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Sharkey Soils in Mississippi

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Preface

This research was conducted in response to observations by farmers, foresters, nurserymen, developers, soil scientists, and others indicating that Sharkey soils might have been incorrectly classified.

Sharkey soils are dominant in the Mississippi Delta, comprising more than a million acres in the state of Mississippi and more than 3 million acres in the United States. The soils extend from the Gulf of Mexico northward to Kentucky in the Southern Mississippi River Valley Alluvium and are immensely important to Mississippi and the nation for food and fiber production. Early soil researchers compared the importance of these alluvial soils to those of the Tigris and Euphrates River Valleys, whose development gave rise to ancient Babylonian agriculture and the dawn of civilization.

Sharkey soils in Mississippi were largely mapped and classified prior to adoption of Soil Taxonomy Soil Classification System in 1965. Subsequent classification and interpretations were made without temporal field research. Detailed agricultural production data provided a basis for classifying Sharkey soils as prime farmland, but no temporal data existed for classification as hydric soils and Inceptisols.

Intensive field and laboratory studies of four Sharkey soil sites in Washington County, Mississippi for 5 years clearly indicate the Sharkey series should be reclassified as Vertisols. The Sharkey soils exhibit maximal properties definitive for Vertisols with pedogenic expression typifying the Vertisol Order on a global basis. The hydrologic data show the Sharkey pedons had average water table depths below 100 inches. Average soil moisture contents decreased with increased depth, and subsoils exhibited small seasonal variations.

This research clearly verifies field observations over the past two decades. Sharkey soils in Mississippi should be reclassified for proper interpretation and utilization.

Acknowledgments

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Contents

Objectives

This research evolved to define and provide a temporal data base of soil morphological, chemical, and hydrologic parameters for the Sharkey series, the dominant soil in the Mississippi Delta region.

The research objectives were to:

1. Determine morphological, chemical, and physical properties of a soil series listed as a hydric soil.
2. Determine dissolved oxygen contents and depth to water table and relate to soil morphological characteristics.
3. Document forest vegetation and determine relationships to water table depths, dissolved oxygen levels, and soil temperature.
4. Interpret data to ascertain if this soil is properly classified as hydric.

The Sharkey soil series was studied because of the vast acreage it comprises over a broad region and its importance to society. The study was conducted from 1991 to 1995.

Introduction

The Sharkey soil series was established in Yazoo County, Mississippi in 1901, and it is one of the oldest soils recognized in the United States. Sharkey is the dominant soil mapped in Mississippi, comprising about one million acres. It is also a dominant soil in the nation, with at least 3 million acres mapped. Many of the original theories concerning the origin and properties of Sharkey soils have persisted since it was established. These soils were initially recognized as clayey, expansive soils occurring on nearly level topography on lower parts of natural levees, terraces, and flood plains of the Mississippi River and tributaries. Their clayey, sticky, and plastic nature gave rise to usage of the terms "gumbo" and "buckshot" when referring to Sharkey soils.

Sharkey soils occur in the Southern Mississippi Valley Alluvium major land resource area (MLRA 131) and extend from the Gulf of Mexico to Kentucky. These soils are extensive in Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee on the Mississippi River flood plain and terraces. Slope gradients are 0 to 5%, with short slopes that typically occur as parallel ridges and swales. Sharkey soils formed in clayey alluvium of recent Holocene age and have clay contents of 60 to 90% in the subsoils. Soil reaction ranges from strongly acid in surface horizons to moderately alkaline in the subsoil. Sharkey soils are typically dark gray to gray, with brownish, yellowish, or reddish mottles.

These soils are currently classed as poorly drained with slow surface runoff and permeability. The expansive clay develops large cracks each year. The Sharkey series is designated prime farmland and hydric soil.

Although classed as poorly drained in soil surveys, several phases of Sharkey soils were mapped indicating a range of drainage or wetness. In the county where the Sharkey series was established, the latest Yazoo County Soil Survey (Scott et al., 1975) mapped Sharkey clay depressional phase (11,500 acres) and Sharkey clay (60,790 acres). Sharkey depressional phase was much wetter than other phases of the same soil series.

In other Delta counties, such as Washington (Morris, 1961), Sharkey clay, level phase, 0 to ½% slopes, was mapped on broad flats or in slightly depressed areas (36,630 acres). Sharkey clay, nearly level phase, ½ to 2% slopes, comprised 100,460 acres or 21.6% of Washington County. Other Sharkey units in the county were Sharkey clay, gently sloping phase, 2 to 5% slopes, which included areas with slopes up to 8%; Sharkey silty clay loam, nearly level phase, ½ to 2% slopes; and Sharkey very fine sandy loam, nearly level overwash phase, ½ to 2% slopes.

The soil surveys recognized the effects of topography on soil wetness and used different phases of Sharkey to depict landscape and drainage differences that were important to land use and management (Appendix Table 1).

The soil surveys of Mississippi Delta counties delineated associated soils wetter than Sharkey in depressions, low swales, and drains as the Dowling series. Low, wet areas flooded much of the time were mapped Swamp, and frequently flooded soils near streams were mapped Alluvial Soils (Morris, 1961). In recent years, Dowling soils were office-correlated into the Sharkey series. Nearly a half-million acres of wetter Dowling soils were correlated to Sharkey soils (Appendix Table 2).

The Mississippi Delta counties were largely mapped and published prior to adoption of Soil Taxonomy (USDA, 1975). The soils were reclassified without additional field mapping and studies. Office correlations merged Dowling and Alluvial soils with very limited or no additional field data of a modern nature. Hence, the drainage and wetness concepts of the Sharkey soils became more general and nondefinitive. Extensive agricultural production data for various crops provided a factual data base for classifying soils, including Sharkey, as prime farmland soils. However, no comparable data existed to provide a framework for classifying Sharkey as a hydric soil.

The Sharkey series was classed hydric (SCS, 1987) based upon criteria (2B3), "water table at less than 1.5 feet from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/h in any layer within 20 inches." Other phases of Sharkey soils classed as hydric were: Sharkey commonly flooded (criteria 2B2, 4); Sharkey, overwash (2B2); Sharkey, ponded (2B2, 3). The list of hydric soils was created by computer using criteria developed by the National Technical Committee for Hydric Soils (SCS, 1987). Water table criteria for Sharkey soils mapped in Mississippi have not been clearly established by field validation over a temporal period.

Sharkey soils were classified as Grumusols prior to Soil Taxonomy, based on shrinking, swelling, and cracking properties. In the Tunica County, Mississippi Soil Survey completed in 1942, Simonson (1956) reported the organic matter content in the A1 horizon was common to many Grumusols. Humic Gley soils were wetter and had very high organic matter contents in surface horizons because of wet, reduced conditions. After 1965, Sharkey soils were reclassified without field studies as very-fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts in spite of numerous data indicating a Vertisol classification (Holmes and Hearn, 1942; Bruce et al., 1958; Fowlkes et al., 1956; Morris, 1961). The Washington County Soil Survey (Morris, 1958) reported cracks in Sharkey soils 1 to 5 inches wide extending several feet in depth.

Large acreages of Sharkey soils are used intensely for production of soybeans, rice, wheat, cotton, grain sorghum, oats, catfish, hay crops, and pasture. Uncleared areas remain in forest.

General Nature of Study Area

The study sites are in the Southern Mississippi Valley Alluvium Major Land Resource Area (MLRA-131), commonly referred to as the Delta (Figure 1). The Delta comprises about 36,130 square miles (93,600 km^2) in Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee (USDA, 1981) and is one of the largest contiguous agricultural areas in the United States.

The Mississippi Delta is an elliptical-shaped physiographic region comprising the western part of Mississippi (Figure 2). 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 largest part of the Delta extends from Memphis, Tennessee to Vicksburg, Mississippi, a distance of about 200 miles. The Delta is about 75 miles wide at its widest point in the state. The area is nearly level, which is typical of large flood plains. The general slope extends to the south. Elevations range from 217 feet near Memphis to about 94 feet above mean sea level at Vicksburg. In addition to the Mississippi River, the main streams are the Yazoo, Big and Little Sunflower, Tallahatchie, and Cold Water Rivers. Abandoned stream meanders and oxbow lakes are common.

The Mississippi River Valley was formed over the last 1.5 million years through a series of down-cuttings and subsequent refillings directly related to advancing and recycling continental glaciation (Saucier, 1974). The last change from braided to meandering stream conditions occurred 10,000 to 12,000 years ago. Meander belts reflect the previous course changes of the Mississippi River.

The climate of the Mississippi Delta is warm and humid, with hot summers and moderate winters. The mean annual temperature is about 63 °F, and the mean annual rainfall is about 51 inches. The area generally has 220 to 260 frost-free days (Pettry, 1977).

The Delta's soils are very productive under proper management, and they are suited to a wide range of crops. One of the early technical studies (Holmes and Hearn, 1942) stressed the agricultural importance of the Mississippi alluvial soils and compared them in importance to soils of the Tigris and Euphrates Rivers and the birth of civilization.

Soil Genesis in the Delta

The factors of soil formation are parent material, climate, organisms, time, and relief (Jenny, 1941). The length of time a material has been in place and under the influence of local climate and vegetation often determines the kind of soil found. Recently deposited alluvium usually shows little development or formation of soil horizons.

Parent Material

Parent material is "the physical body of soil and its associated chemical and mineralogical properties at the starting point of a particular set of other soil-forming factors" (Buol, Hole, and McCracken, 1973). Generally, parent material exerts greater influence on younger soils than on older landscapes. The original parent material becomes less recognizable as weathering and soil formation proceed.

The Mississippi Delta parent material is dominantly alluvium deposited by the Mississippi River and its tributaries. The sediments originated in the vast, diverse Mississippi drainage system, which comprises a large area of the United States. Consequently, the materials have diverse mineral suites because of their heterogeneous origin and differential stages of weathering, and previous pedogenic development. The surficial materials are primarily two types. The first, sands and loamy deposits, occurs as old natural levees of previous stream beds. The other type of sediment consists of clayey materials located in "slackwater" areas (interfluves) between streams. Water velocity decreases as it overflows its banks and moves away from the stream bed. This results in heavier sandier materials being deposited near the stream and clayey sediments being carried in suspension until a low velocity is achieved and they are deposited. The slackwater areas are usually lower in elevation than stream-side deposits (Logan, 1916) and act as a sink for finer-textured materials.

Time

The present surface of the Delta was deposited in recent times in the Holocene geologic timeframe. Material was deposited on a broad scale by the Mississippi River until the levee on the Mississippi side of the river was completed. Local flooding and sedimentation continue to occur in "backwater" areas, where drainage waters flowing into the Mississippi River back up during high flow periods.

Sediments forming the land surface were deposited during and after the advances of Wisconsin glaciers, the latest active in the North Central States about 11,000 years ago (Arnold and Libby, 1951). The present surface of the Mankato drift has been exposed about 8,000 years, and the soils in the Mississippi Delta counties could be slightly older (Simonson, 1956).

Relief

The Delta is characterized by level relief and low hydraulic gradients. Small differences in elevation (microrelief) have a major impact on water movement. A few inches difference in relief in the Delta has a major impact on water movement and soil development.

Climate

The climate of the Delta is warm and humid, with hot summers and mild winters. The temperature and precipitation are conducive to intense weathering.

Organisms

The region was primarily a hardwood forest with intermittent swamps and bayous before it was cleared for cropland. Diverse species, including oaks, gums, ash, hickory, black willow, and cypress, covered this region. A limited area of forest cover still exists in the Mississippi Delta.

Methods and Materials

Study sites were located in forested areas in Washington County, Mississippi on the MAFES Delta Branch Experiment Station Forest near Stoneville, and in Percy Quinn State Park, about 25 miles south of Stoneville (Figure 3). The sites were selected in natural wooded areas representative of the Sharkey series with typical bottomland hardwood vegetation. The areas had not been previously cleared or cultivated. Two research sites were installed February 1991 at each location about 0.5 mile apart in two phases of the Sharkey series (Table 1).

The Delta Experimental Forest sites were about 10 miles east and the Percy Quinn Park sites about 8 miles east of the Mississippi River (Figure 3). The sites were not subject to flooding.

Batteries of piezometers were installed 40 inches apart at 10, 20, 40, and 120 inches depth. Piezometers were constructed of 3-inch diameter polyvinylchloride (PVC) tubes permeated with 0.125-inch diameter holes. Washed gravel was placed in the bottom of the holes and piezometers were driven and fitted snugly into 3-inch diameter auger holes. A clay seal was packed around the piezometer at the soil surface. A vented cap covered the piezometers, which extended about 6 inches above the soil surface. An unlined 3-inch diameter bore hole was drilled to 120 inches about 40 feet from the piezometers and the surface was covered. Piezometers were installed in February and March 1991. No water was encountered during installation at any of the depths. Water levels were measured monthly or more frequently for the duration of the study. Piezometers were pumped dry and allowed to equilibrate to verify water levels.

Field Characterization and Sampling

Soils were examined by hand auger in transects to locate representative pedons for detailed characterization and evaluate spatial variability. Soil pits were excavated by hand shovels. Landscape elements were determined at each site. Soil morphological parameters were determined (USDA, 1994), including horizonation and depth, Munsell color, texture, structure, consistence, mottling and redoximorphic features, presence of concretions, topography and thickness of horizon boundaries, and size and distribution of roots.

Nondisturbed core samples were taken in selected horizons for determination of bulk density, saturated hydraulic conductivity, and moisture retention. Duplicate core samples were taken from selected horizons within a one-meter distance of a contiguous pedon by cutting back the face of the pit and exposing each horizon from the surface to the bottom of the pit.

Surface microrelief was determined on 10-foot intervals in directional transects with a transit level. Soil microdepressions were measured by rigid steel tape and transit level.

Soil moisture content was monitored gravimetrically on a temporal basis in 10-inch increments from the surface using 100-gram auger samples. Soil temperature was measured in the epipedon with a soil thermometer (ReoTemp Instrument Corporation).

Dissolved oxygen levels and temperature of soil water were measured with a YSI model 58 dissolved oxygen meter (Yellow Springs Instrument Co., Inc.). A submersible stirring oxygen probe was lowered into the piezometers containing water to determine oxygen levels.

Fresh soil peds from the surface through the solum were tested with [illegible], [illegible]$^{-1}$-dipyridyl solution for nonvisible redoximorphic features (soluble iron) on a temporal basis (Soil Survey Staff, 1994).

Laboratory Methods

Bulk Density

Soil bulk density was determined by the method described by Blake (1995) on nondisturbed cores taken with a double-cylinder sampler. The inner cylinder of known volume was dried in the oven at 110 °C for 24 hours and weighed. The bulk density was calculated by the following formula:

$$\text{Bulk density} = \frac{\text{sample oven-dry weight}}{\text{volume of sample}}$$

Saturated Hydraulic Conductivity

The constant-head method (Klute, 1965) was used on the nondisturbed cores. The cores were saturated in standing water for 48 hours and then placed on a constant head permeameter rack to equilibrate for one hour. Water passing through the cores was measured at 10-minute intervals for a total of five measurements. Values reported are the average value of five observations.

Moisture Retention

The pressure membrane method (Richard, 1949) was used with the natural aggregates of the nondisturbed cores. The cores were saturated with water for 24 hours on a presoaked ceramic porous plate. Pressures of 0.03, 0.1, 0.3, 0.6, and 1.5 MPa were maintained until equilibrium was achieved. The moisture contents were calculated on an oven-dry basis.

Soil Analysis

Soil samples were air-dried in the laboratory, crushed with a wood cylinder, and sieved through a No. 10 sieve to remove coarse fragments larger than 2 mm (USDA, 1992). Particle size distribution was determined by hydrometer method and sieving (Day, 1965). Organic matter was determined by wet combustion procedure (Allison, 1935). Extractible acidity was determined by the barium chloride-triethanolamine method (Peech, 1965). Exchangeable aluminum was determined in KC1 extractions following the procedure of Yuan (1959). Exchangeable cations were extracted with neutral *N* NH_4OAC and determined by atomic absorption spectrophotometry (USDA, 1992). Soil pH was measured in water and 0.1 N KC1 using a 1:1 soil-to-liquid ratio. Iron was fractionated using the method of Gamble and Daniels (1972). Total Fe was analyzed by HF and $HC1O_4$ digestion in Pt crucibles (Jackson, 1982). Total sulfur was determined on soil ground to pass a 60-mesh sieve with a sulfur analyzer (Model LECO SC 132).

Mineralogy

Clay fractions of selected horizons were separated by centrifugal centrifugation. They were analyzed by x-ray diffraction (Jackson, 1956) with a Norelco Geiger counter spectrophotometer using Cu K[illegible] radiation and a Ni filter. Mineral type and content were estimated from basal spacings and x-ray peak intensity. Microscopic examinations were made of soil peds using conventional light microscopy. Coefficient of linear extensibility (COLE) was determined on < 2 mm extruded soil paste (Shafer and Singer, 1976) where:

$$\text{COLE} = \frac{\text{Length wet - length dry}}{\text{length dry}}$$

Results and Discussion

Morphology

The representative Sharkey pedons had ochric epipedons and cambic subsurface horizons (Tables 2, 3, 4, and 5). Surfaces were dark to very dark grayish-brown in hues of 10YR with values of 3 to 4 and chromas of 2. The upper subsoil was dark to very dark gray in hues of 10YR with values of 4 to 5 and chromas of 1 to 2 with strong brown mottles. Soil color became brighter with increased depth. Site 1 was yellowish-red in 5YR hues below 120 inches depth and highly mottled above this depth. Site 2 had pale brown color with 3 chromas below 36 inches. Site 3 was brownish-yellow to strong brown below 60 inches, and Site 4 was grayish-brown below 50 inches.

The forested soils had well-developed angular blocky structure in the upper sola. The subsoil had compound structure consisting of coarse prismatic parting to angular and subangular blocky structure. Pockets and cracks were evident in the upper sola, with common pressure faces on peds. The surface horizons contained many roots, which extended to depths of 40 inches and greater and promoted structural development. The roots also created many macrovoids in the surface horizon. The soils had friable to firm consistency in the surface horizon and firm subsoils, which were sticky and plastic when moist.

Intersecting slickensides were very prominent features in the Sharkey pedons, reflecting the shrinking and swelling properties, except for Site 2, which had loam textures at 36 inches. The slickensides became wider with depth and were prominent to depths of 60 inches and greater. The soils had cracks at the surface each year of the study. The cracks ranged to 3 inches wide and extended to depths of 3 feet and greater. The cracks were visible from May to October, and they would close and reopen after significant precipitation events. The forest litter tended to obscure the surface cracks, which were exposed when the litter was removed.

White gypsum ($CaSO_4$ $2H_2O$) crystals were prominent features at 40 to 70 inches in the subsoils of sites 1, 3, and 4. The gypsum occurred in a clay matrix as clusters in veins and pockets with individual crystals ranging to 4 mm and larger. The crystal habit of the gypsum was both tabular and fibrous. Round, black concretions occurred intermingled with gypsum at 50 to 65 inches in Site 1. The concretions occurred at different depths in Sites 3 and 4.

The morphological features of the Sharkey soils at the four sites corresponded very closely with previous descriptions and mapping concepts (Brown et al., 1970; Schumacher et al., 1988; Bruce et al., 1958; Holmes and Hearn, 1942; Morris, 1961; Rogers, 1958; Wynn, 1959). The earlier descriptions of Sharkey were limited by the relatively shallow depths at which they were examined. Recognition of brighter colors with increasing depth requires deeper examination (> 60 inches). Also, the common occurrence of gypsum in the subsoils and pronounced compound structure had not been previously recognized and stressed. Cracks that extend to the surface, large intersecting slickensides, and compound structure are distinctive features of the Sharkey pedons.

Particle Size Distribution

All the sites had clay textures in the epipedon (Appendix Table 3). Sites 1, 3, and 4 had clay contents exceeding 60% to depths of 60 inches (Figure 4). Site 2 had loamy materials below 30 inches with clay contents ranging to 72% in the upper sola (Figure 4).

Site 1 had clay contents exceeding 60% to depths of 100 inches, with less than 5% sand to 90 inches, and silt contents less than 30% in the upper 30 inches. Site 2 had average clay content of 56% in the upper 30 inches, with less than 20% sand (Figure 5), and silt contents of 20 to 44%. Clay contents exceeded 40% to depths of 70 inches in Site 3, with less than 10% sand in the upper 50 inches, and silt contents of 23 to 13%. Site 4 had greater than 68% clay in the upper 80 inches, accompanied by sand contents less than 5%, and silt contents of 26 to 13%.

Fine clay dominated the clay fraction in all sites with fine clay (<0.2 μ)/coarse clay (2 to 0.2 μ) ratios ranging from 1.2 to 1.84. There was no indication of fine clay accumulation with increased depth suggesting no eluviation/illuviation. The sand was dominated by very fine and fine fractions reflecting low energy deposition.

Chemical Properties

Chemical properties are presented in Appendix Table 4. Organic matter decreased regularly with depth (Figure 6). Maximum contents exceeded 3% and occurred in the thin ochric epipedon. Soil pH levels were very strongly acid in the surface horizons and increased with depth to slightly alkaline levels at 60 inches depth (Figure 7). Calcium was the dominant exchangeable cation and Ca/Mg levels were less than 2. Cation exchange capacities exceeded 50 cmolc kg^{-1} in the upper 70 inches of Sites 1, 3, and 4 and were greater than 30 cmolc kg^{-1} in Site 2. Higher exchangeable acidity levels in the upper 20 inches correspond to lower pH levels reflecting the effects of organic matter and weathering. Exchangeable Al^{3+} was very low or not detectable.

Total S levels corresponded to the presence of gypsum crystals with maximum values occurring in subsoil Bssyg horizons of Sites 1, 3, and 4 (Figure 8). Sulfur contents were lower in Site 2 where no gypsum was detected. The gypsum appears to be authigenic and probably formed by precipitation and crystallation in an oxidized environment.

Soil Bulk Density

Bulk density levels were extremely low in the surface horizons (Table 6) because of a dense root mat and presence of large macrovoids. Values ranged from 0.77 g cm^{-3} in Site 2 to 1.01 g cm^{-3} in Site 3 in the 0- to 6-inch surface horizon. Bulk densities increased slightly in the subsoil but were relatively low because of the high content of montmorillonitic clay. The higher values in the subsoil of Site 2 reflect the loamy textures and lower montmorillonite clay content.

Soil Moisture Retention

Soil moisture retention data for selected depths are presented in Table 7. Terms applicable to soil moisture retention are: field capacity, permanent wilting point, and available water capacity. Field capacity is the amount of water in the soil after excess gravitational water has drained and the downward water movement has decreased (Veihmeyer and Hendrickson, 1931). Field capacity is defined as the moisture content at one-third (1/3) atmospheric tension (0.03 MPa). Permanent wilting point occurs at 15 atmospheres (1.5 MPa) and is the moisture content of the soil where plants wilt and cannot recover even under saturated conditions. Available water represents the soil water that plants can withdraw, and it is defined as the difference between field capacity and permanent wilting point.

Soil moisture retention values were very similar for the four sites except for lower values in Site 2. The available water was greater in the surface horizons because of higher organic matter content. The high moisture retention at field capacity (0.03 MPa) and permanent wilting point (1.5 MPa) is typical of soils with high montmorillonite clay contents.

Saturation point is the moisture content of the soil when all the pores are filled with water, and it was measured in the laboratory by the Direct Method (Gardner, 1965). Saturation values in the surface horizons ranged from 74 to 88% at all four sites with variation caused by differences in the amount of organic matter and degree of decomposition. The high moisture contents at saturation are due to the high clay content, organic matter, and expansive montmorillonite clay.

Saturated Hydraulic Conductivity

Saturated conductivity in the surface horizon was high because of the presence of roots and associated macrovoids (Table 8). The process of taking cores of the root-matted surface horizon also may have created additional fissures. Very low hydraulic conductivity was measured in the clayey subsoil horizons. Soil cores were not taken in volumes containing cracks and krotovinas.

Mineralogy

Montmorillonite dominates the fine clay fraction (<0.2 µ) at all sites. The coarse clay fraction (2 to 0.2µ) consists of montmorillonite, illite, kaolinite, and quartz. The silt fraction contains quartz, feldspars, and mica.

Coefficient of Linear Extensibility (COLE)

The COLE values of the upper 60 inches of Sites 1, 3, 4, and the upper 30 inches of Site 2 far exceeded the value of 0.09 considered minimum for Vertisols and ranged to 0.28. The COLE values decreased in the loamy subsoil of Site 2 to values less than 0.02. Total clay and montmorillonite contents have been shown to be highly correlated to COLE values (Karathanasis and Hajek, 1985). The high values indicate the very expansive nature of these cracking soils.

Microscopic Examination

Peds from surface and subsoil horizons from each site were examined under reflected light at 50 to 150X. Observations of root-soil matrix in surface horizons revealed no oxidized rhizopheres. Faunal pellets were common in the surface horizons. The soil had very tight adhesion to the roots. Scattered flecks of 5YR and 7.5YR hues were mixed throughout the matrix. Pressure faces on ped surfaces gave the appearance of "scales." The gray matrix had a dull, waxy appearance. Slickenside surfaces were polished and striated and appeared to have a thin coating of colloidal organic matter. In deeper horizons, gypsum crystals had a very sharp boundary with the surrounding matrix. Some crystals had a thin $CaCO_3$ effloresced coating. Concretions were embedded in random patterns in deep subsoil horizons with gradual and sharp boundaries with the matrix.

Extractable Fe

Acid ammonium oxalate (Fe_o) and dithionite-citrate-bicarbonate (Fe_d) extracted Fe are presented in Table 9. The oxalate extraction dissolves the amorphous Fe, and the dithionite extraction dissolves the crystalline Fe (McKeague and Day, 1966). Amorphous Fe_o was dominant in the upper sola of all sites and dominant at all depths in Site 1. Both Fe_o and Fe_d levels in Site 2 dropped sharply in the loamy subsoil materials.

Total Fe

Total Fe_t (Perchloric acid digestion) levels (Table 10) revealed the Sharkey soils have abundant Fe content. Maximum Fe_t values were 44,800 ppm in Site 1, 39,400 ppm in Site 2, 46,800 ppm in Site 3, and 51,000 ppm in Site 4. Fe_t contents decreased in the loamy materials of Site 2 subsoil. The Fe that exists as a structural component of silicates may be estimated by the difference between total Fe_t and dithionite extractable Fe = (Fe_t - Fe_d) according to Blume and Schwertman (1969). Santos et al. (1986) reported the presence of iron-rich montmorillonite in the fine clay fraction in three Boralfs. Other researchers have reported the main phyllosilicate clay in selected soils was comprised of Fe-rich montmorillinite that contained less Fe than nontronite (Mermut et al., 1984).

Exchangeable Fe

Temporal analyses for exchangeable Fe (ferrous) during wetter winter and spring seasons revealed only trace levels (<1 ppm) in the Sharkey pedons (Table 11). In saturated reduced soils, soluble ferrous iron would tend to displace other cations on the soil exchange complex resulting in significant exchangeable Fe (Gotoh and Patrick, 1974; Richardson and Hole, 1979). Gotoh and Patrick (1974) detected 1,065 to 1,979 ppm exchangeable Fe under controlled reduced conditions in the laboratory using Crowley soil. The lack of exchangeable Fe suggests oxidized microsites.

Extractable Mn

Schwertmann and Fanning (1976) reported that permanent soil wetness may lead to complete loss of Fe and Mn by leaching. McDaniel and Bush (1991) quantified the differential movement of Fe and Mn in saturated soils and suggested the relationship could be used to infer the saturated status of soils. Dithionite extractable Mn contents of the Sharkey pedons (Table 12) were similar to levels of upland Vertisols in the state. Higher levels occurred at depths of 40 inches in Sites 1, 3, and 4, and at the textural break in Site 2. Mn levels tended to coincide with presence of concretions in the subsoil. The Mn levels indicate solubility and removal of Mn has not occurred in the Sharkey soils.

Fe Contents in Surface and Subsurface Waters

Surface and subsurface waters were periodically sampled and analyzed during the study with emphasis on ferrous iron levels. Average levels of ferrous iron were as follows for January sampling:

Source	Fe (ppm)
Road ditch	1.77
Stump hole	0.16
Creek	3.66
Piezometer H_2O at 110 inches	0.08

Soil water contained extremely low Fe levels, and runoff waters were also very low in ferrous Fe throughout the duration of the study.

Soil Color -- Fe Relationships

The Sharkey soils have dominant gray colors but contain high levels of Fe similar to well-drained Vertisols in upland positions. The content and form of Fe in soils have long been related to soil color, which has been used to infer drainage and wetness. Soils with low chromas (2 or less) are often considered gleyed. Early workers (Bloomfield, 1950, 1951) suggested gleyed soil color resulted from unmasking of soil material by the removal of iron oxide coatings to expose the mineral grains. Daniels et al. (1961) suggested soils with high Munsell values and low chromas usually have little free iron, and may have small amounts of weatherable iron-bearing materials. These researchers further stated that coloration patterns and redoximorphic features are difficult to understand in these soils. Later work by Bloomfield (1952) reported soils can have significant amounts of extractable Fe and yet be gleyed (chroma 2 or less). Bloomfield suggested the iron was present as an organoferrous complex adsorbed on the mineral surface. Recent research (Dobos et al., 1990) attributed the lower chromas to hematite dissolution allowing goethite and nonoxide minerals to influence color strongly.

Daniels et al. (1961) noted that neutral and gley hues relate to the presence of ferrous iron. Various researchers (Maubach et al., 1994; Daniels et al., 1961) have reported that ferrous iron occurs only in reduced or waterlogged soils depleted of oxygen. The accepted field test (SCS, 1994) to determine the presence of ferrous iron and reduced conditions uses an indicator reaction. The Keys to Soil Taxonomy (SCS, 1994) state, "A freshly broken surface of a field-wet soil sample is treated with [illegible], [illegible]$^{-1}$-dipyridyl in neutral 1-normal ammonium-acetate solution. The appearance of a strong red color on the freshly broken surface indicates the presence of reduced iron ions."

[illegible], [illegible]$^{-1}$-dipyridyl Tests

Freshly broken soil peds from the surface to 70 inches depth were tested seasonally with [illegible], [illegible]$^{-1}$-dipyridyl solution for the presence of ferrous Fe as demonstrated in Table 13. Tests were repeated frequently during the wetter winter and spring months. No positive reactions were detected throughout the total study. Tests were conducted at surface moisture contents as high as 78% with negative results (data not presented). These tests indicate the Sharkey soils did not have reduced conditions producing soluble ferrous iron and agree with analyses indicating 0 to trace levels of exchangeable Fe.

Inherited Soil Color

One of the very difficult and complex aspects of soil color analysis is determining if the color is a reflection of the parent material, relic from previous environmental conditions, or due to current weathering and pedogenesis. One of the early comprehensive studies of the Mississippi River Alluvium (Brown, 1970) reported some of the soil color characteristics were believed to be inherited from the parent materials. This research considered the red colors to be relict from the Permian Red Bed materials deposited by rivers and resistant to color change. A more recent study of Louisiana delta soils (Schumaker et al., 1988) recognized that soil color could be inherited directly from initial sediments or created during weathering processes. Scientific explanations of red colors persisting in delta soils as relic and resistant to change must also consider gray clayey soils that occur in far greater proportion and depth.

Precipitation and Evaporation

The Sharkey sites were not subject to flooding and water input to the soil system is due to precipitation. No other state, except Louisiana, in the continental United States receives as much annual precipitation per square mile land area as Mississippi (Way and Walker, 1986). Despite the extensive precipitation, evaporation exceeds rainfall 7 months of the year resulting in a small surplus (Figure 9). During the 5-year study, normal, dry, and wet years were experienced (Appendix Table 5).

Extensive shrinking occurred in the Sharkey soils when evaporation exceeded precipitation. Large surface cracks typically appeared in May and periodically closed and opened at the surface until early November. The cracks would temporarily close at the surface after precipitation events of 0.5 to 1 inch and reopen within 1 to 3 days. The precipitation affected only the upper surface 3 to 4 inches, with moisture contents largely unaffected below those depths in the hot summer months.

The open cracks served as open conduit for air and water entry into the subsoils. The cracks exposed a large volume of soil to atmospheric air equilibrium about half of the year.

Soil Moisture Contents

Average soil moisture contents over the 5-year study exhibited a very consistent distribution pattern (Figure 10) despite variable precipitation. Highest moisture contents occurred in the surface horizon and decreased with increasing depth. Sites 1, 3, and 4, which contained more clay, exhibited very little subsoil moisture variation. Site 2, which had a loamy substratum, had the lowest moisture contents and exhibited the greatest variation between surface and subsoil portions of the soil profile. The average moisture contents in the surface horizon ranged from 47 to 51%.

The seasonal effects on soil moisture contents were limited to the surface horizons (Figure 11). Soil moisture was highest in the spring and winter seasons and lowest during summer and fall seasons with spring > winter > summer > fall. The surface soil moisture levels coincide with seasonal precipitation and evaporation.

Examination of the average soil moisture content range over the 5-year study indicates 80% of the total variation occurred in the upper 20 inches (50 cm) as illustrated in Figure 12, which includes all four sites. When Site 2 with the loamy substratum is excluded, the range of variation is smaller (Figure 13).

The decrease in soil moisture with increased depths over the 5-year study was not anticipated for the sites separated by a considerable distance. The pronounced lack of seasonal variation in subsoil moisture levels over the extended study was very revealing. Field observations via soil auger readily detected the moisture gradient, with increased dryness consistently observed in subsoils.

Effects of Micro-Topography

Spatial variation of soil moisture in the surface horizons 24 hours after a significant precipitation event is shown in Figure 14. The soil moisture content in the surface ranged from 49% to 53% over a horizontal distance of 21m (70 feet). The sites had small depressions, which were pronounced at Sites 1 and 3 of the Sharkey to 0 to ½% slopes. Although not recognized during the soil surveys, some people have recently referred to these depressions as gilgai features. These features are not evident in cleared, cultivated areas of Sharkey soils. Tree throws during the study produced very similar micro-topographical features. The depressions tend to temporarily collect water during precipitation events. The soil moisture 24 hours after rainfall at a representative micro-depression at site 1 is shown in Figure

15. Moisture contents were similar below 25-cm (10-inch) soil depths with variation confined to the surface. Similar data were obtained at Sites 2, 3, and 4.

Water Table Depths

Average water table depths in Sites 1, 3, and 4 over the 5-year study were about 3m (120 inches) as shown in Figure 16. However, this was the maximum depth of the piezometers and they were dry most months, so the actual water tables were deeper. Site 2, with the loamy substratum, had the highest water table and exhibited the widest fluctuations. The water table in Site 3 came within 45 inches (112 cm) in December 1991, within 49 inches in April 1994 for short duration, and within 29 inches (72 cm) for a very brief period in July 1994 after intensive precipitation for 2 weeks. The water table in Site 3 dropped from 29 inches on July 28, 1994, to 50 inches depth on August 4, 1994, to 120 inches 2 weeks later. The water table in Site 2 came within 7 inches of the surface during the same period, and dropped rapidly to 97 inches in 6 days.

Water table measurements by Soil Conservation Service-USDA soil scientists in forested and cultivated Sharkey soils near the study sites in Washington County showed very similar water table levels (Figure 17).

The presence of high water table levels for short durations in the Sharkey site with a loamy substratum was not expected. The water levels dropped quickly in the loamy subsoil. Dissolved oxygen levels in the fluctuating groundwater indicated it was dynamic and charged with oxygen.

Dissolved Oxygen Levels

Measurements for dissolved oxygen were limited by the lack of water tables in the piezometers. Most of the measurements were made in Site 2 and adjacent drains and puddles. The dissolved oxygen levels decreased with increased depth as shown in Figure 18. Dissolved oxygen was always present in all water measured. Zero oxygen contents were never encountered during the study.

In studies with other gray soils, Cogger et al. (1992) reported dissolved oxygen levels remained high enough in ground water to maintain oxidizing conditions. Ransom and Smeck (1986) measured 0_2 levels in soil water and did not correlate redox potential (E_h) with dissolved oxygen contents.

Soil Implants

Replicated excavations 12 inches wide, 12 inches long, and 12 inches deep were made at Sites 3 and 4 on September 12, 1991. Subsoil (Bt horizon) from a yellowish-red clayey, montmorillonitic Wilcox soil, and a red, fine-loamy, kaolinitic Lucedale soil were implanted in the excavation. The implanted soils were covered with A horizon (0 to 4 inches) and forest litter. Selected properties of the implanted soils were as follows:

Soil	**Color**	**Clay**	**Org. Mat.**	**pH**	**Fe_2O_3**	**Ca**	**Mg**	**K**	**H**
		%	%		%	----cmolc kg^{-1}-----			
Wilcox	5YR 4/8	39.6	1.4	4.9	2.7	1.38	4.36	0.33	22.5
Lucedale	2.5YR 3/6	34.9	0.4	5.2	4.8	1.43	0.67	0.13	6.18

The implanted soils were excavated 3 years after burial for field and laboratory analyses. The implanted soils had "welded" to the surrounding Sharkey soil and roots had extended into the soil mass. The soil hue, value, and chroma had not changed. No physical or chemical differences were detected in field or laboratory analyses. Three years of burial in the Sharkey pedosphere did not alter the implanted soils.

No reduction or migration of iron or bases was detectable. Negative reactions were obtained with α, α^{-1}-dipyridyl on the freshly broken peds of the exhumed soils, and no ferrous iron was detected in water extracts or exchangeable form with ammonium acetate.

Controlled Reduction Study

Sharkey peds (1kg) from each site were subjected to intense reduction under controlled laboratory conditions for 27 months. The soil was covered with H_2O with a sealed gas trap to permit CO_2 discharge but no O_2 entry, and sucrose was added as an energy source for microorganisms. The water column was periodically removed for analyses while maintaining a reduced condition on the soil.

Ferrous Fe and Mn were released from the soil after 33 days reduction. Ferrous Fe levels ranged from 890 ppm for Site 4 peds to 411 ppm for Site 2. Soluble Mn ranged from 61 ppm (Site 4) to 14 ppm (Site 2). A significant color change in the soil peds was detected after 7 months reduction to Blue Green (BG) and neutral hues. The color change became more pronounced with time. The soil peds still exhibited structural features after 27 months immersion conditions. The peds were removed after 27 months for analyses. Bright red reactions were pronounced when α, α^{-1}-dipyridyl solution was placed on the peds after 27 months reduction. The positive reactions, indicating ferrous iron, were the only positive reactions obtained with Sharkey soils during the study. The reduction study clearly demonstrates that Sharkey peds will release ferrous iron and change from gray to blue green colors.

Mausbach and Richardson (1994) reported the presence of ferrous Fe in groundwater discharge zones of reduced soils. Daniels et al. (1961) noted neutral and gley hues relate to the presence of ferrous Fe. They reported ferrous Fe occurs only in reduced or waterlogged soils with depleted oxygen supplies. It was only in the controlled laboratory reduction studies that ferrous Fe was detected.

Vegetation of Sites

According to Simonson (1956), "only the major differences in the original vegetation are reflected to any extent in the soils, probably because of the general youth of the land surface." Apparently, the Delta region originally had a dense forest broken by occasional cane breaks (Simonson, 1956). Heavy stands of cypress comprised the swampy areas, and hardwood stands occupied the better-drained soils and many of the wet ones. According to Simonson (1956), trees on the slight ridges were chiefly hickory, pecan, post oak, blackgum, and winged elm. In the swales and low places (not swampy), Tupelo gum, sweetgum, soft elm, green ash, hackberry, overcup oak, and willow oak occupied the areas.

John D. Hodges, Professor of Forestry at Mississippi State University, directed a vegetative survey of the four Sharkey Study Sites in Washington County September 1993. At each site, four 0.1-acre vegetation quadrants (N, S, E, W) were established to measure overstory and midstory vegetation, and 0.01-acre plots were used to measure understory. General characteristics of the vegetative cover are as follows:

Site 1 Age 45 to 60 years; basal area 75 to 80 ft^2, willow oak, ash, sugarberry, honey locust, elm, ash, persimmon.

Site 2 Age 45 to 60 years; basal area 80 ft^2; average diameter 16 inches; sweetgum dominant, water oak, willow oak, nuttall oak, sweet pecan, dogwood, mulberry, red maple, box elder.

Site 3 Age 50 to 65 years; basal area 85 to 90 ft^2; willow oak dominant, nuttall oak, american elm, sugarberry, sweetgum, overcup oak.

Site 4 Age 50 to 65 years; basal area 80 to 90 ft^2; willow oak dominant, nuttall oak, persimmon.

The total species by site on a per acre basis are as follows:

Site	Overstory	Midstory	Understory	Total No. Individuals
1	11[a] (520)[b]	12 (2,030)	10 (11,000)	13,550
2	6 (190)	15(1,800)	12 (8,300)	10,290
3	9 (300)	12 (2,260)	11 (4,600)	7,160
4	6 (230)	15 (2,060)	10 (5,500)	7,790

[a] Numbers reflect total number species per acre present at each site.

[b] Numbers in parentheses reflect total number of individuals per acre present at each site.

The vegetation survey indicated relatively small differences among the sites (Appendix Table 6). Facultative (FAC) and Facultative Wet (FACW) species comprised 96.7% of Sites 1 and 3, and 99.3% of Sites 2 and 4. Obligate species were overcup oak, nuttall oak, water hickory, and bitter pecan. Only two bitter pecan saplings were detected on Sites 2 and 4.

Although not counted in the survey, poison ivy ground cover was lush and abundant on the Sharkey soils but disappeared abruptly on the adjacent wetter Dowling soils. The Dowling soils commonly contained sedges, cypress, and overcup oak (data not presented).

Summary

Soil Morphology

Intensive field and laboratory studies over 59 months of four Sharkey soils in Washington County, Mississippi revealed the following definitive soil properties.

- Contained prominent intersecting slickensides within 40 inches (100 cm) of the soil surface.
- Contained greater than 30% clay between the surface and 7.2 inches (18 cm) depth, and greater than 30% weighted average clay content between depths of 7.2 inches (18 cm) and 20 inches (50 cm).
- Exhibited cracks each summer of the study period with widths of 3 inches and greater that extended to depths of 3 feet and greater.
- Possessed coefficient of linear extensibility (COLE) greater than 0.09 in the clayey horizons.
- The clay fraction was dominated by montmorillonite with fine clay (<0.2 μ) exceeding coarse clay (2-0.2 μ).
- Base saturation levels exceeded 50% with Ca the dominant exchangeable cation, and high cation exchange capacities.
- Contained high Fe levels comparable to upland well-drained Vertisols dominated by ferric (oxidized) forms.
- Contained gypsum ($CaSO_4$ $2H_2O$) crystals at subsoil depths below 40 inches that apparently formed under oxidized conditions.
- Did not have field indicators of hydric soils, and did not have Munsell values $\geq$ 5 with chromas $\leq$ 2 in the upper 10 inches (25 cm).
- Soil colors became brighter with increasing depths.

Data in this study clearly indicate the Sharkey soil series should be classified as Vertisols. Reviews of previous soil descriptions and supporting data also clearly indicate a Vertisol classification. The Sharkey soils exhibit maximal properties definitive for Vertisols with pedogenic expression comparable to soils typifying the Vertisol order on a global basis.

Soil Hydrology

Temporal soil moisture and water table measurements over the 5-year study encompassed normal, wet, and dry years. The hydrologic data indicated the following definitive relationships.

- Average soil moisture of surface horizons ranged from 47 to 51%. The clayey, montmorillonitic horizons had high moisture retention at field capacity (0.03 MPa) with 8 to 10% moisture differential between field capacity and permanent wilting point.
- Average soil moisture contents decreased with increased depth and subsoils exhibited relatively small seasonal variations.
- Seasonal moisture changes were largely limited to surface horizons with 80% of the total change occurring in the upper 20 inches (50 cm).
- Soil moisture was highest in spring and winter seasons and lowest in summer and fall seasons, with spring > winter > summer > fall.
- Average water table depths were below 100 inches (250 cm) in pedons with clay textures extending to 60 inches depth. The site with loamy textures below 30 inches exhibited the highest water table for very brief duration and had widest fluctuations.
- The Sharkey pedons did not have seasonal water tables within 18 inches.
- Soil water had essentially no ferrous Fe indicating lack of reduced conditions.
- All tests with [illegible], [illegible]$^{-1}$-dipyridyl were negative during all seasons indicating lack of ferrous iron.
- Dissolved oxygen was present in all soil water measurements and tended to decrease with increased depth.

Vegetation

- Overstory, midstory, and understory vegetation was dominated by Facultative and Facultative Wet species.
- Small differences (richness x diversity) existed among sites.
- Obligate species comprised less than 1% of Sites 2, 4 and less than 3.3% of Sites 1, 3.
- Poison ivy was abundant on the Sharkey sites but absent on adjacent Dowling soils.
- Sedges and cypress were common on adjacent Dowling soils but absent on the Sharkey sites.

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