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Productivity in Mississippi Delta Prime Farmlands Drastically Disturbed by Simulated Surface Mining

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Preface

The vast lignite reserve in Mississippi has created much interest in mining and utilizing this valuable resource. The information in this report resulted from cooperative research between the Mississippi Agricultural and Forestry Experiment Station and Phillips Coal Company to address issues relative to proposed lignite mining in the 1980's in the Mississippi Delta. Currently, a lignite mining project is under development in Choctaw County, Mississippi. This will involve construction of an electric power generating plant by the Tennessee Valley Authority to utilize lignite mined by Phillips Coal Company. Our earlier research clearly showed drastic disturbance to Delta prime farmland soils could result in increased crop yields. Several decades of experience in other states have developed reclamation technology for their soils to restore mined land equal to or better than before mining. Growth of crops and plants on reclaimed lands depends on the soils and nature of underlying materials. Performance is site-specific, and each site must be evaluated on its inherent properties.

Knowledge gained over the past decade should be valuable to any future lignite mining in Mississippi.

Introduction

Mississippi has extensive reserves of lignite, a low-grade coal, located in the Wilcox and Claiborne Group geologic strata. These Eocene Series outcrop in 33 counties of the state (Williamson, 1976). Mississippi contains about 22.2 percent of the 22.5 billion short tons of strippable lignite estimated to occur in the Gulf Coast Region of the United States (Lupens, 1978; Hossner and O'Shay, 1985). The Mississippi lignite is suited to surface mining because of the shallow depths to deposits and the unconsolidated overburden. Very limited extraction of lignite has occurred in the state primarily for local use in heating and blacksmith shops. Renewed interest in mining the lignite resulted in mineral leasing of an estimated 400,000 acres by 1976 (Williamson, 1976).

Interest in lignite mining in the 1970's and 1980's resulted in a feasibility study for a proposed surface mine in the Delta region of Quitman county. The project included extensive environmental studies to determine potential impacts of mining. The objectives of this study were to determine the impacts of drastic soil disturbance (simulated surface mining) on agronomic productivity of a prime farmland soil of large extent, and to evaluate different soil handling treatments.

Prime Farmland Soils

The nation's best agricultural lands have been designated as prime farmland. These lands are best suited for the production of food, feed, fiber, forage, and oilseed crops and are available for these uses (Johnson, 1977). Federal legislation enacted in 1977 and the 1977 Mississippi Surface Mining and Reclamation Act direct mandatory reclamation of areas disturbed by mining with special emphasis on prime farmland soils. Surface-mined areas are required to be reclaimed to a level of productivity equal to or higher than before mining.

Surface Mining Impacts to Soils

Surface mining disturbs natural horizonation and physical conditions, and it may limit future agricultural productivity. In parts of the Southeastern United States, subsoil is commonly a poor rooting medium for plant growth. Soil chemical properties may be amended with lime and fertilizer, but physical problems are more difficult to correct. High bulk density, low porosity, and water conductivity in subsoils caused by compaction enhance runoff and accelerate erosion.

Early study of subsoil productivity, when compared to topsoil, have generally considered subsoils inferior (Always et al., 1917). Lathan (1940) reported the surface horizon of Cecil soil in the Piedmont region was 1.6 times more productive than the B horizon (subsoil) and 11 times more productive than the C horizon (deep subsoil). Adams (1949) also found a decrease in the thickness of the surface horizon of a Cecil soil resulted in decreased crop yields. Langdale et al. (1979) estimated that each centimeter decrease in surface horizon thickness of a Cecil soil resulted in a corresponding 147 kg/ha (131.3 lb/A) decrease in grain yield. The early research was conducted on a very limited number of soils, such as Cecil, which has a strongly acid, infertile subsoil with physical and chemical restrictions.

Research on soils located near Mississippi determined the productivity of some subsoils was equal to or better than topsoil. Pettry et al. (1980) successfully revegetated a 65-ha (160-acre) coal mine in northeastern Alabama with fescue and clover using selected overburden material. Soil analysis revealed that plant nutrients and pH levels were much higher in the spoil material than in the natural soil. Considerable research has been conducted on reclamation of lignite surface mines in Texas where the fossil fuel is used for electric power generation (Angel, 1973; Brown and Deuel, 1977; Hons, 197; Hons et al., 1978). Askenasy et al. (1980) conducted field studies to determine the feasibility of raising row crops on leveled lignite mine spoil at the Big Brown steam electric station in Texas. Corn, grain sorghum, and soybeans were grown successfully on leveled mine spoil, provided proper fertilization and cultural practices were used. Hons et al. (1980) reported good yields of grasses and legumes could be obtained on lignite-mined soils with adequate fertilization. Chichester (1981) found when highly acidic spoil was excluded, mixed overburden from lignite mining could support good grass growth when adequately limed and fertilized.

Lyle et al. (1977) reported that tree growth on mine spoil in Alabama was equal to or better than natural soils. These researchers also found that plant abundance on a 25-year-oil spoil was similar to that of adjacent, unmined second growth forest land. Lyle et al. (1977) reported species composition of mine spoil areas became increasingly similar to natural soils as mine age increased, and the rate of succession on mined areas appears similar to that of old field succession on unmined areas of the southern United States.

Methods and Materials

Location and Nature of Study Area

The study site was located in the Southern Mississippi Valley Alluvium Major Land Resource Area (MLRA-131) commonly referred to as the Delta. The Mississippi Delta is an elliptical shaped physiographic region comprising the western part of Mississippi (Figure 1).

The area is bounded on the west by the Mississippi River, and it abruptly meets the loessial bluffs, which rise above the Delta on the east. The research site was located in the northeast part of Quitman County. It was about one mile northwest of the town of Sledge and three miles east of the Coldwater River.

The area was level with a slope of 0 to 1%. The site had been in row crops for the previous 20 years, and it was in soybeans at the initiation of this study in 1980. The site was in the vicinity of the Delta Star lignite mine proposed by Phillips Coal Company.

Soil

Soil at the study site was an Alligator clay (very-fine, montmorillonitic, thermic Allic Dystraquerts). These soils are poorly drained with gray, clayey surface (A) and subsoil (B) horizons. They are sticky and plastic when wet and firm when dry. They are locally referred to as gumbo soils. The high content of expansive montmorillonitic clay produces extensive shrinking and swelling, which form cracks in the summer with widths of 3 inches and greater. The soil was underlain at depths below 60 inches by a nonacid, loamy material that was 120 inches thick and contained dolomite detritus. Detailed soil descriptions and data are presented elsewhere (Wood and Pettry, 1989).

Climate

The climate of the region is mild and moist with mild winters and hot summers. The average annual precipitation is about 51 inches, and the average annual temperature is about 63 °F. The area generally has about 220 to 260 frost-free days.

Experimental Plot Design and Layout

The study site was an 8.2-acre block 900 feet long and 400 feet wide. The experimental design for the study consisted of a split plot arrangement of treatments in a randomized complete block design with four replications. The whole plot treatments were the two methods of land preparation, and subplot treatments were the soil segregation methods. Four plots (153 feet long, 20 feet wide, and 11.5 feet deep) were spaced over the 8.26-acre parcel of Alligator clay soil. Each subplot was 12.75 feet wide by 20 feet long to accommodate four-row equipment on 38-inch centers. The two center rows were used for yield measurements, and the two outer rows served as border rows.

The whole plot treatments consisted of (A) flat-bedded and (B) hipped rows. The six soil segregation treatments were as follows:

Control (C):	The control consisted of an unexcavated subplot in the same soil adjacent to the test plots.
Treatment 1 (T1):	The A and B horizons were removed separately, segregated, and replaced to a depth of 48 inches in the same morphological position existing prior to disturbance over mixed materials. Total depth of cut was 11.5 feet.
Treatment 2 (T2):	The A and B horizons were removed to a depth of 48 inches, mixed, and replaced to a depth of 48 inches over mixed materials. Total depth of cut was 11.5 feet.
Treatment 3 (T3):	The A and B horizons were removed separately to a depth of 24 inches, segregated, and replaced in the same morphological position over mixed materials. Total depth of cut was 11.5 feet.
Treatment 4 (T4):	Loamy material occurring at depths of 5 to 11 feet was segregated separately and replaced to a depth of 48 inches over mixed materials. Total depth of cut was 11.5 feet.
Treatment 5 (T5):	The total cut was randomly mixed to a depth of 11.5 feet.

Plot Construction

The plots were constructed by dragline with a 1.5 cubic-yard bucket and a small bulldozer (Case 450) in September and October 1980. Plots were excavated to a depth of 11.5 feet where the water table was encountered. The A (surface) and B (subsurface) horizons and deeper loamy strata occurring at depths of 5 to 11.5 feet were removed separately and segregated. The soil materials were replaced by dragline and allowed to overwinter before planting. Subplots were limed to bring them to similar pH levels. Piezometers (2-inch polyvinyl chloride) were installed in disturbed and undisturbed plots to 12.2 feet depth to record water table depths.

Plot Preparation and Cultural Practices

Plots were brought to grade following differential subsidence over the winter after construction. Segregated soil, which had been preferentially removed and stockpiled during construction, was used to bring plots to grade according to treatment. Plots were tilled to a depth of 6 to 8 inches.

Cultural Practices

Plant macronutrients (0-20-20) were applied at the rate of 200 lb/A each year (1981-82-83) prior to planting. Fritted micronutrients were applied at the rate of 200 lb/A prior to the first growing season (1981). Treflan® (ELANCO Company), a pre-plant incorporated herbicide, was applied at the rate of 1 pint/acre each year. The fertilizer and herbicide were incorporated with a tiller. The tiller was also used to hip rows to a height of 10 to 12 inches in the hipped treatment. Bedford variety soybean (*Glycine max* L.) was planted in May each growing season. The seeds were inoculated with rhizobium and treated with molybdenum.

After the stand was established, plants were thinned by hand to provide a uniform plant population of 15 plants per 40 inches of row length. Subplots were cultivated twice with a tiller during the growing season. Soybeans were harvested in October and threshed in a stationary rasp-type thresher.

Yields and Statistical Analyses

Harvested soybeans were sieved to remove foreign matter. Seed moisture content was determined with a Burrows moisture computer (Model 700) using 250 grams of soybeans. Yields were expressed on the basis of 13% moisture level. Data were analyzed using the Rummage II - General Purpose Models Program and a Univac 1100 computer.

Soil Analysis

Representative soil samples were collected for major horizons from excavated pits. Soil was air-dried and sieved to remove coarse fragments (>2mm). Particle size distribution was determined by the hydrometer method (Day, 1965) and sieving. Clay and silt fractions were separated by sieving and centrifugal sedimentation. They were analyzed via x-ray diffraction with a Norelco Geiger counter spectrometer using Cu K [illegible] radiation and an Ni filter.

Exchangeable cations were extracted in neutral NH4OAC and determined by atomic absorption spectrophotometry. Extractible acidity was determined by the barium chloride-triethanolamine method (Peech, 1965). Organic matter was determined by disgestion in chromic acid (Allison, 1935). Soil pH was measured using a 1:1 soil-to-liquid ration. Soil bulk density was determined by the undisturbed core method (Blake, 1965).

Results and Discussion

Soil Properties

Clay contents in the surface horizon (A_p) ranged from 65 to 48% over the study area with less than 20% sand and 30% silt. Sand and silt contents increased with depth. The upper clayey horizons were underlain at depths below 60 inches by stratified loamy materials, which contained common with dolomite coarse fragments. Particle size distribution of a representative pedon is presented in Table 1.

The soil was very strongly acid in the surface horizons before liming (Table 2). Soil pH increased with depth to mildly alkaline levels below 53 inches. Organic matter contents decreased regularly with depth to less than 0.2% below 53 inches. Calcium was the dominant exchangeable cation, with cation exchange capacities ranging to 50 $cmol_c kg^{-1}$. Base saturation increased with depth and exceeded 90% at depths of 24 inches and greater. Extractible acidity (H+) was greatest in the surface horizons and decreased with depth as pH increased.

The control and constructed subplots had clay surface textures except Treatment 4 (T4), which was comprised of loamy material occurring at depths of 5 to 11 feet (Table 3). Sand contents exceeded 60% in Treatment 4, with 20.4% silt and 17.2% clay. The clay was dominantly montmorillonite, with lesser amounts of kaolinite, illite, and vermiculite. Sand and silt fractions were dominantly siliceous with appreciable feldspar and mica contents. White detritus present in the loamy substratum materials was comprised dominantly of dolomite and calcite. Treatment 4 had a pH of 8.1 and 0.1% organic matter (Table 4).

Soil bulk density levels of the surface horizons ranged from 1.13 to 1.56 mg/m^3 before plot construction. Values were very erratic for several months after plot construction, reflecting the increase in macropores and temporal change. Bulk density exhibited seasonal variations with lowest values occurring in wetter winter months when freezing and thawing of the surface horizon occurred. Surface bulk density increased slightly after three cropping seasons (Table 5). No compaction problems were detected. Highest bulk density values were in Treatments T4 (loamy materials) and T5 (total mix), which contained less clay and more sand and silt than the other soil-handling treatments. Values tended to remain in the same range for 10 years following construction.

Most of the subsidence in the constructed plots occurred the first winter following fall construction. No subsidence was detected the third year following plot construction, and small amounts of stockpiled soil removed during construction remained. The control subplots and treatments T1, T2, T3, and T5, which had clay textures, exhibited surface cracks each summer during dry periods because of the montmorillonite clay with shrink-swell properties. Surface cracks ranged to 2 inches wide and occurred between the soybean rows. Cracking occurred when evaporation exceeded precipitation and soil moisture contents were less than 23%.

Treatment T4 (sandy loam texture) tended to form a surface crust, which slightly affected seed germination and emergence the first 2 years after plot construction. Organic matter contents increased to 0.36% after three growing seasons in Treatment T4 because of incorporation of crop residue. The organic matter content increased to 1.25% 10 years after plot construction. The increased organic matter contents resulted in darkening the surface color from white/gray to pale brown and development of weak granular structure.

Water table depths were similar in the disturbed and undisturbed plots (Figure 2). Water table depths were deeper than 8 feet throughout the study.

Plant Growth and Yields

Soybean plants in the constructed plots germinated and emerged quicker than plants in control plots. Plants in the soil-handling treatments tended to be taller, and they had deeper, better-developed root systems. The flat subplots generally had taller plants earlier in the season than the hipped subplots. However, plants on the hipped subplots attained similar heights as flat treatment subplots as the growing season progressed. Bloom and pod-set periods were similar for the control and all treatments.

1981 Season

Climatic conditions during the growing season posed a severe test of the ability of the disturbed soil materials to support plant growth (Figure 3). Plots received 18.63 inches of precipitation from the time of planting (May 13) until harvest (October 8). However, 9.8 inches (52.8%) of the precipitation occurred in May before plants were large enough to utilize it fully. It was more detrimental to the young plants than beneficial. Only 8.83 inches of rainfall occurred during the 123-day period from June 1 until harvest, and much of this precipitation was in increments less than 0.5 inch, which largely evaporated and did not infiltrate into the soil.

All soil-handling treatments in both flat and hipped methods of land preparation had significantly (P=0.05) higher yields than undisturbed control plots (Table 6). There were no significant differences in yield between the soil-handling treatments, nor was there a significant difference between flat and hipped treatments (Table 7). No interaction among soil-handling treatments was discernible. The mean yields of the soil-handling treatments were about double the mean yields of the control subplots. Yields in the control plots were similar to the average Quitman County soybean yields.

1982 Season

Timely rainfall and moderate temperatures during the growing season were conducive for high yields. Plots received about 22 inches of precipitation during the May-September growing season. Above average rainfall during August maintained good soil moisture during the critical pod-filling stage.

Plants were generally shorter on the control plots throughout the season. Yields for all soil-handling treatments were significantly higher (P=0.05) than yields of the undisturbed control under similar levels of fertility, management, and growing conditions (Table 8). There were no significant differences in yield between each of the soil-handling treatment subplots or between flat and hipped land preparation treatments (Table 9). Smaller yield differences were noted for the two land preparation methods in 1982 than occurred in the 1981 growing season. Average county soybean yields were similar to control subplot yields.

1983 Season

Very hot, dry weather during the bloom and pod-set caused severe plant stress. The plots received only 0.49 inch of rainfall in August and 7.84 inches June 1 through September 30. High soil temperatures, low rainfall, and low available soil moisture combined to promote poor pod set and development.

The mean yields for the soil-handling treatments were more than double that of the control plots (Table 10). The flat and hipped soil-handling treatments had significantly higher (P=0.05) yields than undisturbed control plots. There were no significant yield differences between each soil-handling treatment (Table 10), or between flat and hipped land preparation methods (Table 11). The large yield differences between the control and treatment plots were very impressive considering the severe drought during the growing season and the designation of 1983 as a crop disaster year for the study area. The control subplot yields were very similar to average county yields.

Three-Year Yield Relationships

Results of the 3-year study, which had diverse climatic conditions, are decisive. All soil-handling treatments increased soybean yields significantly (P=0.05), from 50 to 64% above the yields of the undisturbed control plots (Table 12). Yields of the control plots were very similar to local average yields of Quitman County (Figure 4). There were no significant yield differences between flat and hipped preparation treatments (Table 13).

Crop Growth and Soil Conditions 1984-1994

Crop growth and soil conditions during the decade following the 3-year yield trials were periodically monitored. The plots remained level with no additional subsidence observed over the 10-year period. Although yields were not recorded, the plants in the disturbed plots were taller and sturdier, and readily discernible. No soil toxicities or adverse physical or chemical conditions resulted from the soil-handling treatments. In contrast, the drastic disturbance to the clayer soil enhanced soybean growth and yields. Organic matter content in the treatment T4 (loamy material occurring at depths of 5 to 11 feet replaced to a depth of 48 inches over mixed materials) increased to 1.25% over the 13-year period accompanied by a darkening in color and slight decrease in pH.

Conclusions

All soil-handling treatments of drastically disturbed soil evaluated increased soybean yields significantly (P-0.05) above yields of the undisturbed Alligator soil under similar levels of fertility and management over three diverse growing seasons. Large yield increases resulted from drastic disturbance of the prime farmland soil in tests designed to simulate surface mining. There was no difference among the five soil-handling treatments, which ranged from morphological restoration to a total mix. One treatment was statistically as effective as another. The enhanced growth in the constructed plots was evident for a decade following disturbance. No short-term or prolonged adverse physical or chemical conditions resulted from the soil handling treatments. The increased yields are attributed to increased macrovoids, increased effective rooting depth, and improved porosity and water relationships resulting from the drastic disturbances.

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