January, 1981

Tech. Bul. No. 270

THE BLACKLAND SOILS OF NORTH CAROLINA

Their Characteristics and Management for Agriculture

by

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Their Characteristics and Management for Agriculture

Introduction

The Blacklands of North Carolina are areas in the lower Coastal Plain which are agriculturally important and require special management due to large amounts of organic matter in the surface soils and poor natural drainage. They are the areas known or once known as swamps, pocosins (81), or bays and were named for the dark soils which are exposed when drained and cleared. The blackland soils range from dark surface mineral to deep organic (Histosols) and occur along the entire North Carolina coast (113). All were formed under conditions where organic matter decomposition was slowed by anaerobic conditions caused by saturation of the soil, or surface ponding of water, for much of the year.

The best known area, and the one of most intense development currently is the peninsula lying between Albemarle Sound to the north and Pamlico Sound to the south. The western limit is the Suffolk Scarp. Other significant areas include the Dismal Swamp of Virginia and North Carolina (55), the pocosins of Beaufort and Pamlico Counties, Open Ground in Carteret County, Croatan National Forest and Hofmann Forest, Holly Shelter Swamp and Angola Bay, Green Swamp in Brunswick County, and many of the Carolina Bays (Figure 1). In addition there is a significant number of smaller tracts.

Estimates of the area of North Carolina peat or muck soils (now called Histosols) range from 1.3 to 1.5 million acres (63, 64); however, there are many more acres of dark surface mineral soils which make up most of the cultivated land in the Blacklands. Wilson (113) estimated there were over three million acres of bogs and wooded swamps in 1962. Figure 1 shows the general distribution of the Histosols and dark surfaced mineral soils in North Carolina.

Much swamp land is owned by government agencies and timber companies, reducing the area currently available for agricultural development. However, significant amounts of former timber company lands have been cleared for agriculture in the past (for example, West Virginia Pulp and Paper Co. lands acquired by First Colony Farms) and

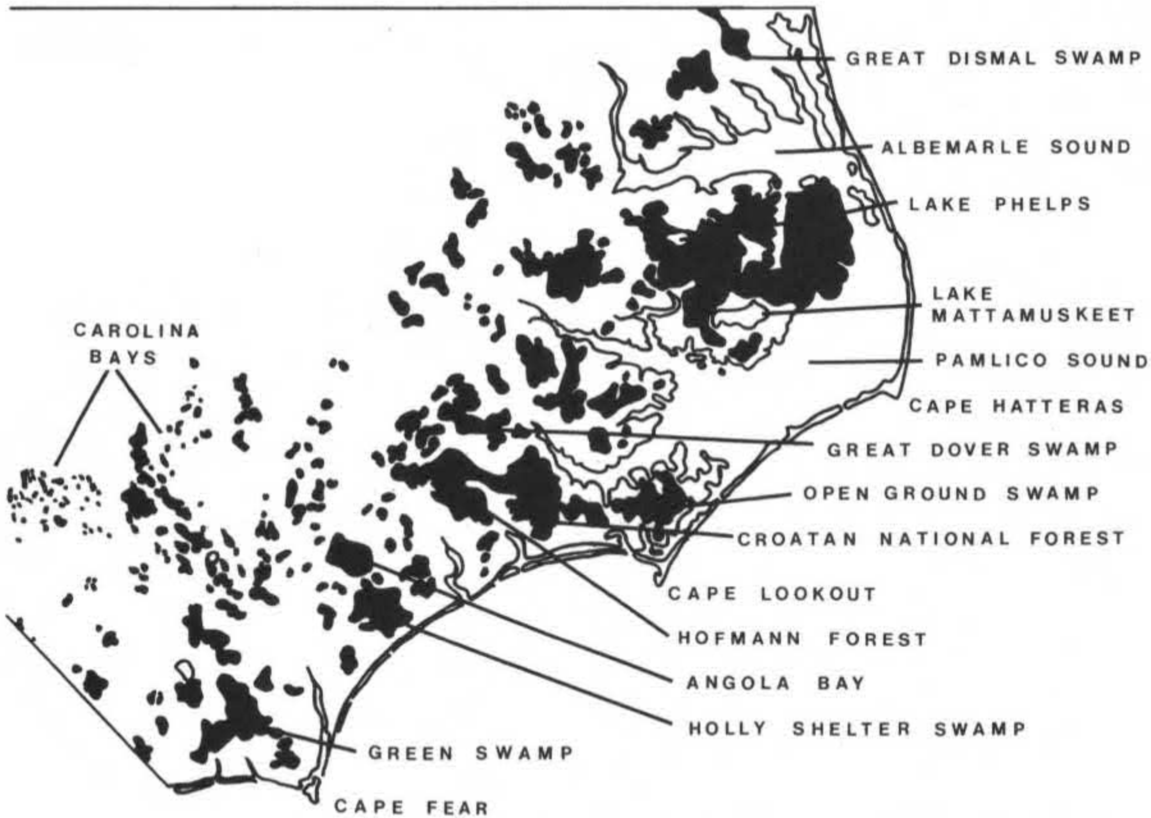

Figure 1. Major areas of Histosols and dark surfaced mineral soils in North Carolina. Adapted from Lee (63) and Wilson (113).

future development will probably depend on economic considerations and land use legislation. Land clearing activity has increased dramatically in the past five to ten years (16, 20) with thousands of acres being cleared each year. Farm land is seen as a desirable investment and it is likely that land clearing will continue at a rapid rate so long as the current economic and regulatory conditions exist.

Climate

The North Carolina coastal zone lies between $33\frac{1}{2}^{\circ}$ and 37° north latitude. The climate varies somewhat from north to south, but is characterized generally by warm temperatures and high rainfall. The average number of freeze-free days (when the temperature does not drop below $32^{\circ}F$) is 235 at Elizabeth City, 215 at Plymouth and 245 at Wilmington (15, 46). One reason for the large differences is the location of the recording stations in relation to large bodies of water; another is that blackland soils tend to warm slowly. Thus in the spring crops grown in the area are more subject to late frost damage than crops grown on land with a higher mineral matter content. Organic soils absorb heat during the day, but they do not conduct heat well and cool rapidly at night by radiation. In addition, they are low lying and flat, and cold air tends to settle in such areas. Corn is normally planted later in the Blacklands than on surrounding, more mineral, land.

Rainfall is fairly high with the annual average ranging from 51.3 inches at Wilmington to 53.0 inches at Plymouth (Figure 2) to 55.4 inches at New Bern (15). Rainfall is lower in the inland areas with Raleigh reporting an annual average of 43.5 inches. Total annual precipitation varies considerably, as does distribution during the year (Table 1). Most rainfall occurs in the summer months as scattered showers and thunderstorms. Consequently, rainfall for a given period can be quite erratic over the region (Table 1). It is not uncommon for some areas to be damaged by drought while other areas only a few miles away have sufficient or even excess water. In addition, the Blacklands are vulnerable to hurricanes and tropical storms in the fall which may cause extremely heavy rainfall at times. This situation can be devastating if crops are in the field at the time of occurrence.

Topography and Geology

The large swamps of North Carolina occur at basically three positions on the landscape and are associated with different geologic formations. The larger ones occur on the Pamlico surface which is the youngest exposed seabed surface of the North Carolina coastal area (23) (Figures 3 and 4). They extend from the Suffolk Scarp (an ancient shoreline) to the eastern salt marshes and include the Great Dismal Swamp (55, 77, 86, 106), the Albemarle-Pamlico peninsula (49),

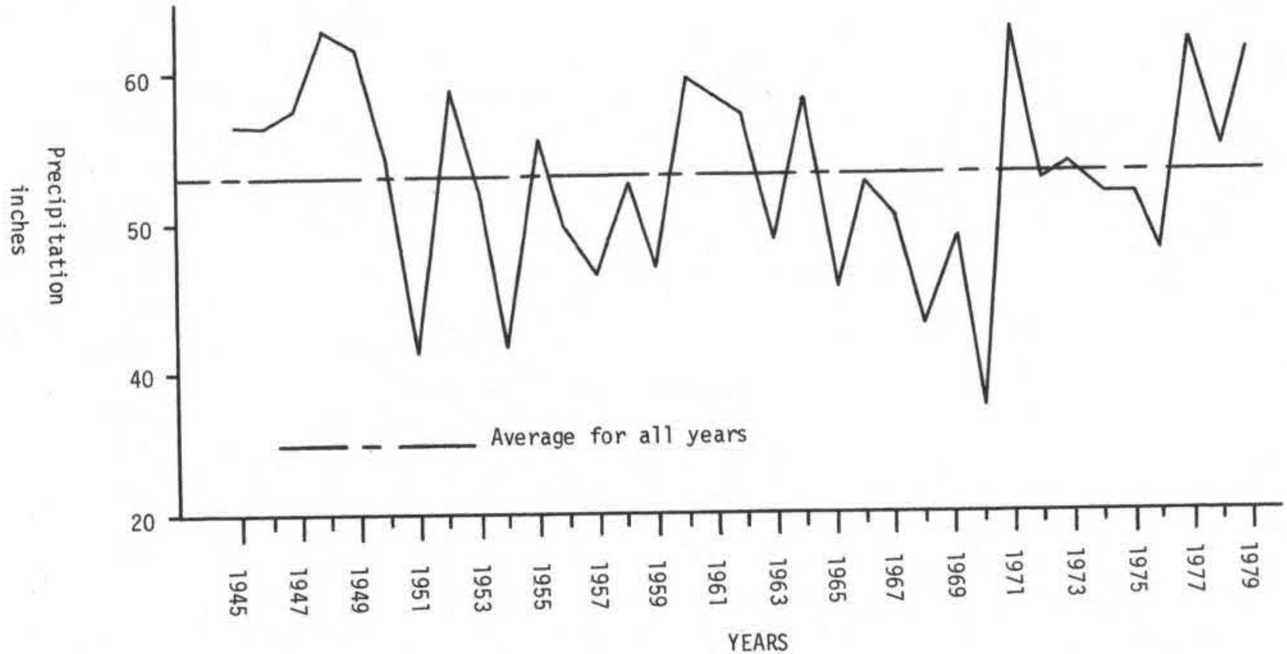

Figure 2. Average annual precipitation at the Tidewater Research Station, Plymouth, from 1945 through 1979.

Table 1. Precipitation distribution during the 35 year period 1945-1979, at the Tidewater Research Station, Plymouth.

		Precipitation, Inches												
Month	Ave Monthly Precipitation	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10+	Highest Month	Lowest Month
	in.	Percent of months in range											in.	in.
Jan	4.0	0	11	23	20	14	14	11	0	3	3	0	9.0	1.1
Feb	4.0	3	14	9	14	31	17	11	0	0	0	0	6.8	0.7
Mar	3.9	6	3	11	29	29	20	3	0	0	0	0	6.0	0.7
Apr	3.0	0	20	29	23	20	9	0	0	0	0	0	5.6	1.1
May	4.7	3	9	20	3	17	11	20	9	3	3	3	11.1	0.9
Jun	5.1	3	9	11	20	17	9	11	6	6	0	9	13.1	0.9
Jul	6.8	3	3	0	6	17	20	11	9	9	3	20	15.0	0.8
Aug	6.0	3	9	9	11	11	6	14	17	3	0	17	13.4	0.3
Sept	5.1	3	6	14	11	17	17	11	9	3	3	6	12.0	1.4
Oct	3.2	6	34	20	11	11	6	3	3	0	0	6	11.5	0.6
Nov	3.5	6	26	20	9	17	6	11	0	0	0	6	10.5	0.6
Dec	3.4	3	11	20	37	11	11	0	6	0	0	0	7.8	0.6
Yearly	53.0													

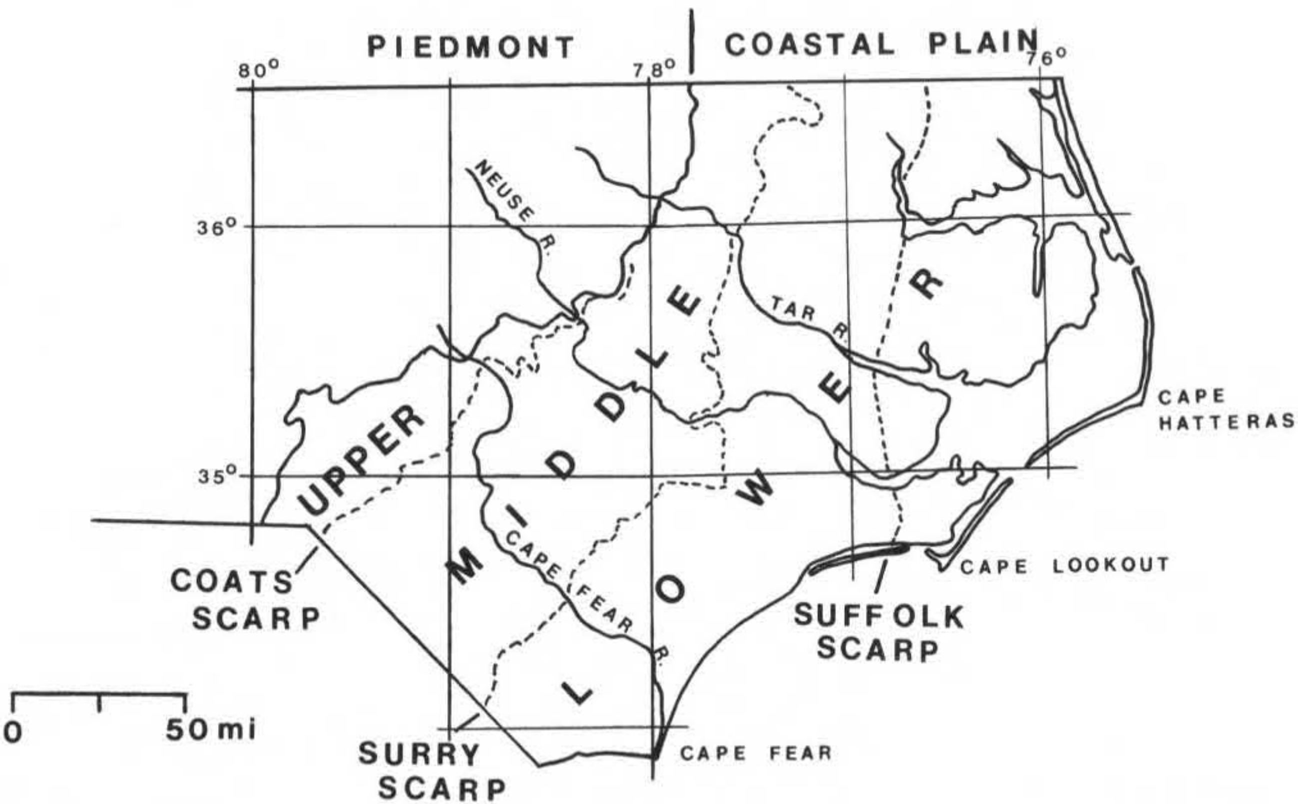

Figure 3. Subdivisions of the North Carolina Coastal Plain based on its formation. Adapted from Daniels, et al., (21, 23).

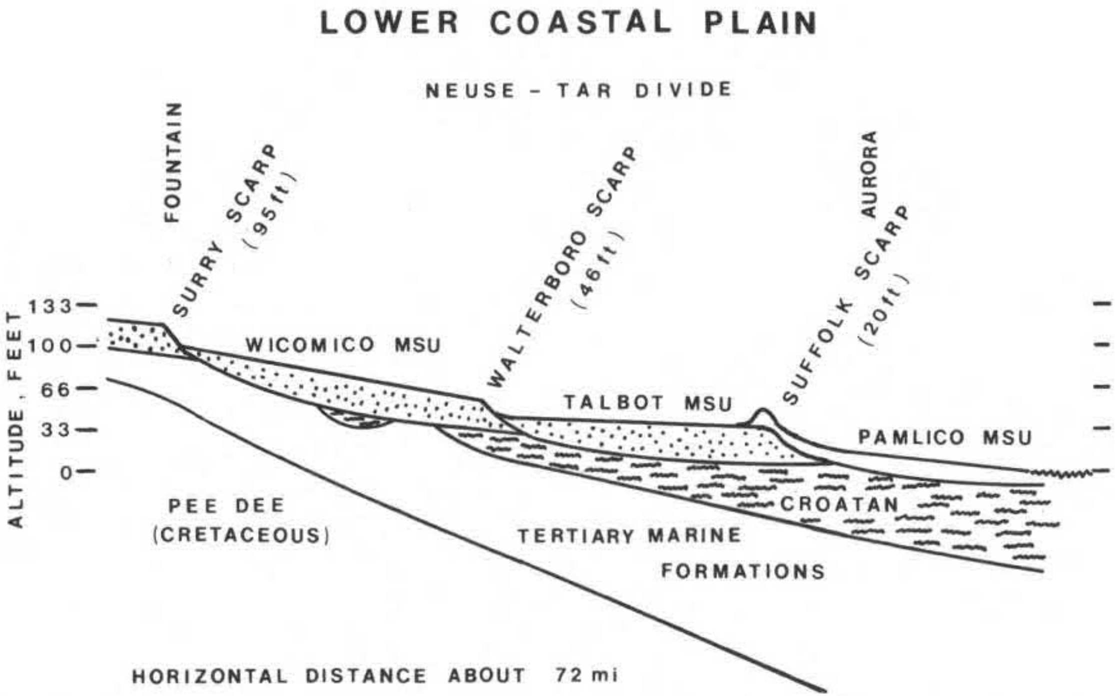

Figure 4. Idealized Lower Coastal Plain stratigraphic sequence on the Neuse-Tar divide. The abbreviation "MSU" is for "morphostratigraphic unit." Adapted from Daniels, et al., (21, 23).

the Pamlico-Neuse peninsula and Open Ground Swamp (19, 40). The elevation varies from sea level to no more than about 20 feet above sea level. The Suffolk Scarp shoreline was formed about 75,000 years ago (76) and from that time until about 35,000 years ago sea level fluctuated both above and below the current level. Beginning about 25,000 years ago the sea level began to drop due to the vast amounts of water tied up in the ice age glaciers, and about 15,000 years ago reached a level almost 400 feet below the current sea level (75, 76). The sea level has been rising since then causing the exposed shoreline to migrate westward and flooding the lower valleys of the coastal rivers and creating the Albemarle and Pamlico Sounds. Early settlers in the area report finding tree stumps on what is now the bottoms of these sounds (83, 85). The sea level has been rising at the rate of one foot per 100 years since 1890 (53). This condition, of course, has serious implications on the long term use of these coastal swamps for agriculture or other intensive uses. For example, currently most of the land east of Lake Phelps is less than five feet above sea level and much of the mainland of Dare County is less than three feet above sea level. The bottom of Lake Mattamuskeet was given an elevation of two feet below sea level in 1974. A chart has been prepared (82) prediciting widespread flooding in the Albemarle-Pamlico peninsula and of the area north of Albemarle Sound in the next 1,000 years. The erosion of shorelines in the coastal area is symptomatic of the long-term continuing rise in sea level.

The next largest series of swamps occurs on the older Wicomico and Talbot surfaces or morphostratigraphic units (MSU) (21) east of the Surry Scarp, a shoreline dating to about 300,000 to 400,000 years ago (23) (Figure 4). These include Croatan National Forest, Hofmann Forest (22, 71), Holly Shelter and Angola Bay, and Green Swamp. The elevation varies from about 20 feet above sea level at the eastern edge of the Talbot MSU (Suffolk Scarp) to about 46 feet at the Walterboro Scarp separating the Talbot MSU and the Wicomico MSU, and about 95 feet above sea level at the Surry Scarp marking the western edge of the Wicomico MSU. Even though these surfaces are much older than the Pamlico surface, the organic deposits appear to be about the same age and it seems most likely that weather changes about 10,000 years ago created conditions conducive to peat formation and accumulation that have continued until the present (22). Organic materials from several locations have been dated (22, 76) and none over about 10,000 years old has been found.

The factors responsible for peat formation for the two preceding swamp types are similar and are believed to be a combination of high rainfall, flat landscape, large distance between streams, and shallow depth to impermeable subsurface layers (22). This combination of factors caused ponding, anaerobic conditons, and accumulation of organic debris which further restricted lateral water flow off the land surface and enhanced the process of swamp development. As a result, these deposits characteristically occur not only in depressions but also in many cases at elevations higher than the surrounding mineral soils. Swamps of this type are termed pocosins, a Delaware Indian term for an upland swamp.

The third type of coastal swamp occurs across all the geologic surfaces but is most prevalent in the southeastern coastal plain. These are the Carolina Bays which range in size from a few to several thousand acres and are true depressional swamps. The origin of these features is still being debated but recent investigators suggest that they were formed by wind and wave action in poorly drained areas of the broad, flat, undissected Coastal Plain (11). Some bays, such as White Lake, North Carolina, are filled with water while others have deposits of organic materials of various depths. Some have been developed for agriculture by cutting a canal through the rim for drainage. The soils formed in Carolina Bays are similar to those found elsewhere under similar drainage conditions. However, they tend to contain less buried wood and are more frequently underlain by loose white sand.

History of Development

Development of swamps in North Carolina has occurred over a long period of time with periods of enthusiasm alternating with periods of inactivity (36, 37, 54, 65). Easily drained land on the edges of swamps was being developed by the late 1600's, but the first large scale drainage of deep organic soils was in the 1790's north of Lake Phelps (83). One reason for the interest in organic soils in America was their extensive use in Europe. Histosols were being farmed in England and on the continent before 1800 (1, 69) and there was much interest in their classification and properties.

Soils high in organic matter were especially attractive in the years before the availability of commercial fertilizers since the natural decay of the organic materials released nutrients, especially nitrogen and phosphorus, for crop growth. Such soils were considered highly productive and were much sought after (83). The first attempts to develop land in North Carolina with deep organic layers occurred in the Great Dismal Swamp. From the earliest years proposals were made to drain the swamp for agriculture and considerable acreage was developed. Shaler (85) reported that by 1889 700 square miles (448,000 acres) of the Great Dismal Swamp had been developed for agriculture, and that about 1500 square miles (approximately 1,000,000 acres) remained. This is probably an exaggerated figure, because in 1950 the total area of the swamp was estimated at 750 square miles (480,000 acres), but the swamp proper at only 375 to 400 square miles or about 250,000 acres (permanently wet, mostly organic) based on soil survey reports (86). The criteria for determining what is or is not swampland has varied from reporter to reporter so that the earlier estimates undoubtably include wet mineral soils. Nevertheless it is apparent that large amounts of what was once considered part of the Great Dismal Swamp have been developed.

A similar pattern of development was followed in other swamp areas of North Carolina. Dark surfaced mineral soils and shallow Histosols were being farmed along the entire coast by the early 1800's.

By the 1830's large acreages were being farmed in the Northeastern part of the state, and an estimated 32,000 acres were being farmed around Lake Mattamuskeet (83). Ruffin (83) described the Mattamuskeet lands in 1860 as "The most extensive and important of all the drained and cultivated swamp lands on the Atlantic coast, and also the oldest--" and states that some of the highest lands were "--under cultivation seventy years ago--." The area north of Lake Phelps was drained and developed as a rice plantation in about 1790 (97). Early accounts state that this was originally dense cypress swamp and that after drainage, in the 1830's, about three feet of surface had been lost due to subsidence (83). The area is still being farmed, though nothing remains of the once-thick organic surface.

Because of the successes at Lake Mattamuskeet and Lake Phelps there arose considerable public interest in development of deeper organic soils. All swamp lands in the state were titled to the State Literary Board (State Board of Education) by law in 1825 (54). Development of these lands for sale was seen as a way of raising money for education, and beginning in the 1830's a large amount of money was spent for this purpose. Lake Landing canal for drainage of Lake Mattamuskeet was completed in 1835. The lake's level was lowered by 3.5 feet and its dimensions reduced from 20 miles by seven miles to 16 miles by five miles (present size). Canals were also dug from Alligator and Pungo Lakes in 1842 and at Open Ground Swamp in 1855. In 1867 (54) a critical report to the State Board of Education stated that more than $200,000 had been spent in the past 40 years on the swamp lands with no return. Factors responsible were lack of access, insufficient drainage, disease (54), and the Civil War. The money was part of $1,433.757.39 the state had received in the 1830's as its share of revenues from the sale of public lands by the federal government (79).

In the late 1800's and early 1900's much of the coastal swamp land was purchased by timber companies and for a number of years very extensive logging operations were common, especially for the manufacture of shingles from Atlantic white cedar (juniper) (57). The Roper Lumber Company established a large shingle mill at Lee's Mill (renamed Roper) in 1885 and built a logging railroad to Pantego (45). By 1907 Roper Lumber Company owned 600,000 acres of land and had cutting rights to 200,000 more. Another large timber company was the Richmond Cedar Works which owned extensive lands in Tyrrell and Dare Counties, and has been estimated to have owned and/or cut over "--far in excess of a million acres--" (45).

As the desirable timber was removed, much of the land was sold to other timber companies or made available for development. Swamp land development continued throughout the early 1900's (80,99) helped by several government aided projects which made drainage possible over wider areas. In addition, the North Carolina drainage act of 1909 enabled groups of land owners to establish drainage districts and support area-wide development projects through assessments against the land (80). Burning was often used to remove all or part of the organic surface so that the land could be farmed.

Due to the continuing interest in the deep organic soils for agriculture the Blackland Test Farm was established in 1912 by the North Carolina Department of Agriculture and North Carolina State College in Washington County at Wenona on what was then a deep organic soil (108). Crop production was not satisfactory and peat fires were a continuing hazard. As a consequence, the test farm was relocated near Roper in 1943 and renamed the Tidewater Research Station sometime later. Deep organic soils were not farmed successfully (87) until relatively recently when lime and micronutrient needs were established. Land development has gained momentum in recent years due to improved equipment technology, improved cultural practices, and increased competition for farm land (4, 16, 20, 49).

Soils

Classification

The soils of the Blacklands vary from dark surfaced mineral soils through deep organic soils called Histosols. Contrary to popular belief, most of the land in cultivation is not deep organic soil but mineral soil with five to 20% organic matter in the surface.

By definition, organic soil material must contain a minimum of 20 to 30% organic matter depending on the amount of clay in the mineral fraction (Figure 5). For example, soil material with no clay can contain as little as 20% organic matter and be classified as organic soil material, but soil material with 60% clay must contain 30% or more organic matter to be so classified. In addition, the organic soil material must be of a certain thickness depending on a number of criteria such as fiber content, bulk density, and periodic flooding before it is classified as organic soil (Histosol) (14, 70, 89). In almost all North Carolina soils the organic soil material has to be greater than 16 inches thick to be classified as a Histosol. Figure 6 shows the general interrelationship between soil organic matter content and thickness for North Carolina Blackland soils. Soils with eight to 16 inches of organic soil material surface are said to have histic epipedons, which means literally "mineral soils with organic topsoils."

These mineral soils with organic topsoil are the most desirable soils of the region and have the fewest inherent liabilities. Some soils have naturally shallow organic surface horizons while others once had thick organic surfaces which have been lost by slow oxidation or fire (32, 83). All organic soils in the Blacklands, if cultivated long enough, will become mineral soils with dark surface horizons due to the inevitable natural loss of organic matter through oxidation.

Essentially all Histosols in North Carolina belong to the suborder Saprist, which indicates that they have a subsurface layer dominated by sapric material, formerly called muck. This means in part that less than 1/3 of the soil mass is made up of identifiable fibers

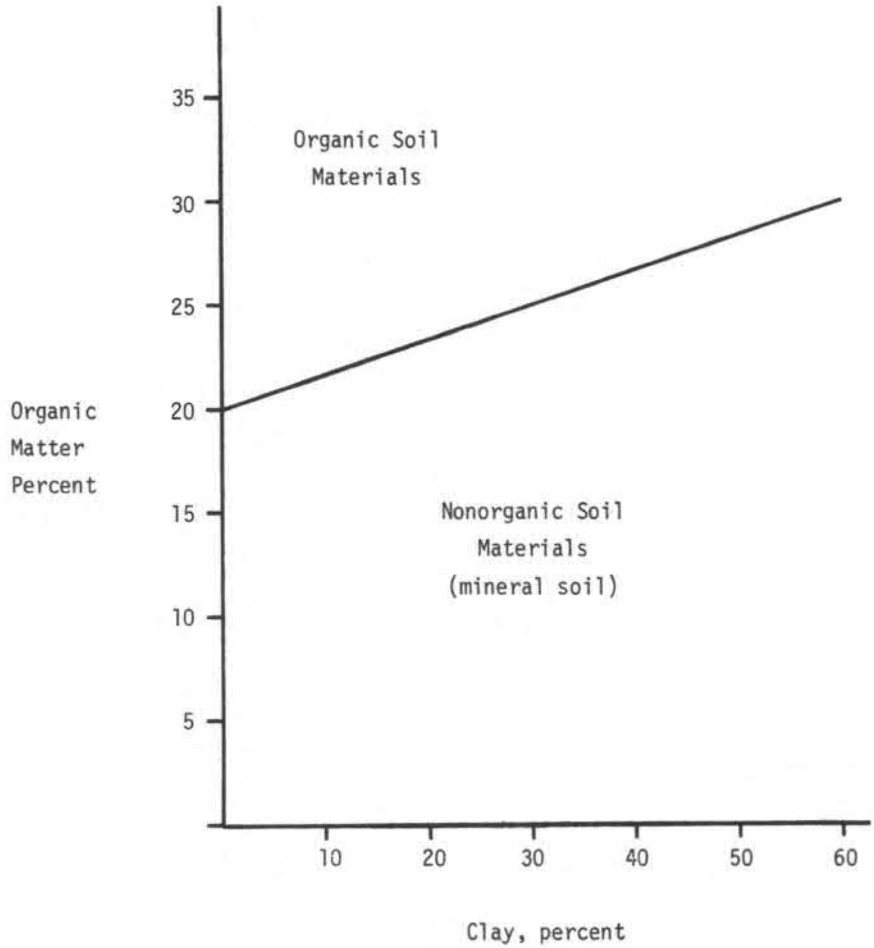

Figure 5. Relationship between soil organic matter content, clay content of the mineral fraction, and soil classification. Adapted from Soil Survey Staff (89).

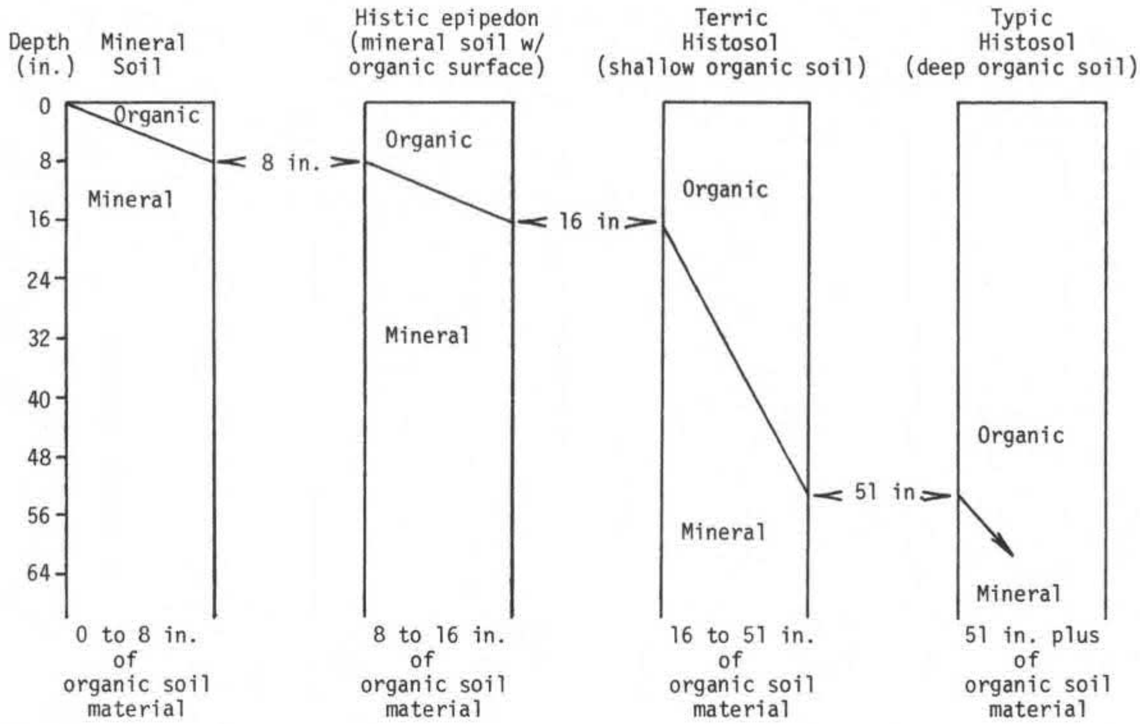

Figure 6. Relationship between thickness of surface organic layer and soil classification.

and is considered to be more decomposed than fibric materials (formerly called peat). They also are in the Great Group Medisaprist, which indicates that they have no significant humilluvic horizons (material moved downward by leaching) and have a mean annual temperature above 47°F with more than a 9°F variation between winter and summer means. Soils that contain sapric materials are higher in bulk density, have lower hydraulic conductivity, lower porosity, and retain more soil moisture (13) than the less decomposed Histosols. Only a few of the less decomposed soils, called Hemists, occur in the area.

The underlying mineral layers of organic soils vary from sand to clay texture and for the most part are of recent marine sediments. The type of underlying mineral soil can change radically over a short distance, and the mineralogy of the accompanying mineral fraction has a strong influence on the physical and chemical properties of the entire soil profile. For example, organic matter-sand soils have less Al than organic matter-silt/clay soils and are unable to hold P effectively.

At present about 150 Histosol series are recognized in the United States. Relatively few Histosol series are established in North Carolina because the organic soil materials are remarkably uniform with respect to their degree of decomposition and acidity. Many more mineral series are recognized because the texture of the mineral matter varies greatly. Table 2 lists some of the currently mapped soils with a brief summary of their characteristics. Soils with "colloidal" organic materials contain colloidal muck, have poor water movement, and are characterized by massive, plastic organic horizons which are usually dusky red in color. Soils with "loamy" (mull) organic surfaces are friable with desirable granular structure that allows water infiltration and are black. Mull is a term for a well-decomposed organic soil that has been modified by drainage and biological activity. The texture of the underlying mineral soil is self-explanatory as is the thickness of the organic surface. The primary mapping characteristic is identified by an "X" while for some soils secondary inclusions are identified by an "I". Other soils are mapped in and around organic soils areas, but the ones listed are the major ones at present.

Colloidal Properties

Most thick Histosols in North Carolina contain colloidal muck, which forms when organic materials are submerged for long periods of time under anaerobic conditions, according to a review by Dolman and Buol (32). Since the organic soils of North Carolina were formed because of poor aeration and not because of high rainfall and/or low temperature, it is not suprising that colloidal muck is common. Some organic matter of this type is beneficial (32) and imparts desirable soil characteristics such as soil granulation, higher nutrient holding capacity, and so on, but when it is present in large amounts and comprises the bulk of the soil, it can be undesirable. Such soils are sticky, plastic, impervious to water movement (32, 33), and very acid.

Table 2. Histosols and related mineral soils of the North Carolina Blacklands with the thickness of their organic soil material surfaces and certain other characteristics.

Soil Series Name	Type and Thickness of Surface				Type of Organic Surface		Texture of Underlying Mineral		
	Organic 51 in. +	Organic 16-51 in.	Organic 8-16 in.	Mineral or under 8 in. Organic	Colloidal	Loamy (Mull)	Sandy	Loamy	Clayey
Dare	X				X		X		
Dorovan	X					X	X		
Pungo	X				X			X	I
Mattamuskeet		X			X		X		
Pamlico		X				X	X		
Belhaven		X			X			X	I
Scuppernong (1)		X			X			X	
Ponzer		X				X		X	
Conaby			X			X	X	I	
Wasda (2)			X		X			X	
Roper (3)			X		X			X	
Pettigrew			X		X				X
Portsmouth (2)				X				X	
Hyde (3)				X				X	
Weeksville (4)				X				X	
Cape Fear				X					X
Roanoke (5)				X					X
Argent (6)				X					X
Arapahoe (7)				X			I	X	
Fortescue (8)				X				X	

X = Primary characteristics; I = Secondary inclusions

1 = Silt layer in profile.
2 = Fine-loamy; 18-34% clay, 15% or more sand coarser than vfs.
3 = Fine-silty; 18-34% clay, less than 15% sand coarser than vfs.
4 = Coarse-silty; less than 18% clay, less than 15% sand coarser than vfs.
5 = Not as wet as Cape Fear, fine sandy loam topsoil.
6 = Similar to Roanoke. Fine sandy loam or silt loam topsoil
Higher pH in the lower B3 and C horizons
7 = Coarse-loamy; less than 18% clay, 15% or more sand coarser than vfs.
8 = Buried muck layer. Fine silty material over muck.

When undrained they may be reddish in color due to their reduced condition and have to undergo a physical and chemical "ripening" process before they are suitable for agriculture. Soil scientists in Holland (102) have termed this a pedologic or soil-forming process. Colloidal muck is much more likely to be present in the thicker Histosols (31, 32), and is generally formed in more stable standing water environments with less varied biological histories. On the other hand, soils with shallow organic surfaces are usually occasionally free of water and have more varied plant and microbiological histories, resulting in thinner, but more agronomically desirable, organic surfaces.

Skaggs (88) found that an unripened colloidal muck lost up to 70% of its original volume when dried, but that the ripened surface lost only 25%. As evidence of the dramatic effect on drying and curing he cites a K (hydraulic conductivity) value of only 0.002 to 0.19 cm/hr (total range) for unripened material and values of 15-37 cm/hr for the ripened top layer. This is much slower than values reported for other organic soils (90).

Soils containing deep colloidal muck layers are difficult to farm because they have poor physical condition, do not allow water to drain through the profile, and are often too plastic to support farm equipment (poor flotation properties). Equipment that breaks through the dry top layer of the soil into the underlying muck loses traction. Since the colloidal muck has little fiber and a very high water content it will not compress, but will flow when put under pressure. Agitation of wet colloidal muck breaks down the loose bonding in the structureless mass and results in a semi-liquid organic slurry, a condition aggravated by ponding of water on the soil surface due to lack of internal drainage. In wet weather such soils may be totally impassable to equipment and even to men on foot. At times cattle pastured on colloidal muck must be moved to better drained land to prevent them from becoming mired and injured.

Organic Matter

Soils high in organic matter content are quite different from mineral soils in their physical and chemical properties. Even small amounts of organic matter (OM) will alter a soil, and in North Carolina, cultural practices begin to change when the OM content of the plow layer exceeds 5% by current soil test methods. Soils with up to 5% OM in the plow layer are considered mineral, those between 5% and 10% are called mineral-organic, and those with over 10% are considered organic from an agronomic standpoint. This classification is based on OM content as determined by the Agronomic Division, NCDA, using a partial chemical digestion procedure which gives an estimate of the reactivity of the OM. It is not the same as total combustion OM and is irrelevant to classification by soil series since only the plow layer is considered, but is very relevant to nutrient, lime, and pesticide use.

The soils in the Blacklands range from mineral soils with more than 5% OM by soil test to deep Histosols testing nearly 100% OM. As a consequence, soil properties are variable. The characteristics of the OM will be imparted to the soil depending on the amount and kind of associated mineral matter. That is, soil properties most influenced by OM content will be expressed most fully in deep Histosols while the effect on dark surfaced mineral soils will be less.

Bulk Density

In general the higher the OM content of soils, the lower the bulk density. Eiumnoh (35) studied a wide range of soils in the Blacklands and found bulk densities ranging from 1.23 g/cc (1.2% OM) to 0.35 g/cc (79.9% OM). Data adapted from Eiumnoh is shown in Table 3; bulk densities lower than this have been reported for less decomposed soils (13). All of the soils studied by Eiumnoh were in cultivation and only the Ap horizon (plow layer) was used.

Soils with low bulk densities are lightweight and may be loose and "chaffy". They are easy to till, but care must be taken to avoid moving too much soil in the process. Such soils are more difficult to keep level since they do not compact well, and slight errors in adjustment of equipment, or allowing a disk to jam with debris, can leave very uneven surfaces which trap water and inhibit surface drainage. Turning equipment carelessly so that it "plows", can leave large ridges and potholes which also trap water and can delay spring land preparation. Smooth, uniform land surfaces are easier to maintain on soils higher in bulk density due to greater mineral content.

Low bulk density soils are subject to erosion since they will float when dry and can be blown by wind. Although they have high surface areas (Table 3) and hold large amounts of total water, they may dry out quickly and be prone to drought. Frost heaving can be a severe problem, and fall establishment of forages and small grains on organic soils has been difficult as a result. Fescue and clover are usually spring planted for this reason. Row crops, especially corn, are more subject to lodging on low bulk density soils because of their low adhesion and light weight, and wind damage can be severe. Plant stalks may not break but entire plants may be uprooted. This characteristic is also a factor limiting timber production.

Soil Moisture

Water holding capacities of soils are closely related to their internal surface areas, which increase as organic matter increases (30, 35). Internal surface areas of some soils shown in Table 3 from Eiumnoh increased 20-fold as organic matter content increased from 4.0% to 79.9%. Table 4 shows the relationship between soil OM and soil moisture at various tensions as well as available moisture based on both weight and volume. By definition available water is water which is not readily percolated but is available for plant roots to absorb. It is a measure of the amount of water that a soil can supply between rains. Available water is estimated as the difference between the amount of water retained in the soil after either .1 or .3 bars pressure and 15 bars, and is expressed either as a percent by weight of

Table 3. Percent organic matter by combustion, bulk density, and surface area by EGME of plow layers in some Blackland soils. Adapted from Eiumnoh (35).

Sample No.	Series	OM	Bulk Density	Surface Area EGME
		%	g/cm^3	m^2/g
1	Augusta	1.2	1.23	15
2	Portsmouth	4.0	1.01	40
3	Cape Fear	7.3	0.86	88
4	Unnamed	7.3	0.95	36
5	Portsmouth	8.8	0.75	73
6	Wasda	11.3	0.71	91
7	Wasda	18.5	0.61	193
8	Ponzer	21.3	0.63	131
9	Ponzer	27.6	0.46	136
10	Unnamed	30.0	0.62	165
11	Conaby	31.9	0.65	148
12	Pettigrew	37.9	0.56	273
13	Roper	38.0	0.46	277
14	Roper	43.9	0.43	274
15	Roper	54.9	0.42	278
16	Belhaven	65.5	0.46	476
17	Pungo	79.9	0.35	812

Table 4. Percent organic matter by combustion, soil moisture retention on a weight basis and plant available water on a weight and volume basis of plow layers in some Blackland soils. Adapted from Eiumnoh (35).

No.	Series	OM	Soil Moisture Tension, Bars			Plant Available Water			
			15.0	0.3	0.1	0.1-15 1/	0.3-15 1/	0.1-15 1/	0.3-15 1/
		%				(% by weight)		(% by volume)	
1	Augusta	1.2	6.20	11.55	21.68	15.48	5.35	19.04	6.58
2	Portsmouth	4.0	8.55	16.80	28.30	19.75	8.25	19.95	8.33
3	Cape Fear	7.3	16.12	26.43	38.39	22.27	10.31	19.15	8.87
4	Unnamed	7.3	7.19	11.92	18.63	11.44	4.73	10.98	4.54
5	Portsmouth	8.8	18.29	32.43	28.12	29.83	14.14	22.37	10.61
6	Wasda	11.3	16.09	30.46	41.25	25.16	14.37	17.86	10.20
7	Wasda	18.5	29.47	49.60	71.73	42.26	20.13	25.78	12.28
8	Ponzer	21.3	20.71	42.68	64.16	43.45	21.97	27.37	13.84
9	Ponzer	27.6	27.26	50.71	65.45	38.19	23.45	21.39	13.13
10	Unnamed	30.0	19.57	45.94	64.71	45.14	25.47	27.99	15.79
11	Conaby	31.9	20.71	36.47	52.14	31.43	15.76	20.43	10.24
12	Pettigrew	37.9	34.80	53.40	71.94	37.14	18.60	20.80	10.42
13	Roper	38.0	35.76	70.71	91.46	55.70	34.95	25.62	16.08
14	Roper	43.9	41.81	78.87	107.24	65.43	37.06	28.13	15.94
15	Roper	54.9	40.57	73.03	91.37	50.80	32.46	21.34	13.63
16	Belhaven	65.5	48.44	68.08	81.12	32.68	19.64	15.03	9.03
17	Pungo	79.9	48.81	88.94	122.43	73.62	40.13	25.77	14.04

1/ Bars

the soil or more practically as percent of soil volume.

The data in Table 4 clearly show that, in general, available moisture on a weight basis increases as OM increases. For example, Augusta had about 15% plant available water by weight while Pungo had nearly 74%. However, since the bulk density of the Pungo is considerably less than the Augusta, plant available water on a weight basis can be misleading. The last two columns in Table 4, which show plant available water on the basis of soil volume, are more representative of field conditions since the volume of soil exposed to plant roots will be the same in each soil. It can be seen that the actual amount of available soil moisture in the root zone increases only a minor amount as soil organic matter increases (35). Furthermore, soils high in organic matter can hold large amounts of total water, but it is held at such high tensions that a smaller percentage may be available to plants than in more mineral soils. Soils with Histic epipedons and dark surfaced mineral soils can contain as much or more available water in the plow zone as Histosols. However, the moisture supplying capacity of a colloidal muck soil improves as the soil ripens and the soil becomes more friable or mellow.

The water holding characteristics of these soils has implications for soil management. First, crops on Histosols are subject to drought stress and may experience it as soon as on more mineral soils. The soil moisture contained in the underlying layers, especially if they are colloidal muck, is not available to the plant because plant roots cannot penetrate into the highly acid layers and because the moisture is held too tightly to move readily upward by capillary conductivity. The pores in the developed surface soil are larger than the pores in the underlying undeveloped soil, and water will not move by capillary conductivity from smaller pores to larger pores. The developed root zones of most North Carolina Histosols receive essentially no recharge of water from the underlying soil materials. In dry weather it is common to find the root zone devoid of plant available water and the underlying organic matter quite wet. The only effective way to increase the plant available moisture is to deepen the root zone by incorporating lime and nutrients to a greater depth or to irrigate. Increasing the root depth from four inches to six inches will increase the rooting zone by one half and will increase the available soil moisture accordingly. Root zones should be developed eight inches deep where possible.

The high water holding capacity of organic soils can be a liability once they are dried beyond the 15 bar moisture content since it takes more water to satisfy their non-available moisture storage capacity than it does to satisfy that in a mineral soil. Thus, light rainfall on a very dry high organic matter content soil is often of less benefit than the same rainfall on a sandy soil since it may only wet the surface which can dry out rapidly by evaporation.

Another characteristic of OM that can complicate the process of rewetting is the phenomenon of irreversible drying. Some organic materials lose a large part of their moisture holding capacity when over-dried. Dolman and Buol (32) found irreversible drying of the surface materials on some saprists (colloidal muck soils). Samples soaked in water for more than six months did not rewet. With proper care, irreversible drying is not a major problem in the Blacklands and is seen mainly in the granular "coffee ground" materials which develop on the soil surface when sapric material (colloidal muck) is dried (Figure 7). Exposing large amounts of colloidal muck during land development can result in a loose "chaffy" surface with poor water holding characteristics. Some irreversible drying is inevitable in developing colloidal muck for agriculture and is a desirable step in the soil ripening process.

Subsidence

Since organic matter only accumulates where poor drainage and lack of oxygen causes reduced conditions, it follows that artificial drainage would allow the accumulated organic matter to decompose. Thus, a natural result of draining organic soils is the loss of organic matter, causing soil subsidence. Deep organic soils will inevitably become dark surfaced mineral soils with time.

According to Stephens (93), subsidence is the result of the following processes:

1. Shrinkage due to desiccation.
2. Consolidation due to loss of the bouyant force of ground water, and loading, or both.
3. Compaction by tillage.
4. Wind erosion.
5. Burning.
6. Biochemical oxidation.

The first two factors are of most importance immediately after land is drained and dewatered for the first time and do not represent a true loss of material. The same is true of compaction by tillage, which is of minor importance in the North Carolina Blacklands. Nearly all these soils have already undergone some shrinkage and consolidation because nearly all have been drained to some degree in the past. Large areas from Great Dismal Swamp to Green Swamp have been canaled to facilitate logging, to improve timber growth, or to limit mosquitos. When such land is cleared for agriculture there is no large initial drop in surface elevation.

Ground fire is a constant hazard on soils containing more than about 30% OM (Figure 8). Most of the Histosols in the state have lost some surface to ground fire. Fire has been used to remove the organic surface when it was considered undesirable and many acres of dark surfaced mineral soils have been developed in this way.

Areas that burn may have to be root raked again for buried wood (Figure 9) and be relimed and redeveloped for agriculture. The soil surface may be left pot-holed and irregular and unripened soil may be

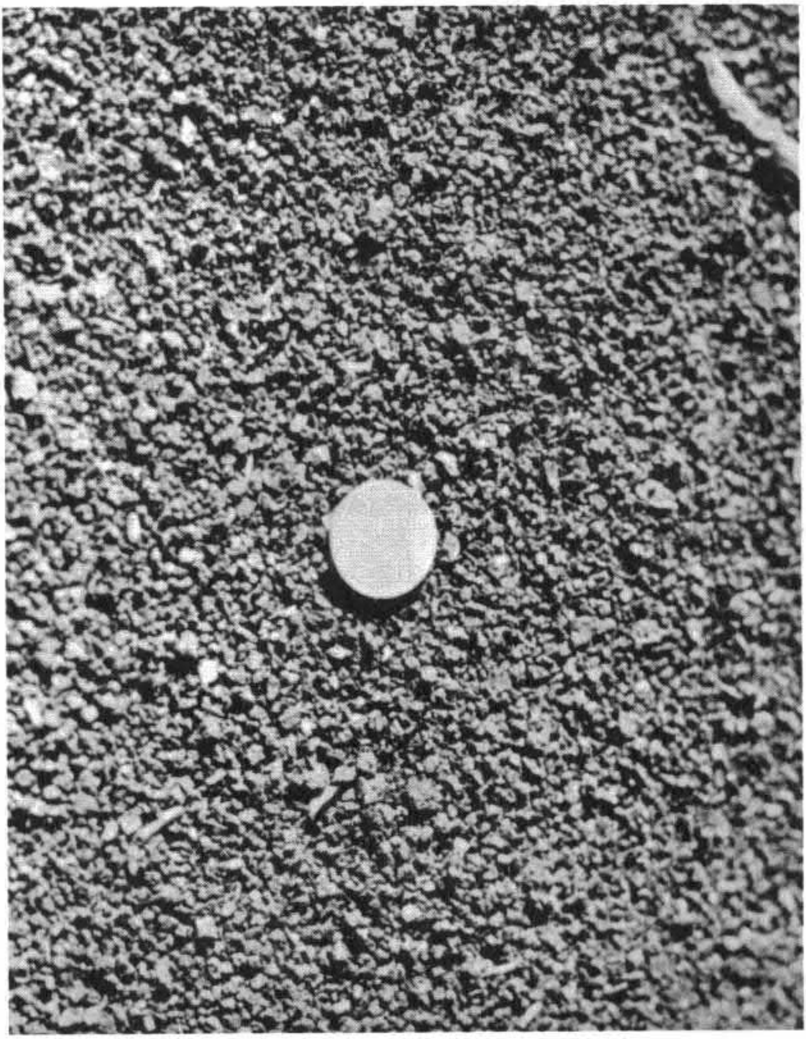

Figure 7. Surface of a ripened colloidal muck soil showing typical "coffee ground" granular structure.

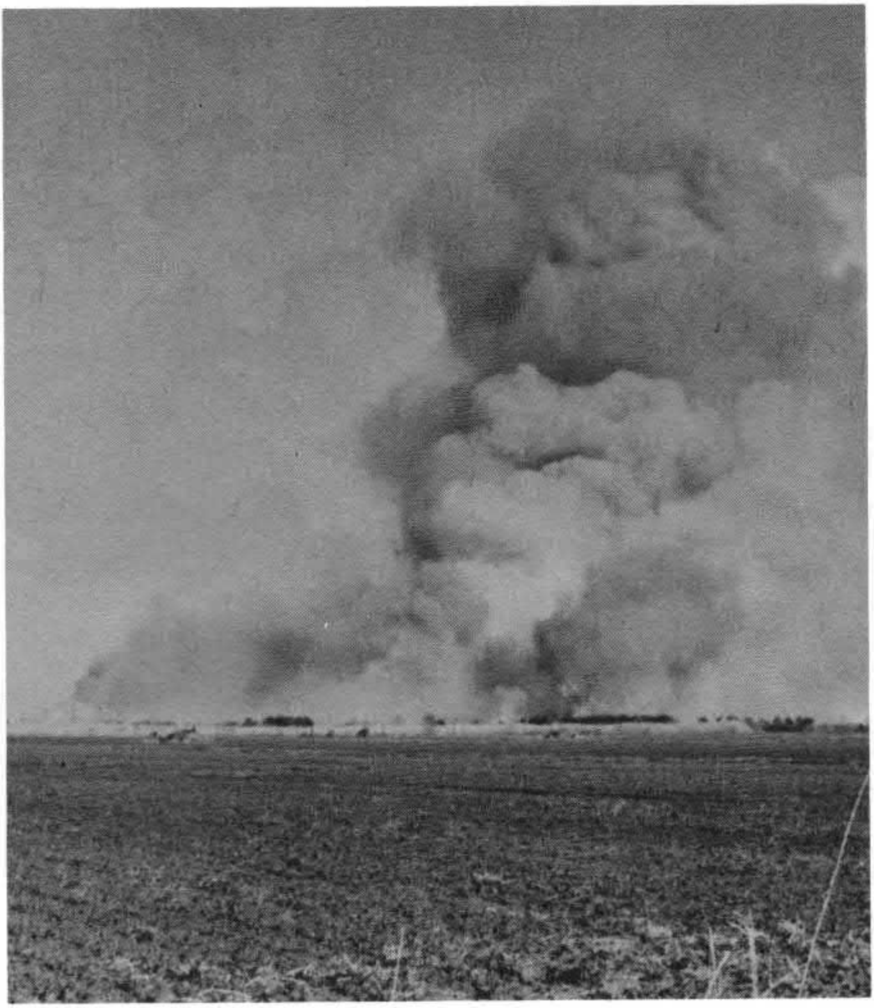

Figure 8. Organic soil and brush burning on the Pungo National Wildlife Refuge, Hyde County.

Figure 9. Buried wood exposed by wildfire destruction of the organic soil surface. The soil may burn for long periods of time and may be destroyed down to the permanent water table.

exposed. Peat fires are often difficult to extinguish since they may be underground and may smolder for months before flaring up again during dry periods. Drastic measures are sometimes necessary to stop a peat fire. Canals can be blocked and water pumped in to flood the area. If accessible, overhead irrigation can be used to wet the area around the fire to halt its advance. If discovered early enough and if soil moisture is high, small fires can sometimes be extinguished by repeatedly disking the area to mix the dry smoldering surface soil with the wet underlying soil.

Wind erosion has not been a severe problem in the North Carolina Blacklands, and is not considered a factor in subsidence. Some precautions for its prevention are noted in the soil management section.

The primary and essentially uncontrollable cause of subsidence is simple decay. Allowing oxygen to enter the soil, as well as liming and other soil modifications, creates ideal conditions for decay of the organic matter. Over time the plow zone must be deepened repeatedly, and eventually little of the organic matter will be left. However, the subsidence rate decreases with time as the mineral fraction in the Ap horizon is concentrated and "caps" the underlying organic layers. Dolman and Buol (32) found several soils with lower OM contents in the surface soil than in the underlying layers.

Few data are available on the rates or amounts of subsidence of North Carolina Histosols. This may seem unusual considering the attention this has received in other areas (28, 29, 50), especially Florida (91, 93, 94, 98, 103), but is attributable to the fact that most North Carolina organic soils are relatively shallow, often do not have very desirable organic surfaces, and over-lie mineral soils that can be farmed. The large area of Histosols south of Lake Phelps has an estimated average depth of about 5.5 feet, and Daniels, et al., (22) reported that the Hofmann Forest Histosols ranged from 16 inches to 6.5 feet thick. Few Histosols in this state are deeper than this. No soils have been abandoned in North Carolina because of subsidence and many dark surfaced mineral soils now being farmed once had thick organic surfaces. Dolman and Buol (32) estimated that one area of mineral soil near North Slope Grain Elevator in Washington County had lost up to 70 inches of surface. In addition, it is known that the soils north of Lake Phelps were Histosols when originally cleared in the 1790's but had lost three feet of surface by the 1830's. More recently Skaggs (88) studied subsidence on a newly drained deep colloidal muck and found the rate to be about 1.06 in/year for the first two years measured. The Soil Conservation Service has monitored soil subsidence at three sites in Washington County since 1973 (96); two sites on Belhaven muck and one on Pungo muck. Measurements made between 1973 and 1976 showed an average yearly loss of 0.15 to 0.46 inches for the two sites on Belhaven soil and 0.15 inches for the Pungo soil. The higher rates were on sites that had recently been placed into cultivation.

The results of soil subsidence are much more serious in Florida for several reasons. First, most Florida Histosols are sawgrass peats and are relatively less decayed than those in North Carolina, resulting in more rapid subsidence when conditions are favorable. Second, much of the Florida Histosols area is underlain by rock, and farming the underlying mineral soil is not an available option. Third, sawgrass peats in general have more desirable physical and chemical characteristics than do the colloidal muck soils in North Carolina. For example, many sawgrass peats are not extremely acid, have quite good internal drainage and contain no colloidal muck. They can be tiled and irrigated through subsurface drains, in contrast to the North Carolina Histosols where this is seldom possible (88).

The only practical method of reducing subsidence in Florida is water table control (17, 90, 92, 93) but recommendations are made with the realization that they will be only partially successful. Florida Histosols have been subsiding at rates ranging from 0.5 to 3.0 inches per year and in 1974 Stephens (93) predicted that "by 2000, the peat and muck will have subsided to the point of widespread abandonment for farming."

As previously discussed, subsidence has not caused land abandonment in North Carolina, but there can be adverse consequences. The underlying mineral soil may be less desirable than the original organic surface if it is heavy clay or loose sand. Another common problem is uneven land subsidence, because the underlying mineral surface is often not smooth, and organic pockets may alternate with mineral ridges. Such land is very difficult to manage, since different water regimes, lime rates, herbicide rates, fertilizer rates and so on will be needed from one part of the field to another. Intentional removal of surface organic deposits to farm the underlying mineral soil is not a new concept, but was practiced in England and Holland before 1800 and has been advocated in the United States (1, 18, 34). Often the organic surface was considered undesirable for farming or was considered more valuable for industrial use (27, 34, 69) and was harvested as a fuel source. There is interest at present in removing undesirable woody colloidal muck surfaces for fuel and farming the underlying mineral soil in North Carolina and in other states (56).

Another hazard of subsidence is loss of elevation and the increased cost of water removal. Pumps may become necessary and drainage canals would have to be deepened with time. If the land contains buried wood it will have to be removed periodically until ultimately all of it will have been eliminated.

While subsidence has not been considered a serious problem in North Carolina, the Histosols that remain to be developed are for the most part woody and are at a low elevation. For the reasons previously discussed subsidence on these soils should be minimized through proper soil and water management. Skaggs (88) has reported that North Carolina organic soils are not very sensitive to water table manipulation, but care should be taken to avoid over-draining. This is more likely to occur on organic soils with good internal drainage than on colloidal muck soils similar to those studied by Skaggs.

Land Development

Clearing

In recent years land clearing procedures have become standardized throughout the Blacklands. Land drainage is the first consideration since it will be needed for crop production and also greatly simplifies the land clearing operation.

The first step is establishment of the primary canal system with connections to an outlet (Figure 10). These lateral canals are usually dug one-half mile apart and empty into a header canal. Right-of-ways are sometimes cleared before the canals are dug, but if the vegetation is sparse or the soil very swampy, the dragline will proceed with no site preparation. Mats are usually needed to support the draglines due to the soft soil. The spoil from the canal is piled along one side and is usually smoothed and used as a roadway. Even in deep Histosols the canal normally extends into the underlying mineral soil and the spoil bank will be capped by mineral soil. This means that additional fill soil for road construction is seldom needed except in cases where soft areas need to be repaired.

After major canals are dug and draining is underway, the field ditches are surveyed about 330 feet apart and right-of-ways for the ditching equipment are cleared (Figure 11). These field ditches are V-shaped and dug two-four feet deep with zero grade from the headland (canal spoil bank) to the canal on the other end of the cut (field), typically 0.5 miles long (Figure 12). The area may be logged at any stage in the clearing process, but if the soil is very wet it may be delayed until after most ditches are established. Similar drainage patterns are used for timber production and in some cases a period of years has elapsed between initial ditching and final clearing.

Once the field ditches are established, clearing can begin. All surface vegetation, as well as stumps and accessible buried wood, is pushed to a long windrow in the center of each cut. It is at this stage that the wisdom of pre-ditching becomes apparent, since the land will be drier and allow bulldozers freer access without becoming mired. The land in the Blacklands area is so flat that artificial slopes must be established to remove surface water. The spoil from the ditches is moved toward the center of the cut in the land clearing process, thus saving an extra soil-moving operation later (Figure 13). The windrows should contain no more soil than is necessary to "crown" the field and establish the final slope since it eventually must be re-shaped and leveled when the windrow is removed.

When the windrows have been completed they may be left to be burned (Figure 14) or allowed to decay while the areas to either side are farmed, or the land clearing may progress to the next step of windrow removal. There are good arguments for both approaches. Leaving the windrows reduces initial investment and accelerates return from the land. However, when the windrows are eventually removed it

Figure 10. Primary canal system being dug as the first step in land clearing and development.

Figure 11. Right-of-way for a field ditch.

Figure 12. Field ditch being dug using a backhoe V-ditcher.

Figure 13. Spoil from the field ditch being moved toward the center of the field during the land clearing process.

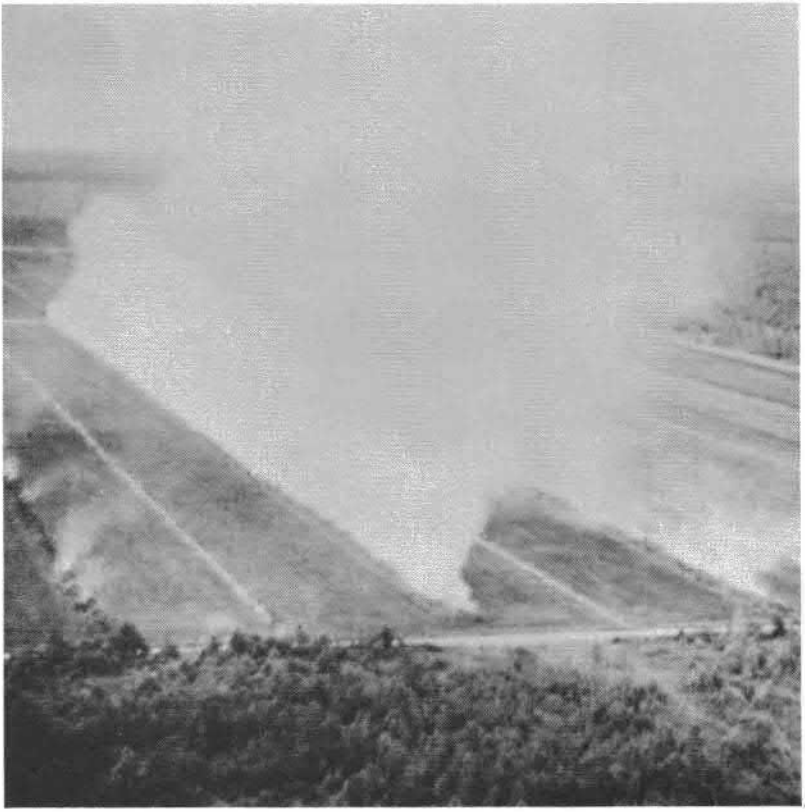

Figure 14. Windrows being burned to eliminate woody debris.

costs just as much and the interim soil improvements such as leveling, liming, and fertilization are disrupted. On the other hand if windrows are removed immediately the initial investment is greater but all land shaping and modification work will be permanent and more land will be available for production. Windrows may also harbor insects, weeds, and other pests.

Windrow removal usually consists of burning, repiling, burning, and repiling until little residue is left (Figures 15 and 16). In cases where the soil is high enough in organic matter to burn, windrows can be burned only in wet weather or the windrow wood must be hauled to the mineral headland for burning. This latter operation is, of course, more expensive. Much of the wood in windrows on deep organic soils is cypress and juniper and will not decay in the windrows within any reasonable length of time. After the windrows have been eliminated or the decision made to leave them until a later time, root zone development begins.

Root Zone Development

The steps necessary for root zone development depend upon the depth of the organic surface, the type of organic matter, and the amount of buried wood. If the soil has a shallow organic surface over a mineral subsoil and has little buried wood, then simple root raking to remove current plant growth followed by heavy disking is all that is needed. However, if buried wood is present the process is more difficult. Buried wood consists of tree remains that have persisted as the swamp grew and the organic surface accumulated. It is almost entirely cypress, juniper, heart pine and bay roots and is thus decay resistant and varies in size from small roots to large stumps (up to 15 feet in diameter) and tree trunks (3 feet or more thick, 20 to 40 or more feet long). In some cases it makes up a significant percentage of the soil volume.

It is not always possible to remove only that wood which interfers with the plow layer since roots and stumps extend vertically in the soil profile and logs can occur randomly in the organic mass. A bulldozer encountering wood may be forced to dig out a large tree trunk to remove what seemed at first to be a minor obstruction. In some cases large subsoilers are pulled behind bulldozers to break logs and pull them to the surface (Figure 17). This creates a great deal of work in re-piling and re-leveling the ground. Soil must be found to fill the holes created by the removal of logs. In any case, a woody Histosol is expensive to clear and wood will have to be removed periodically as the soil surface subsides. Shallow colloidal muck soils are more amenable to development than are deeper soils.

When the buried wood problem has been dealt with sufficiently, root zone development can proceed to the next stage. The soil surface is rough leveled by bulldozers to eliminate stump holes and other depressions, and heavy duty disks are used to loosen the soil surface and chop up roots and debris in preparation for land leveling. Each cut is shaped from edge to center to create a crowned field which is

Figure 15. Windrows repiled after initial burning to separate the soil from the remaining wood and facilitate reburning.

Figure 16. The remaining ashes and soil are spread across the field and leveled after the final burning.

Figure 17. Organic soil with buried logs that have been pulled to the soil surface by large subsoilers.

level from end to end and has about 0.5% slope (6) from the center of the field to the field ditches on either side. Side delivery rotary wood rakes (Darf rakes, Figure 18) are commonly used to windrow pieces of wood too small to be handled by bulldozer-mounted root rakes. Land planes and Darf rakes work together in a circular pattern to level the soil and remove small pieces of wood. Final wood removal may be by hand, by front end loader, or by various modified stone pickers.

Once the fields are crowned, leveled, and relatively free of wood, final land preparation can take place. Lime is applied according to soil test recommendations and incorporated into the soil. Most Blackland soils require substantial amounts of agricultural limestone for successful crop production (Table 5) because they are inherently quite acid. Roots of agronomic crops will grow in these soils only where limestone has been incorporated; thus it is essential that thorough incorporation be accomplished (Table 5). Lime is typically incorporated with large disks initially, but this is inefficient and may not create a root zone of sufficient depth. Buried wood has discouraged the use of turn plows and heavy duty rotary tillers and they are seldom used. However, once sufficient wood has been removed, these implements should be used because the smaller disks used in normal tillage are very poor lime incorporation tools and shallow root zones are common in the Blacklands.

The root zone development phase is completed with lime incorporation. Soil acidity is discussed in greater detail along with nutrient requirements in other sections.

Nutrients

Nitrogen (N)

Organic soils are, by definition, composed of plant (and animal) remains, which means they contain appreciable amounts of nitrogenous compounds. Tonapa found that about 70% of the total N in North Carolina Histosols was in humic and fulvic acids, which are "--amorphous, brown or black, hydrophylic, acidic, poly-disperse substances--" with very high molecular weights (101). They are more resistant to decay than other, low molecular weight, organic compounds such as proteins, carbohydrates, etc., which make up a smaller percentage of the organic matter. The total N content of North Carolina Histosols ranged quite widely with a high of 2.62% for a Pungo with 95.8% organic matter to as low as 0.56% for a Hyde with 29.3% organic matter (101). Values lower than these were found for mineral soils lower in organic matter content. The correlation between organic matter content and total N content was found to be 0.80. This indicates that in general the total N content increased as organic matter content increased, but there were exceptions which Tonapa attributed to differences in original vegetation and length of cultivation.

The release of N through the breakdown of amines and amino acids

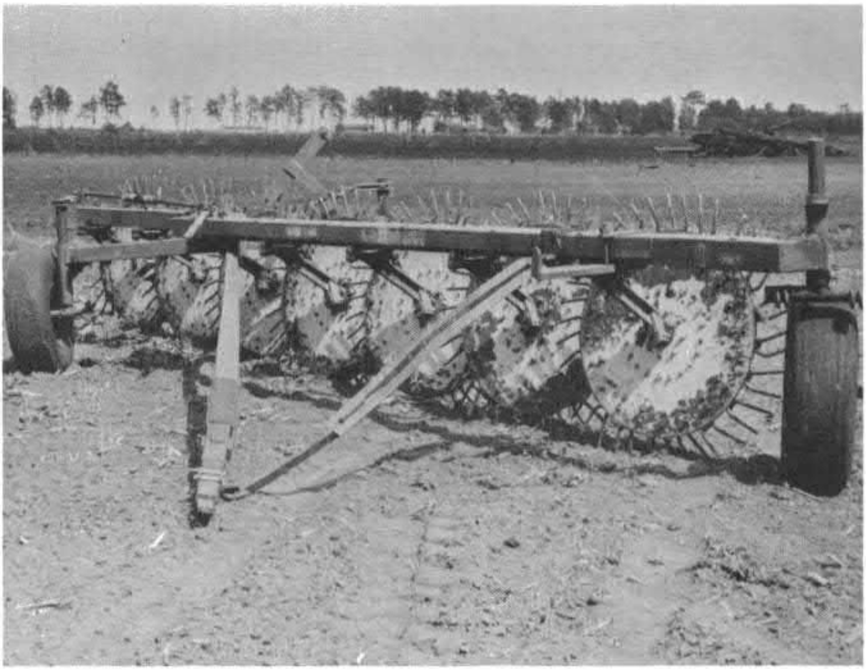

Figure 18. Heavy duty side delivery rotary wood rake (Darf rake) used to windrow small pieces of wood on or near the soil surface.

Table 5. Effects of lime rates and depths of incorporation on soil pH and soybean and corn yields on a Belhaven soil. Pocosin Road, Kilkenny, Tyrrell County. (Unpublished data, J. S. Barnes).

Lime Incorporation Depth (in.)	Lime Rate 1/ (T/A)	pH (1971)	1970 Soybean Yield Bu/A	1971 Corn Yield Bu/A	1972 Soybean Yield Bu/A	1973 Corn Yield Bu/A
4	0	3.8	0	0	0	0
	3	4.4	22	144	31	81
	6	5.0	25	157	38	112
	12	5.7	21	161	39	96
8	0	3.8	0	0	0	0
	3	4.3	19	136	24	65
	6	4.7	33	160	43	121
	12	5.3	31	165	45	123
LSD (.05) Rate			4.3	10.5	4.0	24.7
Depth			2.6	NS	NS	NS
Rate x Depth			6.0	NS	.7	NS

1/ Lime applied in the spring of 1970

is called ammonification because the first form of N in any decomposition of N-containing substances is ammonia (100). Ammonification can occur over a wide soil pH range and is mainly dependent on soil temperature and drainage (101). Other factors include the relative degree of decomposition of the organic material, the N supply, and the resistance of the material to microbial attack. However, the total N content of Blackland soils is not directly indicative of the degree to which N becomes available for utilization by plants.

Nitrogen availability has at times been related to the soil C/N ratio: that is, the ratio between soil carbon content and the soil nitrogen (100). When the ratio is high ample energy (carbon) is available to microorganisms and the mineralized N is immediately utilized by them. In general, when the C/N ratio is above 20 to 25, N is immobilized (98), and when it is below 20 to 25 N will become available for plants. Tonapa found C/N ratios as high as 41.0 (Dare soil, 95.6% OM) and as low as 14.3 (Ponzer soil, 59.5% OM). Unfortunately there was poor correlation between percent organic matter and the C/N ratio on North Carolina soils, and the C/N ratio did not correlate well enough with N availability for practical use in crop production decisions.

Organic soils can be net users of N or may release available N depending on the type of organic matter and stage of development (29). Newly cleared organic soils may require quite large amounts of N for crop production because of N tie-up by soil microorganisms but older organic soils that have been well-limed and have reached a degree of stability can release substantial amounts of N. Work with N rates for organic soils in North Carolina showed that corn yields were maximized with rates varying from as little as 60 lb N/A to as high as 200 lb N/A (101). In this work it was estimated that the available soil N ranged from 37 to 83 lb N/A/year with an average of 56 lb N/A/year. However, Tonapa could find no relationship between estimated available soil N or estimated optimum N rate and soil organic matter content, total N, and C/N ratio of the soils. He concluded that N requirement could vary considerably from year to year and soil to soil depending on uncontrolled soil and weather conditions.

Because of the likelihood that some N will be mineralized, fertilizer N rates for crops grown on soils high in organic matter are lower than for mineral soils. However, there are no reliable analytical methods for satisfactorily predicting fertilizer N requirements, and thus the N rates for optimum production must be based on experience.

Leaching is seldom a problem on Histosols because most of them are impermeable to water movement downward below the root zone. An exception would be friable organic-sand soils (so-called "salt and pepper"), such as those commonly used for commercial blueberry production. Of greater concern is N loss through denitrification, since essentially all soils in the Blacklands are subject to periodic water saturated root zones and warm temperatures. Denitrification occurs when the soil oxygen level drops and soil microorganisms utilize the oxygen component of the nitrate (NO_3) or nitrite (NO_2) molecules. As a result, nitrogen and nitrous oxide are released as gases to the atmosphere and nitrogen loss can be substantial. Recent work with N fertilization of corn on Blackland soils indicates that if all N is applied preplant, a significant amount can be lost (Table 6). Because of the risk of denitrification, fall application of N is never recommended, and single N applications at planting are strongly discouraged. The preferred practice is to apply a small portion of the required N at planting (up to one-half of the total) and the remainder in one or more applications. Normally the second and largest application is at lay-by, and very often liquid nitrogen is used in combination with a herbicide. High clearance equipment used for general crop spraying has the additional capability for application of N late in the growing season. Very little anhydrous ammonia has been used, primarily because buried wood interfers with the injectors. As soils become more developed and economic factors become more favorable, more anhydrous ammonia will likely be used.

Phosphorus (P)

Phosphorus, like N, is a constituent of organic matter and is mineralized as it decays. Mineralization is a natural process, presumed to be by microbiological action, and is enhanced by warm, moist conditions and liming (59).

Daughtrey (24, 25) found that Histosols differ in their P supplying characteristics, with colloidal mucks mineralizing P more slowly than reedbed type soils. The difference is probably due to the more highly decomposed state of the colloidal muck soils. As a result, colloidal muck soils are more likely to need fertilizer P applications to maintain crop growth. However, as a group, Histosols require lower amounts of fertilizer P than do mineral soils.

Although organic matter contains P that can be released through mineralization, it does not hold inorganic P well since P adsorption by organic matter alone is negligible (107). Organic soils low in Fe and Al (sesquioxides) and having only organic colloids will not hold applied P (43, 59, 61). For this reason P can be leached from pure organic soils or quartz sand - organic soils such as those used for highbush blueberry production. The loss will be slowed and may be of no significance if the root zone is underlain by an impervious layer as is the case in many unripened colloidal muck soils (32). The ability of organic soils to hold P will increase with time as subsidence, ditch spoil, and soil amendments such as lime cause increased mineral contents in the root zone (59).

Crops grown on organic soils often do not respond to applied P at soil test levels that are considered deficient for mineral soils (10, 24, 25, 26, 42, 60); in North Carolina 125 bu/A of corn has been produced at a measured soil P level of 8 ppm. Most extractants used in soil testing are relatively ineffective in extracting the organic forms of P present in organic soils (24, 25, 26, 60, 72). However, extracted P levels can be correlated with crop response and soil tests

Table 6. The effect of supplemental sidedress N applications on corn showing the severe loss of N due to denitrification on poorly drained soils when all the fertilizer N had been applied at planting. Hyde County, 1978. (Unpublished data, J. P. Lilly).

Treatment	Yield, Bu/A		
	Organic Soil 1/	Dark Surfaced Mineral Soil 2/	Sandy Mineral Soil 3/
1) 180 lb N/A preplant	64	101	127
2) 180 lb N/A preplant + 25 lb N/A sidedress	91	112	132
3) 180 lb N/A preplant + 50 lb N/A sidedress	103	112	132
4) 180 lb N/A preplant + 75 lb N/A sidedress	121	119	136

1/ Belhaven, about 70% OM

2/ Weeksville, 8% OM

3/ Engelhard, 2% OM

for P in Histosols can be reliable (26).

For the most part the same forms of fertilizer P are used on both mineral and organic soils. One exception is the potential for use of rock phosphate in the Blacklands. When rock phosphate is finely ground (100-115 mesh) and the soil pH is at or below 5.2, it is as effective in promoting crop growth as superphosphate (9). At these pH levels the rock phosphate is acidulated by the soil, but at high pH values it is unavailable.

High P starter fertilizers are often placed with, or close to, the corn seed at planting to improve early corn growth in the Blacklands (Table 7). As shown in Table 7 care should be taken to avoid plant damage from excessive fertilizer rates placed near or with the seed. The soils are usually cold and wet in the spring and are poor suppliers of P at this time. The combination of slow seedling growth under such conditions and the lack of P mineralization can cause severe, if temporary, deficiencies. Starter or pop-up fertilizers are an essential part of a strategy of enhanced early growth to help outgrow insect and weed problems. Slow-growing corn seedlings are often damaged by insect pests such as billbugs and may not be competitive with weeds.

Potassium (K)

Unfertilized North Carolina Histosols are quite low in K content. Potassium is, of course, found in plants in appreciable quantities but is readily leached out of crop residues once the plant dies. Histosols contain no K-supplying or K-fixing silicate minerals and essentially all the K present is held on the organic matter exchange complex and is readily available. For these reasons K relationships are similar to K relationships for acid mineral coastal plain soils which are also low in content of weatherable minerals. The amounts of K required for crop production are the same on both organic and mineral soils though the K is less subject to loss by leaching on the organic soils. Because K is relatively easy to manage and soil tests are reliable, K fertilization of organic soils has received limited attention. Early work established optimum fertilizer rates and correlation with soil tests (5, 6, 7) but no detailed work on soil reactions or chemical relationships has been done. The recommended rates of K fertilization do not change with organic matter content.

Secondary Nutrients

- Calcium (Ca): Calcium deficiency has not been observed in North Carolina and is very unlikely to occur. The high rates of lime needed for crop growth supply ample amounts of Ca. In addition, Histosols are natively high in Ca since it is a constituent of organic matter and usually test high in Ca even before liming.

- Magnesium (Mg): Soils high in organic matter also contain substantial amounts of Mg. As a result calcitic limestone

Table 7. Effect of ammonium polyphosphate (10-34-0) placed with the seed at planting on corn height at 54 days and yield of early planted corn (March 30). Tidewater Research Station, 1979. (Unpublished data; J. P. Lilly).

Treatment	Plant Height	Plant Population	Corn Grain Yield
	in.	Plants/A	Bu/A
1) Broadcast 100 lb/A 10-34-0	75	23,615	146
2) Pop-Up 50 lb/A 10-34-0	84	23,386	148
3) Pop-Up 100 lb/A 10-34-0	90	23,386	153
4) Pop-Up 150 lb/A 10-34-0	93	17,310	132
LSD	6.1	3,111	NS

can be used as described elsewhere and no fertilizer Mg is required. However, Mg deficiency has occurred on soils lower in organic matter content when the natural soil levels were low and calcitic lime was used. Magnesium deficiency can be avoided on Blackland soils by the use of dolomitic limes where soil tests indicate low Mg may be limiting.

- Sulphur (S): Sulphur deficiency is usually associated with leached sandy soils low in organic matter and has not been observed in Blackland soils. Soils high in organic matter content contain sufficient amounts of S since it is an important component of protein and is present in large amounts in such soils. When soils are water saturated and reduced conditions prevail, S may be present as sulfides or poly-sulfides which can be toxic to plants. Toxic amounts of hydrogen sulfide can be formed from sulfates and may escape as a gas.

Copper (Cu)

Copper is the micronutrient most commonly deficient on high organic matter soils in North Carolina, but is now so widely used that deficiency symptoms are seldom seen. The need for Cu on Histosols was discovered in Florida (3) in the mid 1920's, and by 1927 a number of growers in the Everglades were using it. The initial work in Florida was soon followed by additional studies (2) which firmly established the need for Cu, although its essentiality was not proven until 1931. However, its use in North Carolina was not adopted (108, 109, 110, 112) until later, and as a result, utilization of high organic matter content soils was delayed. In 1936 Willis and Piland were advising against the general use of Cu (111), and believed that any beneficial effect was related to a catalytic function in reducing the toxic effect of "soluble iron." It is now known that properly drained well-limed soils will not contain excessive amounts of reduced or soluble iron. Subsequent research showed that the need for Cu was widespread (44, 78, 114) and more recently recommendations have been established for most crops.

Copper forms very stable complexes with organic matter (12, 67, 95) and is believed to be held primarily by phenolic hydroxy groups and carboxylic groups (95). Recent work indicates that copper is bound to carboxylic oxygens (12) and that chelation is not a significant factor. In general, the higher the organic matter content of a soil the more likely it will be deficient in Cu (100). An additional factor is the general lack of Cu-containing primary minerals in Histosols. The bound Cu is rendered at least partially unavailable but is also prevented from loss through leaching (67). Soil pH also influences the availability of Cu and it has been shown that Cu becomes less available as soil pH increases (68). Raising the pH of a North Carolina Histosol above 5.1 reduced the Cu content of wheat plants (115). However, in practice pH has little practical effect on Cu availability since lime must be applied for crop growth and the pH used was higher than the now-recommended level of pH 5.0.

Based on the work of Younts (115), Patterson (78), Hanes (44), Schauble (84), and Barnes (8), the copper needs of agronomic crops was established (Figure 19). Wheat is generally recognized as most sensitive to low soil Cu, so that it was most often used as the test crop. It was assumed that correction of Cu deficiency on wheat would also supply enough Cu for other crops. Significant yield increases for millet were found up to 2.5 lb Cu/A in the greenhouse, but field experiments with wheat indicated that yield would be maximized with 5.0 lb Cu/A (78). Other work has shown that as little as 1.25 lb Cu/A at planting can maximize wheat yield. This and additional work (5, 6, 8) resulted in a standard recommendation for newly cleared Histosols of 5.0 lb Cu/A. Similar rates are recommended by other states, indicating that the performance of Cu is similar. Five lb Cu/A was enough to prevent Cu deficiency for several seasons and a rule of thumb of "5 lb Cu/A every 5 years" evolved since at that time there was no soil test for Cu, but the persistence of applied Cu was widely recognized (2, 47). North Carolina now has a soil test for Cu and fertilizer rates are based on soil test values. In general, soils that test less than about 1.0 ppm Cu, utilizing the North Carolina extractants, are considered deficient.

The rates recommended for Cu in North Carolina are low compared to many reported rates. Initial applications of 50 lb/A copper sulfate (12 lb Cu/A) was used with success in Florida (3), although this was to compensate for inefficient application methods and Allison stated that good results could probably be obtained with 15 to 20 lb/A copper sulfate (3.6 to 4.8 lb Cu/A). Younts and Patterson (115) applied up to 40 lb Cu/A and found little yield reduction, however, it is recommended that Cu not be applied in excessive amounts since damage to some crops may result and the practice is expensive and wasteful.

Copper can be applied to the soil in many chemical forms and work in Florida (41, 58) and North Carolina (8) has shown that copper oxide (CuO) is as effective as any other form and generally is the least expensive. The most common source used is copper sulfate (3, 66, 111) and much of the early research was with this material. The source of copper used is dictated by the fertilizer program used and economics. It may be necessary at times to use chelates or other more expensive forms (for example, in liquid fertilizers), but they are no better agronomically than copper oxide. Of greater importance is the fineness of the material and the method of application to ensure thorough mixing with the soil. To be most effective Cu should be finely divided, uniformly distributed, and well-mixed into the soil. Granular copper materials are less effective initially than finely divided materials. This may be due to localized root toxicity around the particle before the Cu is diluted by the soil solution since concentrated Cu is very toxic to plants. Limited root contact and translocation may also be

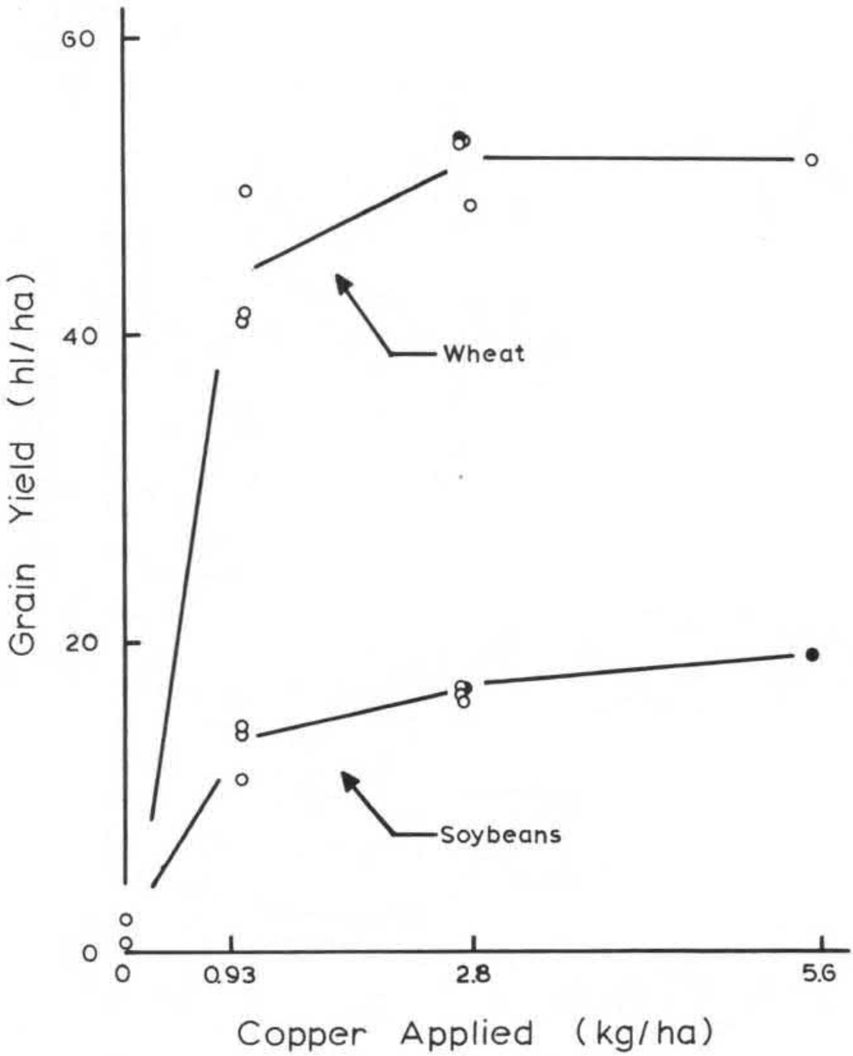

Figure 19. Response of wheat and soybeans to rates of three complexed copper sources (open symbols) and copper sulfate (closed symbols) applied to a Ponzer soil. Barnes and Cox (8).

a factor. Because of this, Cu should be broadcast, and band application is not recommended.

Copper deficiency can be prevented on many plants by foliar applications. Once symptoms appear on agronomic crops the Cu must be applied quickly because affected plants usually deteriorate rapidly. Rates of about 0.5 to 1.0 lb Cu/A are effective. Multiple applications may be necessary if the deficiency is severe. As mentioned previously, wheat is the most sensitive crop to Cu deficiency. Symptoms are most common when the weather warms in the spring and wheat begins to grow rapidly, since soil Cu levels may not be high enough to meet the increased needs of the plant. Cu deficiency is associated with Ca nutrition within the plant and symptoms reflect this. Affected wheat plants typically develop dead leaf tips which break over into classic "flagging." Also, new leaves fail to unroll, twist, and subsequently die. Corn plants exhibit interveinal chlorosis, leaf twisting, and shortened internodes, and soybeans are stunted with loss of lower leaves.

Other Micronutrients

No micronutrients other than Cu have been shown to be widely deficient in the Blacklands.

- Boron (B): Boron has been found to be deficient in some Histosols (29) but no response by agronomic crops has been obtained in North Carolina. Boron is used only for certain vegetable crops such as broccoli, cauliflower, etc. which are known to be especially sensitive to low B availability. There is no reliable soil test for B.

- Zinc (Zn): Zinc deficiencies have been limited mainly to overlimed sites. Zinc deficiency has been observed on corn in fields with varying soil types where the mineral outcrops have been overlimed. It may be accentuated by high P levels and is worse under cool, wet growing conditions. Soil application is effective and is preferred since deficient plants are difficult to salvage. The use of byproduct lime from zinc mining has prevented Zn deficiencies in some cases, but such lime is not widely available in the Blacklands.

- Manganese (Mn): Manganese deficiency induced by overliming is the most commonly observed micronutrient deficiency on soybeans; it results primarily from residual lime left on the headlands in the liming process. It will also appear if entire fields are overlimed and may be more evident on burned land. Because Mn may be rendered unavailable in overlimed soil and because plants respond quite well to foliar Mn, many growers choose to correct the deficiency foliarly as it appears. It is not uncommon for soybeans to exhibit Mn deficiency early in the growing season but to grow out of it as the root systems encounter more acid underlying soil where Mn is more available. Deeper plowing sometimes corrects Mn deficiency by mixing acid underlying soil with the overlimed topsoil. This can lower pH in the root zone to a more desirable level and enhance Mn availability. If soil application is used the Mn should be banded to minimize soil contact.

- Molybdenum (Mo): Molybdenum is important in the fixation of N by legumes. It is less available in acid soils and deficiencies can often be corrected by proper liming. The deficiency is more likely to occur on soils lower in organic matter. The amount of Mo necessary for good crop growth is very small and is usually supplied through seed treatment of legumes such as soybeans. Many growers apply Mo material as insurance treatments.

Soil Acidity and Liming

pH and Soil Acidity

A dominant characteristic of North Carolina Blackland soils is their inherently low pH value (32, 73, 110) which is typically 3.4 to 4.2 for newly cleared land. The environment under which these soils developed contained almost no calcium materials; the only exception being occasional deposits of sea shells. The mineral fraction is mainly highly weathered siliceous marine sediments, and high rainfall has probably contributed to loss of bases.

Because of the very large amount of internal surface area of organic matter and the reactivity of its chemical components, Blackland soils have very high cation exchange capacities (CEC's). The CEC of a soil is a measure of its capacity to hold cations, both basic (Ca, Mg, K, etc.) and acidic (H, Al), and in general increases as the soil organic matter content increases (52). Thus high amounts of lime are required to change the pH value of such soils because they contain large reserves of acidic cations (51) and have large capacities to adsorb basic cations from lime (38, 39). Enough lime must be added to counteract the acidifying effects of the H and Al. Research has shown that agronomic crops grow well on organic soils that have been limed to about pH 5.0 (5, 6, 68, 74) (Table 5). This is considerably more acid than for mineral soils and is thought to be due to their much lower Al levels for this pH and the relatively high Ca concentration (38, 39). However, large amounts of lime, up to 6 T/A or more, are required to achieve this relatively low pH level (Table 5). Liming to raise the pH above the recommended level can induce nutrient deficiencies (62, 68), is expensive, and has resulted in no improvement in crop yields.

The recommended pH value for soils containing over 10% OM by the North Carolina soil test procedure is 5.0 for agronomic crops, while the recommended pH level is 5.5 for soil containing between

5 and 10% OM. This compares with the recommended pH value of 6.0 for mineral soils in North Carolina and recognizes the unique characteristics imposed by organic matter. Lime requirement is determined primarily through the extractable acidity (Al + H) content of the soil and the desired pH change.

Liming Materials

The primary purpose of liming materials is to neutralize soil acidity, and the secondary purpose is to supply calcium and/or magnesium. This secondary role is very important on the mineral soils of the North Carolina coastal plain where calcium and magnesium contents are naturally very low, but is of much less importance on Histosols since they contain large amounts of calcium and in many cases magnesium before liming. The result is that on many soils high in organic matter either calcitic or dolomitic lime can be used (7) (Table 8). The choice for soils lower in organic matter content is dictated by the magnesium level since calcium will be supplied in either case.

Once the decision has been made as to the type of limestone required, attention should be placed on its quality. The two main quality factors are neutralizing value (NV) and fineness of grind.

Neutralizing value determines the true worth of a lime since this measures the relative amount required to neutralize a given quantity of soil acidity. Pure calcium carbonate is rated 100%, and lime rates as recommended on soil test reports assume a NV of 100%. High quality dolomitic limestone can have NV's slightly higher than 100% because of the lower molecular weight of the magnesium ion, as can materials with higher calcium contents such as calcium oxide or calcium hydroxide. Materials with NV's less than 100% must be used at higher rates to achieve the same degree of soil acidity neutralization. Cost of lime should be calculated on the basis of tons of NV rather than tons of material. A material with a NV of 85% must be used at a rate of 18% higher than a material with a NV of 100% in order to achieve the same results. The relative cost of purchasing the material, transportation, and spreading must be considered.

The other primary factor in lime quality is fineness of grind. Material with particles larger than 10 mesh is ineffective in neutralizing soil acidity since neutralization of acidity requires that the lime dissolve and come in intimate contact with the soil. Larger particles dissolve too slowly to rapidly change soil pH values. Particles smaller than 100 mesh are rated as 100% effective since they react quite rapidly in the soil. A good agricultural limestone contains a blend of very fine materials for quick reaction and somewhat coarser particles for longer lasting effect. A coarse limestone is a poor buy, and materials sold as agricultural liming materials are regulated by law to ensure their effectiveness.

Both quality factors must be kept in mind when purchasing marl for use as lime. Marl is calcitic limestone and quite acceptable for

Table 8. The effect of lime sources on soil pH and soybean and corn yields on a Belhaven soil. Hyde County. (6, and unpublished data, J. S. Barnes).

Treatment[1/]	1969		1970		1971		1972	
	pH	Soybean Yield	pH	Corn Yield	pH	Soybean Yield	pH	Soybean Yield
1) Check, no lime	4.2	12	4.2	74	4.5	15	4.4	23
2) Dolomitic	5.0	11	5.0	120	5.3	18	5.1	31
3) 1/3 Dolomitic 2/3 Calcitic (marl)	5.0	16	4.9	124	5.2	19	5.0	33
4) Calcitic (Va.)	5.1	17	5.0	124	5.0	20	5.0	32
5) Calcitic (marl)	4.8	21	4.9	118	5.0	20	4.9	35
6) Calcitic (marl) + Mg SO_4	5.0	19	4.9	114	5.1	21	5.0	34
LSD .05		6		26		NS		6

1/ All lime applied at 6 T/A adjusted to 100% $CaCO_3$ equivalent use on soils high in organic matter, but the NV is typically not high and rates must be adjusted upward. Most marketed marls have NV's of 80 to 85%, but a few are higher and some much lower. Because of the scarcity of good liming materials in the coastal plain, very poor materials have been explored. Lime users should be careful to ascertain the NV and particle size of any local materials they decide to use. The lime law sets particle size requirements, but is effective only if the materials are marketed for agricultural use. A seller can sell, and a buyer can buy and apply, any material so long as the seller makes no guarantee. For example, in recent years large quantities of very coarse crushed marl were sold and applied to Blackland soils because it was less expensive. However, the results were very unsatisfactory even though very high rates per acre were used in some cases.

Lime Application and Incorporation

Lime is only as effective as its distribution, both on the soil and within the soil. The widespread use of spinner spreaders in combination with the unique field shapes in the Blacklands has created problems in lime distribution on the land. Because fields are long and narrow, spreaders tend to follow the same pattern time after time. Non-uniform distribution, which is inherent with spinner spreaders, can be enhanced by repeated trips and create areas of low pH and overlimed areas. The area of most concern is the field edges along the ditches where there is no overlapping pattern. It is common to find low pH problems along the field ditches in the Blacklands. The cure is not easy, because it involves use of full-width drop spreaders to apply additional lime along ditches, or else the spinner spreader must drive close to the ditch and waste lime in non-crop areas. More attention should be paid to spreader patterns and care taken to prevent underlimed and overlimed zones. For example, if a field is 300 feet wide and 15 feet on either side is not well limed or well fertilized then 10% of the field is underutilized. This is not uncommon and causes substantial loss of income.

The other factor in lime distribution is soil incorporation. In acid Histosols roots of crops will grow only in the well-limed zone, thus it is essential that lime be effectively incorporated. The characteristics of many Histosols makes this difficult. Buried wood has made the use of bottom plows almost obsolete, and the plastic nature of colloidal muck prevents effective lime mixing. The chisel plows and disks commonly used for lime incorporation are not very effective. The best incorporation tool for moderately woody Histosols is the heavy duty power rotary tiller. This piece of equipment incorporates lime thoroughly and has been shown to be quite durable. Buried wood will interfer to some extent with the operation of the machine but it does the most complete job of incorporation. Chisel plowing followed by a heavy disk is probably the most practical procedure on rough land if the disk is adjusted to cut deep enough, and is angled so that it throws the soil from side to side. Heavy duty disks can survive the unavoidable abuse from wood in the soil by rolling over the larger obstructions.

The recommended root zone is six to eight inches deep but there are many Histosols in cultivation with less than this. Some of the advantages of deeper root zones have already been discussed, but basically they provide more water, more nutrients, better plant support, and better drainage. Every effort should be made to achieve an acceptable root zone depth and to maintain it with time as the higher organic matter soils subside.

Soil Management for Crop Production

Introduction

One of the most important management factors in successfully farming Blackland soils is timeliness. The higher the organic matter content the more important timeliness becomes. Because these soils are more subject to becoming water saturated and untrafficable, and because they dry out slowly, the amount of access time is less than for mineral soils. For example, some sandy mineral soils can be tilled only a few hours after substantial rains, while colloidal muck soils may be inaccessible for days after a rain. It is not unusual for soils high in organic matter content to become too wet to cultivate and remain that way until it rains again, establishing a cycle that may prevent field work for long periods of time. People who farm such soils know that all available access time must be used in the spring before and during the planting season or it is likely that planting will be excessively delayed or prevented altogether. It is fortunate that the corn planting period in the North Carolina Blacklands coincides with a period of relatively low rainfall in March and April (Table 1). Timeliness is important for all field operations, because delayed field re-entry can be devastating for insect and weed control, proper fertilization, and harvest. Delayed re-entry can be a special hazard for specialty crops such as vegetables which are especially sensitive to timing. This, and the other special cultural requirements of Blackland soils are related to the unique physical and chemical properties imparted by the organic matter.

Crops

The periodic high moisture content of Blackland soils limits them to crops which can tolerate some periods of soil saturation. For the most part this means corn and soybeans in an every-other-year rotation. Crops such as tobacco, peanuts, etc. which require well drained soils are not grown. The flat topography, moisture supplying capacity, and climate are well suited to the needs of corn and soybeans. They are grown in large blocks and can be highly mechanized. Small grains lend themselves to inclusion in a three-crop-in-two years rotation of corn, fall planted small grain, followed by soybeans. If problems with certain diseases, primarily glume blotch, can be overcome, large acreages of small grain may be grown economically. Other considerations are value of the small grain and delay of soybean planting date, although soybeans following small grain are often planted no-till. Most of the discussion on soil management will be directed toward corn-soybean production.

Vegetable crops are limited at present to potatoes, cabbage, cucumbers, and small amounts of a few other crops. Mineral soils with histic epipedons are better suited for these crops because of faster re-entry time, more uniform soil (for more uniform crop growth) and less buried wood. The Histosols in North Carolina are for the most part much less desirable for vegetable production than those of Florida. Another major limiting factor is the accessibility of markets. There are few canneries located convenient to the area, and the fresh market has been limited due to problems with producing crops consistently and at an advantageous time of year. Erratic weather has made contract production difficult, and the limited spring and fall growing seasons compete with other production areas. However, as the area matures and soils become more stable with irrigation available, the natural assets of nearness to markets (upper east coast) and available land will probably result in an expanded vegetable industry. Transportation costs, and other limitations are eroding the recent dominance of the current production areas.

Many forage crops do quite well on these soils, though there are limitations. Fescue-clover is the preeminent forage combination on all soils in the Tidewater area. On the mineral soils this can be coupled with a productive summer perennial such as Coastal Bermuda grass for a well-balanced forage program. Fescue does quite well on Blackland soils if they are properly limed, but growth of clover has been unpredictable. In addition, there are no desirable well-adapted summer perennial forages for deep organic soils at present. At one time it was hoped that deep woody colloidal mucks that were unsuited for row crops could be used for pasture. Unfortunately, the adapted forages require as much lime for good growth as do row crops, and incorporation of lime in woody soils remains a serious hinderance. Effort has been made to find acid-tolerant forages since Histosols contain sufficient calcium and magnesium, but this has been unsuccessful. Other problems such as poor trafficability in wet weather have for now reduced interest in large-scale development of permanent pasture. Soils that will support row crops will certainly grow good pastures, but row crops are more profitable at present.

Drainage

Nearly all water removal is by surface drains. The need for canals and the establishment of field ditches and crowned fields has been discussed. Fields should be shaped so that water will move from the center toward the field ditches on either side. However, nearly all crops are planted on raised beds which run across the slope of the field and prevent water movement down the slope. Shallow ditches called "hoe drains" are cut parallel to the slope of the land, perpendicular to the beds, after the crops are planted to intercept water trapped in the interbed furrows and conduct it to the field ditches.

Hoe drains are normally little deeper than the interbed furrows so they can be crossed easily by equipment, and are dug using tractor-mounted PTO powered rotary ditchers designed for that purpose. They are sometimes dug at random from the low spots in the fields to the field ditches, but are more often routinely established every few hundred feet and are placed in the same position year after year. The first hoe drains are almost always dug at the foot of the slope off the headland to intercept water running off of the field road and its side slope. If no hoe drain is used, the intersect between the headland side slope and the rest of the field may be the wettest place in the field and prevent entry for crop tillage due to the accumulated run-off from the headland. Hoe drains must, of course, pass through the raised edge of the field ditch, and once an outlet has been dug it will likely be used from year to year. They should be cleaned after each cultivation and some may be cleaned after harvest or fall tillage to provide winter drainage, thus enhancing earlier field entry in the spring.

Subsurface or tile drains are used only on dark surfaced mineral soils and some deep organic soils with acceptable internal drainage. Tile drains have been installed in colloidal muck soils in the past (108) but were not effective due to the cost and difficulty of installation and the slow water movement through the soil. Tile installed at the Blackland Research Station near Wenona in 1915 and 1916 lowered the water table only 0.6 feet when compared with undrained areas (108). However, the tile drains were spaced 330 feet apart. The main limitations of tile drainage in many North Carolina Histosols is the difficulty of installation (buried wood) and the extremely close spacing needed for effective drainage (88) of soils containing colloidal muck. Also, water from the frequent heavy rains during the cropping season must be removed rapidly to prevent crop damage.

Most drainage in the Blacklands is by gravity, but there are many areas where the land elevation does not permit complete gravity drainage that are at least partially dependent on pumps for water removal. Boundary dikes are formed using the canal spoil as the boundary canals are dug. Tide gates should be installed at the pumping stations to allow gravity flow when the outer water level is low enough. The tide gates have the additional advantage of preventing salt water intrusion and the boundary dikes give some protection from storm tides. Salt water intrusion may be a hazard at low elevations and tide gates should be used for protection even where pumps are not considered necessary. If development continues in areas under five feet in elevation, most of the drainage will be pump-assisted. (Figure 20).

Erosion

Water erosion is not usually considered serious on land with so little slope, but because of the unique features of Blackland soils it can be important in places. The low infiltration rates of many soils as well as the run-off concentration by furrows and hoe drains

Figure 20. Pumping station with tide gates to remove excess water from low-lying farm land.

can cause erosion in hoe drains and at outlets. The result is loss of topsoil, deepening of hoe drains, and siltation of field ditches. At times field ditches are blocked by sediment, and even moderate erosion will cause more frequent ditch cleaning. Even when the land is flat, sheet erosion can occur. Soils with high organic matter contents have low bulk densities and require relatively low amounts of energy for transport. When they are water saturated they sometimes move as a slurry and are very erosive. Moving water can cause ditch and canal erosion which results in siltation and loss of farm land through collapse of ditch banks. Effort should be made to reduce water erosion by providing sufficient hoe drains and protecting ditch and canal banks with vegetation. Fescue sod is frequently used for stablilization since it grows well, will not become a pest, and is easily maintained by mowing.

Wind erosion has not been a serious problem in the Blacklands but growers should be aware of the potential hazard. It is most likely to occur in the early spring when the area receives strong, steady winds and the soils are being tilled. It is not a problem at other times because the soil is covered with a growing crop or by crop residue. Care should be taken to avoid leaving the soil disked flat, in a loose, and highly pulverized condition. Under such circumstances it will be blown and may be lost into the air and deposited in ditches. Bedding the land is an effective deterrent to wind erosion, especially if the beds are perpendicular to the prevailing winds. The wind loses energy near the ground, edies are formed, and the capacity of the wind to move soil drops dramatically. Other practices which will eliminate or minimize the problem are crop residues, rough tillage, minimum tillage, and high soil moisture content. Wet soils will not be eroded by wind action until they have been at least partially dried. Wind breaks at the major canals will probably be more important as larger areas are opened to cultivation. However, if conditions are favorable, a field of only a few acres can be severely eroded.

No-till planting has a place in the Blacklands, both from an erosion and from an energy savings standpoint. Soybeans are commonly planted in small grain stubble where a three crop in two year rotation has been used, and corn can be no-till planted following soybeans quite successfully.

Tillage

The implements used for primary tillage in the Blacklands vary depending on soil characteristics. Chisel plows and disks are used on all soil types at times and on some soils exclusively. Bottom plows are not used on soils with buried wood and this has resulted in reduced use on other soils where they are advantageous. Rather than have two sets of tillage tools many growers till all their land with the tools that can be used universally. Other growers farming land that could be bottom plowed are influenced to shift to practices they perceive as faster and simplier. This decision can be potentially damaging as discussed in the lime use section.

After the land is broken and disked, or in many cases only disked repeatedly, individual row beds are formed using disk bedders. The practice is nearly universal for corn and soybeans on both Histosols and dark surfaced mineral soils. Beds provide localized drainage, deeper root zones immediately under the plant, and expose more soil surface for early season warming. Bedded land will dry out faster in the spring and reach planting temperature earlier. It is especially useful on newer land where surface irregularities can cause water ponding and plant loss over large areas. Bedding can provide a drained soil for seedling growth even with some field ponding. Bedders have been designed which are independently mounted for each row to allow the implement to flex and roll over buried wood without disturbing the other rows.

Ripper-bedders are used by some growers to chisel immediately under the row. This practice is more likely to succeed on some deep surfaced sandy soils and is counter-productive on soils with acid subsoils or high clay content. Care must be taken to firm the seedbed to prevent collapse of the furrow slit and loss of seedlings. Some growers feel that the practice helps improve drainage under the row. However, in general, positive results are obtained only where the underlying soil does not contain toxic levels of soil acidity, in years when there is moisture stress at a critical time. Soils underlain by undesirable clay subsoils are usually better left undisturbed. The same is true of deeper organic soils since the underlying unripened colloidal muck is acid, massive, and quite damaging to root growth. The only result of using a ripper-bedder may be the introduction of toxic soil materials into the seedling root zone, causing plant loss and requiring higher lime rates.

No-till planting of both corn and soybeans is possible in the Blacklands. Soybeans planted following small grain are often planted no-till since less land preparation is required, the stubble does not have to be dealt with, and it is faster. Soybeans can be planted immediately following harvest of small grain. Such time savings are valuable since soybeans lose production potential rapidly when planting is delayed during that time of year.

No-till planting of corn into soybean stubble is a newer practice but has been successful when certain precautions are observed. Best results are obtained on soils with high fertility status, good residual row-bedding, and few weeds in the previous soybean crop. There should be enough bed left from the soybean crop to provide adequate drainage. In addition, high nutrient status will simplify fertilization, and low weed residue will simplify planting and weed control. Heavy weed residues may prevent effective herbicide application and can hinder the planter. The two main advantages of no-till corn in soybean stubble are earlier field entry and reduced trips across the land. The soil surface is firm, and often fields can be planted under wetter conditions than can conventionally tilled land. After the corn is planted and is growing, cultural practices are little different from conventional tillage. Old soybean fields usually have so little residue left on the soil surface that the corn can even be cultivated if desired. Increased energy costs and concerns about non-point source pollutants may result in increased interest in no-till planting.

Pest Management and Pesticide Use

Organic matter is highly reactive with many pesticides (48, 104, 105) and may render them ineffective or effective only at higher than usual rates. Pesticide rates often vary as the soil organic matter content varies, so it is important to verify that the selected pesticide is appropriate for use on soils with high organic matter contents. This applies to all soil-applied pesticides and not to herbicides alone. Certain soil fumigants and soil insecticides are also inactivated by organic matter.

Because of the inactivation of pesticides by organic matter essentially all herbicides are applied to the soil surface in the Blacklands or to weeds growing in the crop rather than being soil incorporated. This practice minimizes pesticide-organic matter contact and thus reduces inactivation. Many growers economize by using band rather than broadcast applications and rely on cultivation or contact herbicides to control weeds between the rows. Wide press-wheel planters help to firm the soil in the row and improve the effectiveness of surface-applied herbicides.

It is important that the pesticide available be used skillfully since there are fewer available for use on soils high in organic matter. If a pesticide fails there may not be a backup alternative. In addition, there may not be an approved pesticide available for some specialty crops or specific pests. Before deciding to grow a crop not common to the area the grower should investigate the availability of effective chemicals or other control strategies for his soil condition.

Rapid plant growth is a vital part of the pest control strategy in the Blacklands, since competition by the crop being grown is one of the best control tools for both insects and weeds. If the crop cannot provide significant competition, it is economically impossible to control some pests. Another important practice is crop rotation. The dominant crops, corn and soybeans, have dissimilar pests and compliment each other very well in an integrated pest management program. Some of the more severe pests of corn cannot reproduce on soybeans, and vice-versa. An example would be control of corn billbug through block rotation to soybeans. Some weeds that are nearly impossible to control at times in one crop may be relatively easy to control in the other. For example, pigweed is much easier to control in corn than in soybeans since corn is resistant to certain herbicides which will kill pigweed and soybeans. Before a crop is grown the grower should know the pests present and plan a control strategy.

Synopsis

North Carolina has about 3.7 million acres of freshwater wetlands (113) of which about 1.4 million acres are Histosols (63). These swamp lands are an important resource and one that is in demand by a number of different special interest groups. Utilization of such land is not a new activity, but dates back to the first period of land shortages in the late 1700's. Much former swamp land is being farmed, and essentially all that remains uncleared has been extensively modified by forestry activities and drainage projects. Recently interest has developed in using the deeper organic deposits for fuel, and there are others that believe more swamp land should be preserved for esthetic or ecological reasons. Considerable acreages are devoted to all of these uses, including about 400,000 acres in public ownership. However, there continues to be much conflict between user groups over the future of certain key areas.

Drained swamp land varies from dark surfaced mineral soils with few hazards for agriculture to deep, woody colloidal muck Histosols with severe management problems. The latter soils require considerable effort, money, and time to make them productive. In general they are better agriculturally when the overlying woody muck is removed, and this may be more practical in the future if peat harvesting for fuel is developed. Regardless of the thickness of the original organic surface, all drained swamp soils will become dark surfaced mineral soils through natural oxidation and will continue to be productive indefinitely.

The agricultural future of the North Carolina Blacklands is very bright. The topography and soils are well suited for row crops, and its strategic location near large population centers will likely result in increasing vegetable production. Water management will receive more attention and the area's excess rainfall and large ground water reserves will be used more efficiently to relieve periodic drought. It is likely that swamp land in private ownership will continue to be developed for agriculture and forestry as long as current investment opportunities exists.

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