	33	58	3.6	180	152	47	57	79	5.8	290			90	145	55	A	428
429	Palsgrove silt loam	66	22	24	43	2.6	130	108	36	47	63	4.5	225	325	1.4	65	110	45	C	429
430	Raddle silt loam	92	29	32	57	3.5	175	149	45	59	83	5.8	290			90	145	55	A	430
431	Genesee silt loam	86	24	28	53	3.2	160	137	44	57	73	5.1	255	500-600	0	80	135	55	B	431
435	Streator silty clay loam	90	29	28	57	3.1	155	129	45	54	77	4.8	240			85	130	45	B	435
440	Jasper silt loam	90	28	32	64	3.3	165	138	42	57	88	5.3	265			85	135	50	B	440
442	Mundelein silt loam	92	32	36	64	3.7	185	141	44	57	87	5.5	275			95	135	40	B	442
443	Barrington silt loam	86	29	32	61	3.3	165	130	42	55	85	5.4	270			85	130	45	B	443
448	Mona silt loam	69	21	23	43	2.5	125	115	37	51	74	4.5	225	300	1.5	65	115	50	C	448
451	Lawson silt loam	101	34	35	66	3.9	195	161	48	62	86	5.7	285			100	155	55	A	451
452	Riley silty clay loam	84	26	30	52	3.1	155	122	41	55	75	4.7	235	425-575	0	80	125	45	B	452
453	Muren silt loam	79	23	26	0	3.2	160	129	39	54	0	5.2	260	400	2.0	75	130	55	B	453
454	Iva silt loam	86	26	29	0	3.2	160	137	40	55	0	5.2	260	350	1.7	80	135	55	B	454
456	Ware silt loam	83	24	28	53	3.0	150	115	39	52	72	4.6	230	450-600	0	80	115	35	C	456
457	Booker silty clay	48	18	16	28	1.5	75	78	28	34	45	2.9	145	350-450	0	50	80	30		457
460	Ginat silt loam	64	21	21	33	2.1	105	106	35	45	62	3.9	195	225	1.2	60	105	45	C	460
461	Weinbach silt loam	70	21	24	40	2.5	125	113	39	53	70	4.5	225	275	1.4	65	115	50	C	461
462	Sciotoville silt loam	68	20	23	37	2.4	120	108	35	47	64	4.3	215	325	1.6	65	105	40	C	462
463	Wheeling silt loam	61	19	22	35	2.3	115	103	34	45	59	4.1	205	350	1.8	60	105	45	C	463
465	Montgomery silty clay	72	23	22	35	2.4	120	115	39	47	64	4.2	210	225	1.0	70	115	45	C	465
467	Markland silt loam[e]	53	15	20	29	2.0	100	91	33	46	65	3.6	180	200	1.3	50	95	45		467
469	Emma silty clay loam	70	24	24	39	2.5	125	115	35	45	58	4.2	210	275	1.3	70	110	40	C	469
470	Keller silt loam[e]	66	22	24	43	2.5	125	94	33	44	59	4.0	200	200	1.2	65	95	30		470
471	Bodine cherty silt loam[e]	20	9	10	15	1.0	50	34	13	16	26	2.0	100	150	.9	25	35	10		471
471	Clarksville cherty silt loam[e]	20	9	10	15	1.0	50	34	13	16	26	2.0	100	150	.9	25	35	10		471
472	Baylis silt loam	53	21	22	33	2.1	105	92	31	40	59	3.5	175	250	1.3	55	95	40		472
474	Piasa silt loam	52	17	18	25	1.9	95	77	28	37	48	3.1	155	125	.6	50	80	30		474
475	Elsah cherty silt loam	66	22	23	41	2.6	130	113	39	52	69	4.6	230	425-575	0	65	115	50	C	475
481	Raub silt loam	100	32	35	66	3.9	195	155	51	63	92	6.1	305			100	155	55	A	481
482	Uniontown silt loam	75	22	24	47	2.9	145	120	35	49	64	4.8	240	325	1.5	70	115	45	C	482
484	Harco silt loam	99	33	37	64	3.7	185	154	47	62	87	5.6	280			100	150	50	A	484
490	Odell silt loam	97	31	33	61	3.6	180	143	48	61	87	5.6	280			95	145	50	A	490
493	Bonfield loam	78	25	25	53	2.9	145	117	41	52	72	4.5	225	325	1.4	75	120	45	C	493
494	Kankakee fine sandy loam	80	26	29	57	3.1	155	112	40	52	70	4.6	230	350	1.5	80	115	35	C	494
495	Corwin silt loam	90	25	28	55	3.2	160	132	44	59	83	5.3	265			85	135	50	B	495
496	Fincastle silt loam	80	24	28	50	3.0	150	131	41	55	73	5.0	250	300	1.4	75	130	55	B	496
497	Mellott silt loam	82	24	26	53	3.2	160	133	44	57	76	5.2	260	375	1.8	75	130	55	B	497
501	Morocco fine sand	55	17	18	33	2.0	100	90	29	41	61	3.5	175	100	1.2	55	90	35		501
503	Rockton loam	71	21	23	48	2.9	145	109	31	51	77	4.4	220	225	1.1	65	105	40	C	503
504	Sogn silt loam[e]	26	11	10	16	1.1	55	49	16	20	30	2.1	105	100	.5	30	50	20		504
505	Dunbarton silt loam[e]	37	12	15	28	1.7	85	72	23	32	58	3.2	160	200	1.0	35	70	35		505
506	Hitt silt loam	70	24	26	45	2.8	140	108	40	47	65	4.5	225	350	1.5	70	110	40	C	506
508	Selma loam, bedrock substratum	85	28	28	53	3.1	155	126	44	52	72	4.8	240			85	125	40	B	508
509	Whalan loam	56	18	21	34	2.1	105	98	28	40	72	4.2	210	200	1.0	55	95	40		509
511	Dunbarton cherty silt loam[e]	35	10	11	20	1.3	65	55	21	26	30	2.5	125	150	.9	30	60	30		511

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Table 2. — continued

Soil type No.	Name	Estimated crop yields per acre[a] — Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b]: Deciduous	Conifer	Productivity indexes — Grain crops: Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
513	Granby loamy fine sand	57	21	24	33	2.0	100	92	30	38	57	3.3	165	125	0	60	90	30		513
516	Faxon clay loam	66	21	23	39	2.6	130	112	37	40	69	3.8	190	300	1.3	65	110	45	C	516
524	Zipp silty clay loam	69	23	18	33	2.6	130	115	39	41	61	4.4	220	180	1.2	65	115	50	C	524
531	Markham silt loam	66	21	23	39	2.4	120	112	37	49	69	4.4	220	300	1.4	65	110	45	C	531
537	Hesch, gray subsoil[e]	80	25	29	50	2.8	140	117	39	46	66	4.4	220	100	.8	75	115	40	C	537
546	Keltner silt loam	66	21	23	43	2.5	125	110	36	48	74	4.5	225	325	1.4	65	110	45	C	546
547	Eleroy silt loam	55	19	21	36	2.2	110	101	35	45	67	4.3	215	275	1.2	55	105	50	C	547
549	Marseilles silt loam[e]	63	20	22	39	2.3	115	105	36	46	65	4.4	220	175	.9	60	105	45	C	549
551	Gosport silt loam[e]	30	12	13	22	1.4	70	63	19	22	37	2.5	125	100	.6	30	60	30		551
554	Kernan silt loam	66	21	22	43	2.4	120	108	37	51	68	4.3	215	275	1.4	65	110	45	C	554
555	Shadeland loam	63	19	21	36	2.3	115	101	35	50	75	3.9	195	150	.7	60	105	45	C	555
556	High Gap loam[e]	56	18	21	34	2.1	105	95	33	46	66	3.3	165	125	.8	55	100	45		556
560	St. Clair silt loam[e]	41	14	17	26	1.7	85	78	31	41	53	3.4	170	225	1.2	40	85	45		560
561	New Glarus silt loam	52	17	21	33	2.2	110	82	32	43	58	3.6	180	250	1.1	50	90	40		561
562	Port Byron, sandy substratum	78	25	28	52	3.0	150	124	42	52	73	4.8	240	275	1.8	75	125	50	B	562
563	Seaton, sandy substratum	55	17	21	33	2.2	110	101	31	43	61	4.1	205	250	1.6	55	100	45		563
564	Waukegan silt loam	72	22	25	42	2.6	130	108	38	47	65	4.2	210	325	1.6	70	110	40	C	564
565	Tell silt loam	66	21	22	40	2.3	115	102	35	45	60	4.0	200	300	1.5	65	105	40	C	565
567	Elkhart silt loam	79	22	25	47	2.9	145	132	39	53	73	5.1	255	350	1.7	75	125	50	B	567
568	Niota, thin A	40	14	15	26	1.5	75	74	25	34	47	2.9	145	150	.9	40	75	35		568
570	Martinsville silt loam	71	22	23	45	2.9	145	121	37	51	66	4.8	240	300	1.6	70	115	45	C	570
572	Loran silt loam	69	25	26	44	2.8	140	120	39	49	68	4.7	235	300	1.3	70	120	50	C	572
574	Ogle, silt loam substratum	69	20	22	50	2.6	130	103	35	48	66	4.1	205	275	1.4	65	105	40	C	574
576	Zwingle silt loam	54	18	17	31	1.9	95	92	33	41	58	3.7	185	200	1.2	55	95	40		576
578	Dorchester, cobbly subsoil	72	21	23	47	2.4	120	124	40	49	70	4.6	230	400-500	0	70	120	50	C	578
581	Tamalco silt loam[e]	47	15	17	0	1.8	90	70	24	34	0	2.9	145	150	.7	45	75	30		581
583	Pike silt loam	68	21	24	0	2.6	130	116	37	54	0	5.0	250	350	1.7	65	120	55	C	583
584	Walshville loam[e]	37	12	14	0	1.3	65	60	21	29	0	2.4	120	75	.4	35	65	30		584
585	Negley loam	51	18	18	0	1.9	95	96	33	47	0	3.6	180	225	1.3	50	105	55	C	585
587	Terril loam	89	30	32	61	3.4	170	141	44	59	79	5.4	270			90	135	45	B	587
589	Bowdre silty clay	76	23	24	50	2.8	140	110	36	48	68	4.2	210	400-550	0	70	110	40	C	589
590	Cairo silty clay	79	26	24	51	2.9	145	115	37	48	67	4.3	215	375-525	0	75	115	40	C	590
594	Reddick silty clay loam	97	30	29	58	3.3	165	141	48	56	81	5.3	265			90	140	50	B	594
597	Armiesburg silty clay loam	97	30	32	63	3.6	180	147	46	60	75	5.5	275			95	140	45	B	597
598	Bedford silt loam	40	14	16	26	1.3	65	74	25	34	47	2.5	125	200	1.2	40	75	35		598
599	Baxter cherty silt loam	25	11	10	15	1.0	50	49	16	21	29	2.1	105	175	1.0	30	50	20		599
600	Huntington silt loam	94	31	34	63	3.9	195	147	48	59	81	5.7	285			95	145	50	A	600
603	Blackoar silt loam	92	29	30	59	3.3	165	144	47	55	68	5.0	250			90	140	50	B	603
605	Ursa silt loam[e]	30	12	13	22	1.4	70	63	18	22	37	2.4	120	125	.7	30	60	30		605
606	Goss cherty silt loam	26	10	10	15	1.0	50	48	16	20	30	2.0	100	175	1.0	25	50	25		606
609	Crune silt loam	103	29	33	62	3.7	185	138	46	59	77	5.2	260			95	140	45	B	609
617	Otterbein silt loam	84	25	28	53	3.1	155	135	43	55	80	5.1	255	300	1.4	80	130	50	B	617
619	Parkville silty clay	78	24	24	40	2.8	140	122	42	47	66	5.0	250	450-550	0	75	120	45	C	619
620	Darmstadt silt loam[e]	46	14	17	0	1.7	85	69	26	36	0	3.0	150	125	.6	45	80	35		620
628	Lax silt loam	49	17	20	36	1.4	70	86	26	32	55	3.3	165	225	1.3	50	80	30		628
633	Traer silt loam	76	23	23	46	2.5	125	124	39	49	68	4.5	225	300	1.2	70	120	50	C	633
647	Lawler loam	80	25	28	44	3.3	165	115	39	44	61	5.0	250	300	1.3	75	115	40	C	647
656	Octagon silt loam	77	23	25	46	3.0	150	125	41	53	75	5.0	250	325	1.5	75	125	50	B	656
660	Coatsburg silt loam[e]	39	13	16	28	1.5	75	80	25	28	44	3.2	160	150	.9	40	75	35		660
661	Atkinson loam	76	23	25	55	3.0	150	120	39	49	68	4.8	240	350	1.4	75	120	45	C	661
665	Stonelick fine sandy loam	63	19	20	42	2.3	115	94	28	40	61	3.9	195	350-450	0	60	90	30		665
673	Onarga, reddish subsoil	67	19	22	43	2.4	120	101	34	45	64	4.0	200	175	1.5	60	100	40		673
682	Medway silty clay loam	86	26	30	57	3.3	165	132	42	53	72	5.3	265	400-500	0	80	130	50	B	682
683	Lawndale silt loam	102	32	34	66	3.9	195	156	50	62	87	5.8	290			100	155	55	A	683
684	Broadwell silt loam	97	31	32	64	3.7	185	145	44	59	84	5.6	280			95	140	45	B	684
685	Middletown silt loam	69	23	25	45	2.5	125	117	34	53	70	4.7	235	300	1.6	70	110	40	C	685
691	Beasley silt loam	29	11	13	22	1.0	50	63	19	22	37	2.5	125	125	.6	30	60	30		691
696	Zurich silt loam	69	21	23	46	2.8	140	117	37	49	69	4.7	235	300	1.6	65	115	50	C	696
697	Wauconda silt loam	83	28	31	56	3.3	165	129	41	54	80	5.2	260			85	125	40	B	697
698	Grays silt loam	78	24	28	52	3.1	155	124	40	52	77	5.0	250	325	1.7	75	120	45	C	698
706	Boyer sandy loam	53	19	21	31	2.1	105	85	29	36	53	3.5	175	175	1.1	55	85	30		706
723	Reesville silt loam	80	24	26	52	3.1	155	131	40	54	72	5.1	255	300	1.4	75	125	50	B	723
727	Waukee loam	69	22	25	46	2.6	130	103	35	46	66	4.2	210	275	1.3	65	105	40	C	727
728	Winnebago silt loam	75	23	25	51	2.6	130	121	40	51	68	4.8	240	350	1.7	70	120	50	C	728
731	Nasset silt loam	74	23	25	48	2.6	130	112	37	48	67	4.5	225	350	1.5	70	110	40	C	731

(Footnotes on page 16)

Table 2. — continued

Soil type No.	Soil type Name	Estimated crop yields per acre[a] Basic level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	High level of management: Corn	Soybeans	Wheat	Oats	Mixed hay	Mixed past.[c]	Timber yield per acre[b] Deciduous	Conifer	Productivity indexes Grain crops Basic mgt.	High mgt.	Difference	Prime agr. land class[d]	Soil type No.
		bu.	bu.	bu.	bu.	tons	days	bu.	bu.	bu.	bu.	tons	days	bd. ft.	cords					
740	Darroch silt loam	98	32	34	64	3.7	185	152	46	60	83	4.7	235			95	145	50	A	740
741	Oakville fine sand	43	15	14	26	1.5	75	62	23	32	48	2.9	145	100	1.2	45	65	20		741
742	Dickinson, loamy substratum	71	21	24	50	2.6	130	109	36	49	69	4.4	220	200	1.7	65	110	45	C	742
743	Ridott silt loam	68	24	25	43	2.5	125	110	37	47	61	4.5	225	275	1.2	70	110	40	C	743
745	Shullsburg silt loam[e]	66	20	22	37	2.4	120	110	40	47	65	4.1	205	200	1.0	65	115	50	C	745
746	Calmine silt loam	64	21	22	35	2.3	115	109	40	46	64	4.1	205	200	.9	60	115	55	C	746
752	Oneco silt loam	66	22	24	40	2.5	125	105	37	46	63	4.3	215	325	1.4	65	105	40	C	752
753	Massbach silt loam	60	20	22	40	2.4	120	106	35	46	70	4.4	220	300	1.3	60	105	45	C	753
761	Eleva sandy loam[e]	40	11	14	21	1.2	60	66	20	23	37	2.4	120	175	.9	35	65	30		761
763	Joslin silt loam	83	28	31	56	3.3	165	135	43	55	80	5.1	255			85	130	45	B	763
764	Coyne fine sandy loam	63	18	20	43	2.3	115	101	35	47	67	3.8	190	200	1.3	60	105	45	C	764
765	Trempealeau silt loam	62	19	21	44	2.6	130	103	35	46	66	4.2	210	225	1.3	60	105	45	C	765
768	Backbone loamy sand	48	15	20	29	1.9	95	75	28	38	50	3.1	155	150	1.1	45	80	35		768
769	Edmund silt loam[e]	57	19	25	39	2.3	115	86	32	44	55	3.7	185	225	1.2	55	90	35		769
771	Hayfield loam	69	22	25	39	3.1	155	103	35	41	60	4.7	235	275	1.2	65	105	40	C	771
772	Marshan loam	84	25	26	43	2.5	125	109	39	41	63	4.4	220	250	1.1	80	110	30	C	772
774	Saude loam	61	18	18	39	2.6	130	103	35	46	66	4.2	210	225	1.1	55	105	50	C	774
776	Comfrey clay loam	92	30	30	55	3.1	155	140	46	51	66	5.0	250			90	135	45	B	776
777	Adrian muck	63	20	0	0	0	130	98	33	0	0	0	175	0	0	60	95	35		777
779	Chelsea fine sand	44	11	13	24	1.4	70	66	23	34	46	2.5	125	150	1.3	40	70	30		779
780	Grellton sandy loam	64	20	23	39	2.5	125	103	34	46	66	4.4	220	250	1.4	60	105	45	C	780
781	Friesland sandy loam	80	23	26	59	3.1	155	120	39	49	68	4.8	240	275	1.5	75	120	45	C	781
782	Juneau silt loam	86	26	29	63	3.5	175	137	40	54	79	5.5	275	425-550	0	80	130	50	B	782
783	Flagler sandy loam	55	18	21	35	2.1	105	87	31	39	55	3.5	175	250	1.2	55	90	35		783
786	Frondorf loam[e]	46	12	16	0	1.7	85	69	23	30	0	3.1	155	225	1.1	40	70	30		786
787	Banlic silt loam	62	21	21	31	2.2	110	115	37	46	62	4.2	210	425-550	0	60	115	55	C	787
791	Rush silt loam	92	30	32	61	3.5	175	132	42	57	77	5.5	275			90	130	40	B	791
792	Boves silt loam	98	31	33	63	3.1	155	141	46	60	79	5.3	265			95	140	45	B	792
903	Muskego muck	84	26	0	0	0	150	126	39	0	0	0	215	0	0	80	120	40	C	903
940	Westmore silt loam	52	20	21	32	2.0	100	90	29	38	57	3.4	170	200	1.2	55	90	35		940
955	Berks loam[e]	21	9	10	15	.9	45	34	13	15	27	1.7	85	100	1.1	25	35	10		955
956	Brandon silt loam	52	17	18	0	2.0	100	80	31	37	0	3.9	195	250	1.2	50	85	35		956
956	Saffel gravelly silt loam[e]	34	13	16	0	1.2	60	57	22	32	0	1.9	95	200	1.1	35	60	25		956
961	Burkhardt sandy loam	51	13	16	29	1.8	90	78	25	34	50	3.1	155	75	1.0	45	75	30		961
977	Neotoma stony silt loam	20	9	10	15	.7	35	34	13	15	26	1.4	70	125	1.1	25	35	10		977

Footnotes:

a Wheat, oats, hay, and timber yields are not given (indicated by zero) for some soils where these crops are not well adapted.

b Timber yield is given as annual timber growth per acre. It is not given for soils with a basic management grain crop productivity index of 85 or greater.

c Number of days that one acre of mixed pasture will carry one cow.

d Prime agricultural land classes have high level management grain crop productivity indexes of 145-160 for Class A, 125-140 for Class B, and 105-120 for Class C.

e Soils with unfavorable subsoils or other shallow layers that have maximum reduction in productivity for increasing slope and erosion.

ALPHABETICAL INDEX AND SLOPE RANGE OF SOIL TYPES IN ILLINOIS*

98 - Ade loamy fine sand, 1-7
777- Adrian muck, 0-2
308 - Alford silt loam, 1-40
306 - Allison silty clay loam, 1-3
131 - Alvin fine sandy loam, 1-30
302 - Ambraw clay loam, 0-2
293 - Andres silt loam, 0-5
365 - Aptskisic silt loam, 0-5
78 - Arenzville silt loam, 0-3
227 - Argyle silt loam, 2-18
597 - Armiesburg silty clay loam, 0-2
411 - Ashdale silt loam, 2-20

232 - Ashkum silty clay loam, 0-3
259 - Assumption silt loam, 2-18
661 - Atkinson loam, 2-20
70 - Atlas silt loam, 4-18
61 - Atterberry silt loam, 0-5
14 - Ava silt loam, 1-18
204 - Ayr sandy loam, 1-10
768 - Backbone loamy sand, 2-18
787 - Banlic silt loam, 0-2
443 - Barrington silt loam, 0-5
105 - Batavia silt loam, 0-12
599 - Baxter cherty silt loam, 2-30

472 - Baylis silt loam, 8-30
188 - Beardstown loam, 0-5
691 - Beasley silt loam, 2-20
70 - Beaucoup silty clay loam, 0-2
598 - Bedford silt loam, l-7
298 - Beecher silt loam, 0-6
382 - Belknap silt loam, 0-5
955 - Berks loam, 3-45
332 - Billett sandy loam, O-20
334 - Birds silt loam, O-2
233 - Birkbeck silt loam, O-12
603 - Blackoar silt loam, O-5

5 - Blair silt loam, 4-25
53 - Bloomfield fine sand, 1-20
23 - Blount silt loam, 0-6
13 - Bluford silt loam, 0-7
471 - Bodine cherty silt loam, 4-60
35 - Bold silt loam, 5-35
493 - Bonfield loam, 0-5
108 - Bonnie silt loam, 0-2
457 - Booker silty clay, 0-2
397 - Boone loamy fine sand, 2-40
589 - Bowdre silty clay, 0-8
792 - Bowes silt loam, O-10

706 - Boyer sandy loam, 0-40
956 - Brandon silt loam, 2-30
149 - Brenton silt loam, 0-3
684 - Broadwell silt loam, 0-12
136 - Brooklyn silt loam, 0-1
235 - Bryce silty clay, 0-3
961 - Burkhardt sandy loam, 0-30
427 - Burnside silt loam, 0-4
590 - Cairo silty clay, 1-5
746 - Calamine silt loam, 0-12
400 - Calco silty clay loam, 0-2
134 - Camden silt loam, 0-30

347 - Canisteo silt loam, 0-2
422 - Cape silty clay loam, 0-2
286 - Carmi sandy loam, 0-12
323 - Casco silt loam, 0-45
171 - Catlin silt loam, O-12
315 - Channahon silt loam, 1-25
241 - Chatsworth silt loam, 4-50
287 - Chauncey silt loam, 0-3
779 - Chelsea fine sand, 0-20
282 - Chute fine sand, 5-40
2 - Cisne silt loam, O-3
147 - Clarence silty clay loam, l-12

257 - Clarksdale silt loam, O-5
471 - Clarksville (or Bodine) cherty silt loam, 2-60
18 - Clinton silt loam, 2-18
660 - Coatsburg silt loam, 5-20
428 - Coffeen silt loam, 0-4
402 - Colo silty clay loam, 0-2
122 - Colp silt loam, l-18
776 - Comfrey clay loam, 0-2
495 - Corwin silt loam, 0-10
112 - Cowden silt loam, 0-3
764 - Coyne fine sandy loam, 0-12

609 - Crane silt loam, 0-3
337 - Creal silt loam, 0-7
379 - Dakota silt loam, 0-18
56 - Dana silt loam, 0-6
620 - Darmstadt silt loam, 1-10
740 - Darroch silt loam, 0-3
71 - Darwin silty clay, 0-2
192 - Del Rey silt loam, 0-5
45 - Denny silt loam, 0-2
262 - Denrock silt loam, 0-2
417 - Derinda silt loam, 4-12
742 - Dickinson, loamy substratum, 1-12

*The soil type number precedes the soil type name; the slope range in percent follows the soil name. For a numerical listing of soil types in Illinois, see Table 2, pages 10-16.

87 - Dickinson sandy loam, 1-15
266 - Disco sandy loam, 0-5
24 - Dodge silt loam, 0-20
40 - Dodgeville silt loam, 0-30
239 - Dorchester silt loam, 0-3
578 - Dorchester silt loam, cobbly subsoil variant, 0-3
128 - Douglas silt loam, 2-15
346 - Dowagiac silt loam, 0-12
386 - Downs silt loam, 2-20
325 - Dresden silt loam, 1-10
152 - Drummer silty clay loam, 0-2
75 - Drury silt loam, 1-12
29 - Dubuque silt loam, 3-30
505 - Dunbarton silt loam, 2-45
511 - Dunbarton silt loam, cherty variant,2-45
321 - DuPage silt loam, 0-2
180 - Dupo silt loam, 0-2
416 - Durand silt loam, 1-20
48 - Ebbert silt loam, 0-1
272 - Edgington silt loam, 0-1
249 - Edinburg silty clay loam, 0-1
769 - Edmund silt loam, 2-35
312 - Edwards muck, 0-2
198 - Elburn silt loam, 0-5
119 - Elco silt loam, 3-18
264 - El Dara sandy loam, 7-30
547 - Eleroy silt loam, 2-30
761 - Eleva sandy loam, 2-35
567 - Elkhart silt loam, 3-20
146 - Elliott silt loam, l-3
137 - Ellison silt loam, 0-10
475 - Elsah cherty silt loam, 0-5
469 - Emma silty clay loam, 0-12
516 - Faxon clay loam, 0-2
280 - Fayette silt loam, 1-25
380 - Fieldon loam, 0-1
496 - Fincastle silt loam, 1-3
6 - Fishhook silt loam, 2-12
419 - Flagg loam, 0-20
783 - Flagler sandy loam, 0-9
154 - Flanagan silt loam, 0-5
327 - Fox silt loam, 1-30
320 - Frankfort silt loam, 1-12
781 - Friesland sandy loam, 0-12
786 - Frondorf loam, 6-50
413 - Gale silt loam, 2-60
431 - Genesee silt loam, 0-2
201 - Gilford fine sandy loam, 0-2
460 - Ginat silt loam, 0-2
162 - Gorham silty clay loam, 0-3
551 - Gosport silt loam, 5-45
606 - Goss cherty silt loam, 2-45
513 - Granby loamy fine sand, 0-2
301 - Grantsburg silt loam, 2-15
698 - Grays silt loam, 1-12
780 - Grellton sandy loam, 0-20
363 - Griswold loam or sandy loam, 2-15
30 -Hamburg silt, 7-60
484 - Harco tilt loam, 0-3
67 - Harpster silty clay loam, 0-2
127 - Harrison silt loam, 0-10
244 - Hartsburg silty clay loam, 0-2
344 - Harvard silt loam, 0-10
252 - Harvel silty clay loam, 0-1
771 - Hayfield loam, 0-3
331 - Haymond silt loam, 0-5
25 - Hennepin loam, 12-65
62 - Herbert silt loam, 0-3
46 - Herrick silt loam, 0-3
390 - Hesch fine sandy loam, 2-45
537 - Hesch fine sandy loam, gray subsoil variant, 0-5
389 - Hesch loamy sand, thin to sandstone variant, 0-5
8 - Hickory loam, 5-60
556 - High Gap loam, 1-12
506 - Hitt silt loam, 1-12
326 - Homer silt loam, 0-6
354 - Hononegah loamy coarse sand, 0-25
172 - Hoopeston sandy loam, 0-2
214 - Hosmer silt loam, 1-25
103 - Houghton muck, 0-2
97 - Houghton peat, 0-2
3 - Hoyleton silt loam, 0-6
120 - Huey silt loam, 0-2
600 - Huntington silt loam, 1-5
77 - Huntsville silt loam, 0-5
338 - Hurst silt loam, 1-6
307 - Iona silt loam, 0-5
43 -Ipava silt loam, 1-4
454 -Iva silt loam, 1-4
85 - Jacob clay, 0-1
440 - Jasper silt loam, 0-15
314 - Joliet silty clay loam, 0-4

* The toll type number precedes the soil type name; the slope range in percent follows the soil name. For a numerical listing of soil types in Illinois, see Table 2, pages 10-16

763 - Joslin silt loam, 0-6
275 - Joy silt 1oam, 0-5
28 - Jules silt loam, 0-2
782 - Juneau silt loam, 0-6
343 - Kane silt loam, 0-3
494 - Kankakee fine sandy loam, 0-12
426 - Karnak silty clay, 0-1
470 - Keller silt loam, 2-12
546 - Keltner silt loam, 2-15
242 - Kendall silt loam, 1-7
17 - Keomah silt loam, 1-5
554 - Kernan silt loam, 1-5

309 - Keytesville silt loam, 2-7
361 - Kidder silt loam, 0-35
191 - Knight silt loam, 0-2
102 - La Hogue loam, 0-5
175 - Lamont fine sandy loam, 3-25
304 - Landes fine sandy loam, 1-15
60 - La Rose silt loam, 5-30
647 - Lawler loam, 0-5
683 - Lawndale silt loam, 0-3
451 - Lawson silt loam, 0-3
628 - Lax silt loam, 2-12
210 - Lena muck, 0-2

59 - Lisbon silt loam, 0-3
81 - Littleton silt loam, 0-4
265 - Lomax loam, 0-5
394 - Longlois silt loam, 1-6
572 - Loran silt loam, 1-10
318 - Lorenzo loam, 1-12
167 - Lukin silt loam, 1-4
176 - Marissa silt loam, 0-3
531 - Markham silt loam, 1-18
467 - Markland silt loam, 1-35
549 - Marseilles silt loam, 1-15

393 - Marseilles silt loam, gray subsoil variant, 0-4
772 - Marshan loam, 0-2
570 - Martinsville silt loam, 1-18
189 - Martinton silt loam, 0-5
753 - Massbach silt loam, 1-15
342 - Matherton silt loam, 0-6
89 - Maumee fine sandy loam, 0-1
248 - McFain silty clay, 0-1
173 - McGary silt loam, 0-6
310 - McHenry silt loam, 0-12
682 - Medway silty clay loam, O-3

497 - Mellott silt loam, 0-12
205 - Metea sandy loam, 0-15
27 - Miami silt loam, 0-25
685 - Middletown silt loam, 2-12
69 - Milford silty clay loam, 0-2
219 - Millbrook silt loam, 1-5
82 - Millington loam, 0-2
317 - Millsdale silty clay loam, 0-2
187 - Milroy sandy loam, 0-2
295 - Mokena silt loam, 0-5
448 - Mona silt loam, 0-10
229 - Monee silt loam, 0-2

465 - Montgomery silty clay, 0-1
57 - Montmorenci silt loam, 0-5
194 - Morley silt loam, 1-35
501 - Morocco fine sand, 0-2
268 - Mt. Carroll silt loam, 1-20
442 - Mundelein silt loam, 0-5
453 - Muren silt loam, 1-6
41 - Muscatine silt loam, 0-3
903 - Muskego muck, 0-2
425 - Muskingum stony silt loam, 5-70
414 - Myrtle silt loam, 2-18
228 - Nappanee silt loam, 0-4

731 - Nasset silt loam, 5-20
585 - Negley loam, 6-35
977 - Neotoma stony silt loam, 6-35
218 - Newberry silt loam, 0-3
561 - NewGlarus silt loam, 1-30
261 - Niota silt loam, 0-3
568 - Niota silty clay loam, clayey subsurface variant, 0-4
741 - Oakville fine sand, 0-50
387 - Ockley silt loam, 1-18
113 - Oconee silt loam, 1-7
656 - Octagon silt loam, O-12

490 - Ode11 silt loam, 0-6
412 - Ogle silt loam, 2-18
374 - Ogle silt loam, silt loam substratum variant, 2-7
84 - Okaw silt loam, 0-5
289 - Omaha loam, 0-2
673 - Onarga fine sandy loam, reddish subsoil variant, 0-4
150 - [redacted]Onarga sandy loam, 0-10
752 - Oneco silt loam, 1-12
200 - Oric sandy loam, 0-2
415 - Orion silt loam, 0-2

* The soil type number precedes the soil type name; the slope range in percent follows the soil name. For a numerical listing of soil types in Illinois. see table 2, pages 10-16

76 - Otter silt loam, 0-4
617 - Otterbein silt loam, 0-5
100 - Palms muck, 0-2
429 - Palsgrove silt loam, 2-30
256 - Pana silt loam, 5-15
42 - Papineau fine sandy loam, 0-3
15 - Parke silt loam, 0-35
619 - Parkville silty clay, 0-2
221 - Parr silt loam, 2-18
142 - Patton silty clay loam, 0-2
21 - Pecatonica silt loam, 2-18
153 - Pella silty clay loam, 0-2

330 - Peotone silty clay loam, 0-2
288 - Petrolia silty clay loam, 0-2
474 - Piasa silt loam, 0-2
583 - Pike silt loam, 1-12
159 - Pillot silt loam, 0-12
420 - Piopolis silty clay loam, 0-2
130 - Pittwood fine sandy loam, 0-2
54 - Plainfield sand, 0-30
199 - Plano silt loam, 1-12
240 - Plattville silt loam, 1-5
277 - Port Byron silt loam, 1-12

562 - Port Byron silt loam, sandy substratum, 1-12
148 - Proctor silt loam, 0-15
109 - Racoon silt loam, 0-5
430 - Raddle silt loam, 1-8
74 - Radford silt loam, 1-5
238 - Rantoul silty clay, 0-1
481 - Raub silt loam, 1-3
594 - Reddick silty clay loam, 0-2
723 - Reesville silt loam, 0-6
4 - Richview silt loam, 3-12
151 - Ridgeville fine sandy loam, 0-5

743 - Ridott silt loam, 1-10
452 - Riley silty clay loam, 0-10
297 - Ringwood silt loam, 0-10
324 - Ripon silt loam, 1-12
311 - Ritchey silt loam, 1-12
335 - Robbs silt loam, 0-3
184 - Roby fine sandy loam, 0-5
503 - Rockton loam, 0-25
93 - Rodman gravelly loam, 12-40
316 - Romeo silt loam, 0-4
73 - Ross loam, 0-4
230 - Rowe silty clay, 0-2

279 - Rozetta silt loam, 0-8
178 - Ruark fine sandy loam, 0-2
791 - Rush silt loam, 0-6
16 - Rushville silt loam, 0-3
322 - Russell silt loam, 3-18
375 - Rutland silt loam, 1-5
236 - Sabina silt loam, 0-5
68 - Sable silty clay loam, 0-2
956 - Saffel gravelly silt loam, 1-30
92 - Sarpy sand, 1-12
774 - Saude loam, 1-9
107 - Sawmill silty clay loam, 0-3

145 - Saybrook silt loam, 1-12
370 - Saylesville silt loam, 0-20
418 - Schapville silt loam, 2-20
462 - Sciotoville silt loam, 0-12
274 - Seaton silt loam, 2-45
563 - Seaton silt loam, sandy substratum, 2-18
125 - Selma loam, 0-2
508 - Selma loam, bedrock substratum, 0-6
208 - Sexton silt loam, 0-2
555 - Shadeland loam, 0-6
72 - Sharon silt loam, 0-5
138 - Shiloh silty clay loam, O-2

424 - Shoals silt loam, 0-2
745 - Shullsburg silt loam, 1-25
55 - Sidell silt loam, 0-12
504 - Sogn silt loam, 0-15
88 - Sparta loamy sand, 0-12
243 - St. Charles silt loam, 0-12
560 - St. Clair silt loam, 2-45
132 - Starks silt loam, 1-5
155 - Stockland loam, O-15
665 - Stonelick fine sandy loam, O-2
253 - Stonington loam, 5-30
164 - Stoy silt loam, 0-10

224 - Strawn silt loam, 5-45
435 - Steator silty clay loam, O-3
278 - Stronghurst silt loam, 0-5
234 - Sunbury silt loam, 1-7
91 - Swygert silty clay loam, 1-7
19 - Sylvan silt loam, 2-30
294 - Symerton silt loam, 0-10
34 - Tallula silt loam, 5-20
36 - Tama silt loam, 1-20
581 - Tamalco silt loam, 1-4
565 - Tell silt loam, 1-20
587 - Terril loam, 2-14

212 - Thebes silt loam, 0-15
206 - Thorp silt loam, 0-1
284 - Tice silty clay loam, 0-4
271 - Timula silt loam, 5-40
404 - Titus silty clay loam or silty clay, 0-2
353 - Toronto silt loam, 0-6
633 - Traer silt loam, 0-2
765 - Trempealeau silt loam, 0-2
197 - Troxel silt loam, 0-2
482 - Uniontown silt loam, 0-12
605 - Ursa silt loam, 4-20

223 - Varna silt loam, 3-12
250 - Velma loam, 7-20
47 - Virden silt loam, 0-3
50 - Virden silty clay loam, 0-2
104 - Virgil silt loam, 0-7
83 - Wabash silty clay, 0-2
26 - Wagner silt loam, 0-3
333 - Wakeland silt loam, 0-4
292 - Wallkill silt loam, 0-2
584 - Walshville loam, 4-15
456 - Ware silt loam, 1-6
290 - Warsaw silt loam, 0-12

215 - Wartrace silt loam, 1-30
296 - Washtenaw silt loam, 0-2
49 - Watseka loamy fine sand, 0-3
697 - Wauconda silt loam, 0-5
727 - Waukee loam, 1-9
564 - Waukegan silt loam, 0-12
369 - Waupecan silt loam, 0-7
398 - Wea silt loam, 1-6
461 - Weinback silt loam, 0-5
165 - Weir silt loam, 0-3
339 - Wellston silt loam, 0-35
388 - Wenona silt loam, 2-15

141 - Wesley fine sandy loam, 0-5
300 - Westland clay loam, 0-2
940 - Westmore silt loam, 2-50
22 - Westville silt loam, 2-30
509 - Whalan loam, O-25
463 - Wheeling silt loam, 0-5
116 - Whitson silt loam, 0-3
329 - Will clay loam or silty clay loam, 0-3
348 - Wingate silt loam, l-6
728 - Winnebago silt loam, 2-30
410 - Woodbine silt loam, 2-25

37 - Worthen silt loam, 1-12
12 - Wynoose silt loam, 0-3
291 - Xenia silt loam, 1-5
340 - Zanesville silt loam, 2-20
524 - Zipp silty clay loam, 0-2
696 - Zurich silt loam, 1-18
576 - Zwingle silt loam, O-2

* The soil type number precedes the soil type name; the slope range in percent follows the roil name. For a numerical listing of roil types in Illinois. see Table 2, pages. 10-16.