MANAGING RECLAIMED SOILS IN THE CORN BELT[1]

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Abstract.--In this discussion of the management of reclaimed soils at coal surface mines in the Corn Belt, it is assumed that a reclamation plan will have been developed and implemented so that soil and topography are replaced sufficiently to meet the demands of corn production. Therefore, managing these lands primarily deals with the problems associated with compaction. Amelioration of reclaimed soil requires time. Setting aside of reclaimed lands in government programs offers a means to ameliorate these soils through natural process.

INTRODUCTION

Over fifty percent of the corn grown in the United States comes from five states: Ohio, Indiana, Illinois, Iowa, and Missouri, collectively known as the Corn Belt. Each state possesses soils, topography and favorable weather that support intensive row crop production. Within these same states, however, lie coal resources that can be extracted by surface mining methods. In the recent past, growing corn was impossible on unreclaimed land and where early reclamation had been done it was accomplished with difficulty if at all. Only recently have mine operators been required to restore the land to its previous capability to grow corn. Consequently, managing reclaimed soil to grow corn was addressed by only a few pioneer researchers in the past and remains a problem today.

MANAGING RECLAIMED SOIL

Iowa is a major corn growing state within the Corn Belt but approximately one-third of the state is underlain with coal. During the early 1900's, over 12,000 acres of land were surface mined for coal and abandoned to become acid wastelands. Coal production in Iowa had nearly ceased 20 years ago but the energy crisis of the early 1970's renewed interest in coal mining. The problems associated with high sulfur coal and the desire to grow row crops (corn and soybeans) on every possible acre of farmland served to propel a state-funded research program that became the Iowa Coal Project. As part of this project, Iowa State University operated its own coal mine from 1975 to 1977 and continued agricultural research on the site until 1985.

The Iowa Coal Project Demonstration Mine site is located approximately 45 miles southeast of Des Moines, Iowa in Mahaska County, a historic coal mining district in the state. Iowa State University leased forty acres of land that were underlain with 28 acres of coal. The excess land was used for stockpiling soil and overburden and construction of a sediment control structure. The topography of the site was that of a hillside above a stream with its associated flood plain. The elevation of the coal was above the stream which had truncated the coal seam.

Reclamation of the site required a plan for growing corn, a stated objective of the Iowa Coal Project. Before mining, a corn/hay rotation was used on the steep, sloping hillside with hay dominating the rotation because of the erosion hazard. Continuous row crops such as corn and soybeans could be grown on the relatively flat flood plain. In order to achieve the project goals, a reclamation plan was developed to build a series of parallel, nearly level, benched terraces to reduce the erosion hazard that would otherwise impede row crop production. The details of the reclamation planning for the Demonstration Mine are presented by Henning and Colvin (1977).

Reclamation was carried out at the Demonstration Mine concurrent with mining. It accomplished two things: the soil was saved and returned to the site and the topography was developed for an intended land use. After the site was reclaimed, other management considerations had to be

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developed in order to grow corn. These included the following:

1. establishment of a yield goal,
2. determination of soil fertility needs (lime and fertilizer),
3. selection of a tillage system,
4. selection of pest control methods,
5. selection of a corn cultivar and planting rate.

It was expected that additional unforseen problems in soil management would emerge after the project was begun, but the site was producing corn in 1978, the year following completion of mining and reclamation. Henceforth, the research on this site concerned agricultural management of a disturbed soil.

Corn Yield Goal

The minimum yield goal for lands reclaimed under PL 95-87 is easily established; it must be equal to or greater than the premining productivity. At the Demonstration Mine site, a yield goal was established from soil survey information and county yield records. Three soil series occurred at this site in five mapping units. Table 1 identifies each and gives their corn suitability rating (CSR) and land capability unit.

Table 1.--Soils and corn suitability of soils at the Iowa Coal Project Demonstration Mine - Mahaska County, Iowa.

Soil Unit	Capability Unit	CSR
Colo silty clay loam[1], 0-2%	IIw-2	80
Colo silty clay loam, 2-5%	IIw-3	75
Clinton silt loam[2], 5-9% eroded	IIIe-1	63
Clinton silt loam, 9-14% eroded	IVe-1	59
Boone fine sandy loam[3], 18-40%	VIIs-1	1

[1]Fine-silty, mixed, mesic Cumulic Hapludoll.

[2]Fine, montmorillonitic, mesic Typic Hapludalf.

[3]Mesic, Uncoated, Typic Quartzipsamment.

The CSR for a soil is a relative value based on 100 for a soil unit best suited for corn production. For the Demonstration Mine, a weighted CSR of 57 was obtained. The weighted CSR of land used for corn production in Mahaska County is approximately 73 during the period of 1973 to 1982 when the county yield of corn was 100.1 bushels of corn per acre. Consequently, the target yield for the mine site should be 57/73 of the county yield or 80 bushels per acre.

Over the ten-year period of 1973 to 1982, county corn yields ranged from 49 to 128 bushels per acre. This was due to the annual variations in weather. Recent work by Thompson (1986) has shown that there are six factors to be considered when calculating the effect of weather on corn yields. They are (1) preseason precipitation (September through June), (2) June temperature, (3) July rainfall, (4) July temperature, (5) August rainfall, and (6) August temperature. With the appropriate coefficients, a quadratic equation can be solved to determine weather's effect on corn yield. Further applications of this work have enabled Thompson to quantify the impact of technology on corn yields from the 1930's to the present time.

All the above factors were considered either directly or indirectly when the yield goal of the Demonstration Mine was established. The goal finally chosen was 150 bushels per acre and probably reflected optimism that affects farmers during the spring each year.

Soil Fertility Management

Initial soil test results of the reclaimed soil showed an average pH of 6.8, 9 pounds available phosphate per acre, and 100 pounds available potash per acre. The soil organic matter was low and variable across the site. Nitrogen was applied at 150 pounds of N per acre, phosphorus and potassium were applied at 100 pounds per acre of P_2O_5 and K_2O per acre. Three tons per acre of limestone with an average effective calcium carbonate equivalent (ECCE) of 50 percent were also applied to raise the soil pH to 6.9 or greater. Limestone was to be applied only once, but nitrogen, phosphorus and potassium were applied each year. The fertility program was maintained at this high level in order to increase the amount of plant available-phosphorus and potassium in the reclaimed soil. After five years, available phosphorus and potassium were approximately 50 and 170 pounds per acre of phosphate and potash, respectively.

To summarize the status of soil fertility management on reclaimed soils, soil testing can determine the amount of most plant-available nutrients and an appropriate quantity to add as fertilizer. Secondly, plant available nutrients, except nitrogen, in the reclaimed soil can be increased in a fertility program designed to build up soil test levels in addition to meeting plant demands. Finally, soil pH of reclaimed soil where no pyrites are present can be easily adjusted by determining an appropriate amount of limestone to be applied from a calibrated buffer soil pH test.

Tillage System

A tillage system based on chisel plowing was first adopted at the Demonstration Mine. This system was thought to be necessary to mix soil without interfering with the surface drainage of the nearly flat benched terraces. A moldboard plow was ruled out as the basis of the tillage system because it would leave "dead" furrows. The chisel plow system has been adequate to prepare a seedbed if used in the fall. However, a chisel plowed soil has to be disced in the spring and that has been difficult in wet years. A cloddy seedbed has often resulted and poor seed germination and emergence have occurred. A no-tillage system was introduced at the Demonstration Mine and it met with limited success. It worked fine in dry years but in wet years, mud could interfere with the planter and very uneven seed placement in very wet soil resulted in poor germination and emergence. During the last years of the project, a ridge-till system was tried with success. In the ridge-till system, seeds are planted on top of a ridge built the previous year when the row crop was cultivated with a cultivator designed to do so. The ridge will be firmer, drier, and warmer than a seedbed on flat soil during a wet year. This generally results in more uniform germination and emergence.

In summary, the physical condition of the reclaimed soil dictated that a ridge-till system be adopted for the Demonstration Mine site. The soil was poorly drained and of poor tilth because of compaction and its low organic matter content. The ridges built by cultivation of row crops the previous year provided the elevation needed for drainage and the crop residue lies between the ridges to provide erosion protection for the soil. In addition, the ridge-till system provides a means to control machinery traffic away from the important seedbed on top of the ridge.

Pest Controls

Weeds

Replacing topsoil restores viable weed seeds that will germinate and reduce corn yields. Weeds must be controlled either by cultivation, with chemicals or by a combination of both. Both cultivation and tillage of reclaimed soil at the Demonstration Mine was hindered by the physical condition of the soil. The period of time available for reclaimed soil to dry sufficiently to be cultivated as needed was limited. The poor tilth of the soil caused clods to be thrown over small plants, and although this could be overcome with shields, they then could plug in tough field conditions.

Choosing a chemical weed program is equally challenging on reclaimed soil. Variations in organic matter content force the use of chemicals not sensitive to this factor. Similarly, soil pH can be expected to be somewhat variable and chemicals sensitive to this factor should not be used. Soil texture seems to be the least variable factor in reclaimed soil and was not as important in chemical selection.

A combination weed control program takes advantages of the important properties of both cultivation and chemicals. Such a program is generally used in the ridge-till system. This system uses a band of chemical applied over the seedbed on top of the ridge just after planting. It controls weeds in the row. Cultivation between the rows controls weeds where no chemicals are applied and rebuilds the ridge for next year's planting. This program of weed control will reduce the amount of chemical used and yet eliminate weeds in corn.

In summary, weed control is necessary on reclaimed soils used for row crop production. Chemicals must be carefully selected where the soil physical conditions are variable. Of the soil factors that influence chemical selection, organic matter and pH are the most variable and hence most important to consider. Soil texture appears to be the least variable. The most desirable of all chemical programs for weed control may be those that are applied to the foliage.

Insects

Insect control in crops grown on reclaimed soil present no greater problem than on other agricultural soils. All crops must be scouted regularly to determine which pests are present and if their numbers are sufficient to warrant treatment. Crops grown on agricultural soils use the concept that treatment should not be undertaken except at a threshold where economic injury occurs. But on minelands, the level of productivity needed to achieve a bond release places an added value to the economic threshold. Consequently, the mine operator is required to control insects where there is the threat of yield losses.

Cultivar Selection

The yield potential of corn has increased dramatically since the 1930's. Much of the increase is due to the introduction of hybrid seed corn, to improved genetic potential which achieves greater yields, and to the introduction of modern technologies such as fertilization and chemical pest control. Of the hybrids used today, those produced by single cross or modified three-way crosses have the greatest yield potential and are very uniform in their growth habits. This uniformity contributes to greater yields but has the detrimental effect of subjecting the entire corn crop to whatever stress may be encountered at pollination. An entire corn crop may be lost if heat and drought stress occur simultaneously as pollination begins. The solution to this problem is to plant the same hybrid once a week for three weeks, or to plant several hybrids of different growing-degree day requirement in adjacent strips and hope that one or more escapes an serious pollination-reducing weather stress.

For the Demonstration Mine, an adapted hybrid utilizing the inbred parent B73 was selected. This hybrid has a high yield potential because of the erect growth habit of its leaves which allow sunlight to penetrate deeper into the plant canopy. At the time of its introduction, it had relatively high stress tolerance among the hybrids available then.

A planting rate of 22,000 kernels per acre was chosen to achieve the 150 bushel goal. This rate was derived by determining the weight of ear corn in pounds and dividing that by a desired ear weight of one-half pound. Farmers in the area will plant 27,000 to 30,000 kernels per acre on their better land hoping to achieve yields of 200 bushels per acre.

RESULTS

Corn was grown at the Demonstration Mine with some success from 1978 to 1984. Yields for this period were as follows: 1978 - 67.7, 1979 - 84.0, 1980 - 75.1, 1981 - 122.7, 1982 - 65.3, 1983 - 0, and 1984 - 81.8 bushels per acre. The average yield through the period was 70.9 bushels per acre or ten bushels less than the minumum yield goal that was set for the site. Weather had a dominant and varying effect on corn yields from year to year as was best illustrated in 1983, when a complete crop failure occurred.

Throughout the period, the pest control methods worked well. The soil fertility program supplied all the phosphorus and potassium required by the corn but nitrogen deficiency symptoms were visible where water stood for extended periods of time. Water began to stand, and form small ponds on the surface of plots where minor settling of the soil had occurred. Differential setting interfered with drainage and farming operations as well. Drainage into the soil of the ponded water was very slow because compaction was so severe in the replaced subsoil.

The effects of weather were compounded by soil compaction in the reclaimed soil. In the spring of a wet year, the soil was very difficult to work and subjected the corn crop to uneven emergence. If the soil became saturated, denitrification of nitrogen fertilizer occurred and robbed the plant of this yield building nutrient. Similarly, in very wet years saturated soil conditions and high soil strength would prevent the deep root penetration (3-5 feet) that would be needed later in the growing season for moisture extraction when moisture in top few inches of soil had been exploited by the crop.

The problem of soil compaction was investigated by determining the soil bulk density, volumetric water content, and saturation percentage of soil cores obtained to a depth of two feet. In this study, soil that had been maintained in continuous corn production was compared to soil where alfalfa had been grown.

Table 2.--Calculated physical properties of soil from continuous corn and alfalfa plots.

Crop	Soil depth - inches 6	12	18	24
	Bulk density - Mg/m^3			
Continous corn	1.41	1.44	1.48	1.63
Alfalfa	1.43	1.42	1.58	1.58
	Volumetric water content - percent			
Continuous corn	34.5	35.3	36.4	32.8
Alfalfa	29.7	29.7	26.0	26.7
	Saturation - percent			
Continuous corn	74.4	77.1	82.7	84.9
Alfalfa	54.7	64.6	64.9	68.7

The soil density data from the corn plot show sharp density increases at depths between 18 and 24 inches. Corn root penetration into the soil can be expected to be greatly impeded at values beginning at 1.50 Mg/m^3. Consequently, we would expect little water extraction at and below 24 inches. It is interesting to note from these data that soil from under corn and alfalfa had similar densities except at the deepest depths, and that where alfalfa had grown, the volumetric water content was less, and hence the percent saturation of the soil is also less.

RECOMMENDATIONS

Soil compaction as it relates to agricultural productivity is a central problem in the reclamation of minelands, especially in the Corn Belt where row crop production is given the top priority of land-use options. Yet the deleterious effects of compaction are tempered by the soil's tilth, that unique property of soil that includes bulk density, available water-holding capacity, texture, structure, soil strength, organic matter content, and mineralogical makeup to name a few. Measurement of the combined effects of these parameters is difficult, but that is what is necessary.

Voorhees (1983) states "Penetrometer resistance is probably a more sensitive indicator of soil [compaction] amelioration that bulk density determination because the latter is sensitive to pore volume and insensitive to fracture planes or planes of weakness." He adds that although water content and bulk density of soils can considerably affect soil penetration-resistance values, in some cases (on agricultural soils) it has been shown that the effects of variable water content on penetrometer readings can be controlled so that the results have meaning. However, Voorhees found in his study that the effect of the soil water on penetrometer resistance was best quantified at relatively low densities and generally became increasingly more difficult as soil bulk density increased. This indicates a need for more defining research in mineland applications, since encountered soil bulk densities are in or above the highest range studied by Voorhees. Additionally, a properly calibrated estimation of the "return to productivity" because of the large number of readings possible in a given time relative to other traditional soil strength measuring instruments.

Natural Amelioration

Soil compaction can be alleviated in nature by several related processes that are all temporally mediated. These include effects from wetting and drying, freezing-thawing, and the intrusion of macrofauna (e.g. earthworms) and roots into the soil along planes of weakness. These processes physically force the opening of fissures and micro-cracks. Repeating cycles of wetting and drying in compacted soils result in volume change of certain expandable clay minerals, a process that is referred to as shrink-swell. The forces generated within a soil mass by clay shrink-swell cause the development of cracks along existing planes of weakness, resulting in a general increase in porosity and, in turn, improved water transmission characteristics in the soil. Normal seasonal wetting and drying cycles are important in the shrink-swell process, but the introduction of plant roots that remove water can extend both the depth and occurrence of desiccation and rewetting effects within the soil mass.

Gill (1971) observed that freeze-thaw effects on the structure of agricultural soils were likely limited to areas roughly north of the 38th parallel, where the soil freezes annually to a minimum depth of 38 centimeters. Two freeze-thaw phenomena can be considered in the alleviation of soil compaction; physical expansion of soil water at temperatures near freezing, and the redistribution of soil water in response to changing water potentials due to the conversion of liquid water to solid water (ice) near lenses and other segregated soil ice forms. Water reaches its lowest density, that is, it occupies the greatest volume, at approximately +4 degrees C. It is unlikely that the force exerted as a moist soil freezes is great enough by itself to significantly reduce soil bulk density. However, the development of planes of weakness in s soil from water volume changes alone cannot be discounted as a factor in allowing other compaction alleviating forces to act.

There are two requirements for the growth of ice lenses at low soil temperatures. First, there must be enough soil water available to establish an effective soil water potential gradient, and second, there must be adequate initial porosity to allow for the movement of water along the potential gradient to the growing ice body. An extreme example of this phenomenon is found in the wet, porous artic lowlands where there are pingos, which are landforms raised by ice up to 30 m above the surrounding landscape. But the development of ice lenses is unlikely on mineland soils; initially at least, reclaimed soil will be too dense for sufficient water conductivity except where soil materials have been loosened mechanically.

Whether ice lens formation is beneficial in reclaimed soil is questionable. Evidence suggests that platy soil structure develops where lenses have occurred. Platy structure orients soil material in horizonal directions, effectively forcing water to move laterally as well as downward. The additional movement decreases the rate of drainage through soil.

The effects of flora and fauna on improving minesoil tilth are of great potential importance. Mention has been made of the development of fracture planes, desiccation cracks, or "planes of weakness" within the compacted soil mass. Plant species with roots capable of growth into the soil materials with mechanical impedance (high soil strength) and tolerance to adverse soil water conditions can take advantage of these planes to exploit more and more of the soil mass. As roots grow through these cracks, they allow for water from the surface to reach greater depths and they also extract water, effectively drying the soil mass, which then contributes to the formation of further desiccation cracks. Consequent and subsequent faunal activity is encouraged by proper vegetative cover, resulting in temporally mediated amelioration of reclaimed soil in the Corn Belt.

POSSIBILITIES

Productivity must be demonstrated on reclaimed soil under the Office of Surface Mining's Permanent Program Performance Standard[3] (PPPS). PPPS section 823.15 b-5 states, "Restoration of soil productivity shall be considered achieved when the average yield during the measurement period equals or exceeds the average yield of the reference crop established for the same period for unmined soils of the same or similar texture or slope phase of the soil series in the surrounding area under equivalent management practices." Corn is expected to be in this comparison because it is the dominant row crop in the Corn Belt. The use of a dominant row crop is addressed by PPS 823.15 b-6 which states "The reference crop on which restoration of soil productivity is proven shall be selected from the crops most commonly produced on the surrounding prime farmland. Where row crops are the dominant crops grown on prime farmland in the area, the row crop requiring the greatest rooting depth shall be chosen as one of the reference crops."

Corn today is a surplus commodity in the Corn Belt. The fence-row to fence-row farming goal of the 1970's no longer should be a driving force to re-establish productivity on reclaimed land. The emphasis today must rest with utilizing land for its capability and setting aside from production those lands which present an erosion hazard. This changed attitude, brought about by a marginally profitable agricultural economy, in turn suggests

[3]"Mineral Resources," Code of Federal Regulations Title 30, Pt. 700 to end 1986 rev.

new possibilities for reclamation in the Corn Belt.

If one scrutinizes the Conservation Reserve Program (CRP) of the Food Security Act of 1985 (PL 99-198), one can see that the goals of the Act are consistent with land management practices that protect the soil, even at the expense of reduced grain production. The Report of the House Committee on Agriculture to Accompany the Food Security Act of 1985[4] listed the following as necessary goals for a successful conservation reserve:

- protect our long term capability to produce food and fiber,
- reduce soil erosion of land in the program by as much as 20 tons per acre per year,
- reduce sedimentation in streams and along roads,
- improve water quality,
- create better habitat for fish and wildlife through improved food and cover and better moisture conditions,
- provide some needed income support for farmers.

PL 99-198[5] states, "The term "highly erodible land" means land - (i) that is classified by the Soil Conservation Service as class IV, VI, VII, or VIII land under the land capability classification in effect on the date of enactment of this act: or (ii) that has or that if used to produce an agricultural commodity, would have an excessive average annual rate of erosion in relation to the soil loss tolerance level ..." Applying these concepts to the Demonstration Mine would have made three soil mapping units available to be enrolled in the CRP before mining. Upon the completion of mining, all the reclaimed soil would be eligible for enrollment because they present an erosion hazard until vegetation is sufficiently re-established to provide it protection.

Both CRP and PPPS show similar concerns for soils but the latter requires production in spite of a changed farm economy and attitude toward production. The objective of demonstrated productivity, though important, must yield to concern for the soil and redevelopment of its potential over the long term.

[4]U.S. House of Representatives. 99th Congress. 1985. Food Security Act of 1985, Report of the Committee on Agriculture to Accompany HR. 2100. Rep't. 99-271, Part 1. Washington D.C.

[5]"Conservation." Food Security Act of 1985. PL 99-198, Title XII, 99 Stat. 1504-5. Washington, D.C.

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