Papers Commemorating a

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Contents

SOIL SURVEY FROM RALEIGH TO NEWBERN, N.C. [1]

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Introduction

The area mapped extends from Raleigh to Newbern, along the line of the Southern and the Atlantic and North Carolina railways, a distance of 105 miles, about 9 miles wide, and contains approximately 1,000 square miles, or 640,000 acres (Figure 1).

The State Department of Agriculture paid all the field expenses of the survey party, as well as all expenses incident to the making of a good base map showing wagon roads, railroads, houses, towns, and streams, and proposes to follow up the survey and locate test farms on the more important soil types revealed by the soil survey, the object being to study further the fertilizer problems as well as the cultural methods and crops adapted to the different soil types. Two test farms are already located, one at Tarboro, in Edgecombe County, and the other at Red Springs, in Robeson County. The farm at Tarboro was visited by the survey party and its soil correlated with a similar soil type of the area surveyed.

Credit is due the State geological survey for aid furnished through the State Department of Agriculture in securing competent traverse men to make the base map.

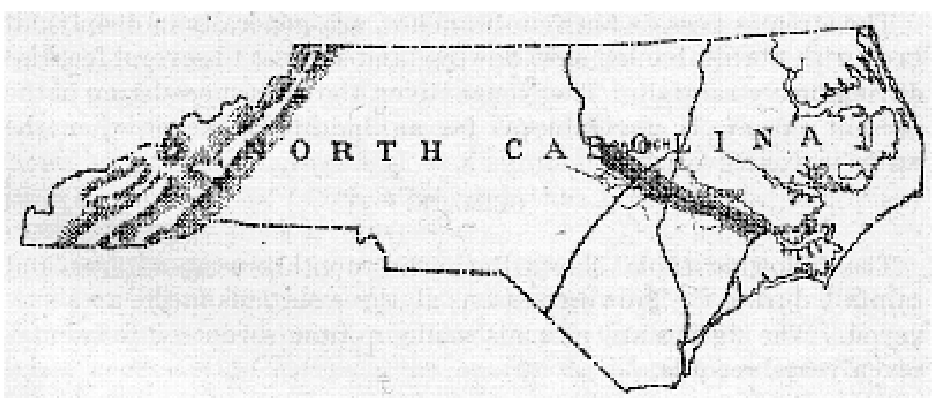

Figure 1. Sketch map of North Carolina, showing area surveyed.

[1] This article is a reprint of the original paper with renumbered figures: Smith WG. 1900. Soil survey from Raleigh to Newbern, N.C. In: Field operations of the Division of Soils. Washington (DC): U.S. Government Printing Office. p 187–205. [USDA report no. 64].

Topography

From Raleigh to Newbern there is a gradual change from the rolling uplands of the Piedmont Plateau to the low, level country of the Coastal Plain region. Raleigh is situated near the eastern edge of the Piedmont Plateau, so the greater portion of the area surveyed lies within the Coastal Plain.

The Piedmont Plateau extends about 25 miles east of Raleigh, and is characterized by rough, hilly country, with narrow stream valleys in which the streams have considerable fall. The greatest development of the Piedmont Plateau lies west of Raleigh, extending to the foot of the mountains. In the vicinity of Raleigh the elevation above sea level is about 300 feet, and a few miles southeast, at Garner Station, on the Southern Railroad, the elevation is 383 feet. From Garner eastward there is a fall of about 7 feet per mile to Selma, where the elevation is 175 feet and where all trace of the plateau region is lost and the flat or gently rolling Coastal Plain area proper begins. The fall from Selma to Newbern, which has in elevation of 16 feet, averages about 2 feet per mile. From Selma to Newbern the country is generally low and flat and in the eastern portion are swamps. The largest swamp is located about Dover and is known as the Dover Pocoson, while the next largest is near Newbern. They are depressions of from 2 to 10 feet below the surrounding, generally flat land, and represent about 200 square miles in extent. The elevation at Dover is 65 feet, making an average of less than 2 feet fall eastward to Newbern.

The streams possess but few branches, are generally in deeply cut beds with abrupt banks, slow flowing, and subject to several feet rise during heavy rainfall. The Neuse River, the largest occurring in the present survey, is navigable as far as Smithfield except when the water is excessively low.

Climate

The following table[1] shows the mean monthly temperatures and rainfall during the growing seasons at three stations in the area surveyed. The figures are normals made up from seventeen to twenty-seven years' records.

Mean monthly temperature and rainfall

Month	Raleigh Temper-ature *(°F)*	Raleigh Rainfall *(inches)*	Goldsboro Temper-ature *(°F)*	Goldsboro Rainfall *(inches)*	Newbern Temper-ature *(°F)*	Newbern Rainfall *(inches)*
April	59.1	3.22	60.6	4.76	59.6	3.72
May	68.2	5.45	69.6	4.99	68.4	4.44
June	75.7	4.32	77.2	5.18	75.9	4.75
July	78.0	6.44	79.8	6.08	78.9	7.07
August	76.4	6.24	78.3	7.27	77.3	8.08
September	71.1	3.22	72.8	4.80	72.9	5.45
Annual	59.6	50.21	61.5	53.56	61.3	56.08

[1]*Climate Conditions Affecting Water Power in North Carolina, 1899, by C. F. Von Herrmann.*

The average temperature and rainfall for the Coastal Plain section for the seasons are as follows:

Average seasonal temperature and rainfall

Season	Temperature *(°F)*	Rainfall *(inches)*
Spring	59	12.85
Summer	77	17.04
Autumn	62	13.10
Winter	45	12.24
Year	60.8	55.23

Conditions of Agriculture

From Raleigh eastward to Newbern there is a gradual increase in the size of the farms. In the hilly regions east of Raleigh the farms contain about 110 acres; in the middle portion of the area surveyed the farms contain on an average about 140 acres, while in the level country about Newbern there are many large plantations of more than 1,000 acres, and the average farm contains 225 acres.

The improvements on these farms vary greatly in the different sections of the area. Usually they possess a dwelling house, barns for stable purposes, and wagon sheds, and in the tobacco area curing sheds are always found. The tenant houses for the colored laborers form a part of the farm equipment, especially on the larger plantations. Fences are maintained at a minimum expense, for the stock laws in most of the counties are such that protection against stray cattle and other stock is unnecessary.

There are several systems of cultivating the farms. Where the farms are small they are usually farmed by their owners, but where they are larger the owners may manage the entire farm and employ labor necessary to carry on the operation. Again, portions of the farm may be rented for a cash rent or on the share system. A favorite system is to rent portions of a large farm to a tenant on shares provided he buys his provisions, etc., from the plantation owner, who conducts a large general store. In the entire area the labor is both white and colored, and frequently both kinds are employed on the larger farms. For such crops as cotton and tobacco, the negro labor is as capable as white labor. Figure 2 shows a typical cabin of a negro family in this section.

As the area surveyed follows so closely the railroad throughout the entire distance, transportation by rail is very good, and some of the industries, as, for example, the trucking industry, have been made possible by the advantage which comes from rapid transportation. In the eastern part of the area water transportation is available and has been utilized to a considerable extent in developing the resources of the country. The wagon roads of the area are not good. While some of the roads have been constructed at considerable expense and can be easily traveled, by far the larger number of roads have received no attention whatever, and are consequently in poor condition for either light or heavy hauling.

The principal crops are corn, cotton, tobacco, and truck. Corn has always been one of the staple crops of the entire area and occupies a prominent place in the various crop rotations used in the different sections of the area. Cotton is also one of the important crops grown, and the yield per acre shows the beneficial results of improved methods of culture and of the attention given to fertilizers. The effort, is being made to manufacture the crop where it is grown, and in this way an important industry is being developed which has a far-reaching influence on the economic development of the State.

Since the introduction of bright tobacco in the eastern part of the State it has achieved remarkable success, and large districts of the area surveyed produce a fine type of lemon-yellow tobacco. In addition to the crops grown the development of the truck industry in the eastern portion of the area has made valuable large tracts of land which were formerly not desirable for agricultural purposes. Nearly all classes of early truck and early fruits are grown, and handsome profits are realized by successful farmers. The largest shipments of truck are from Goldsboro, Newbern, Kinston, and Lagrange.

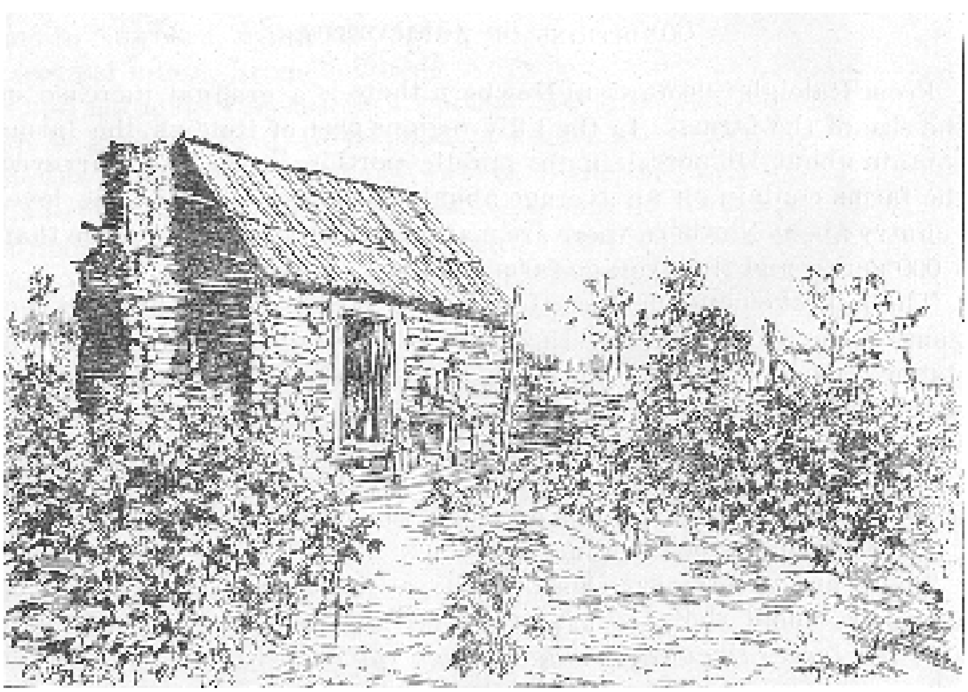

Figure 2. Typical negro cabin.

Figure 3. Cotton field.

Figure 4. Hauling cotton to market.

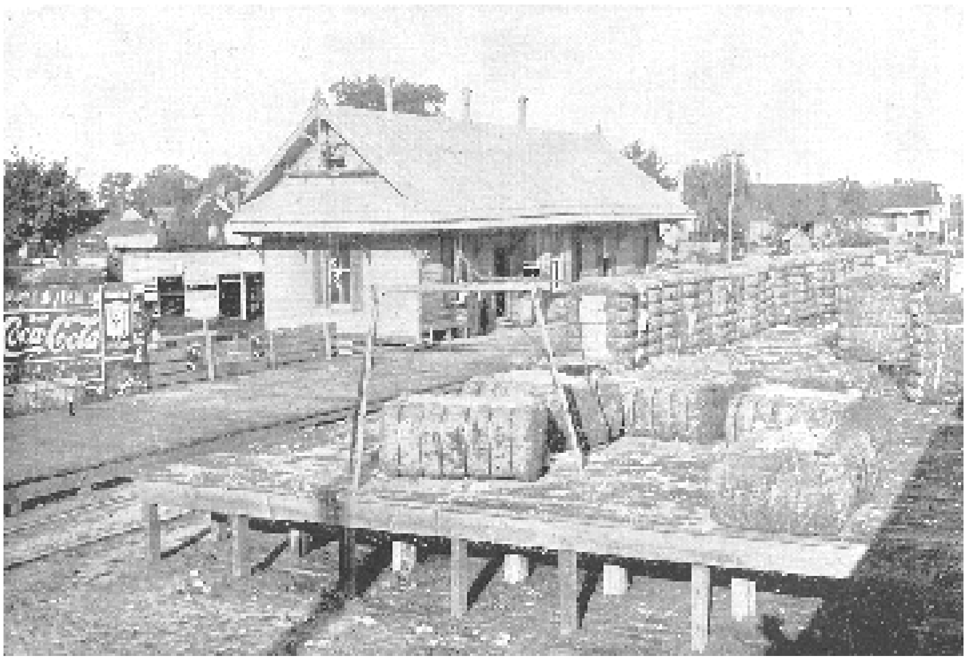

Figure 5. Cotton platform at Kinston.

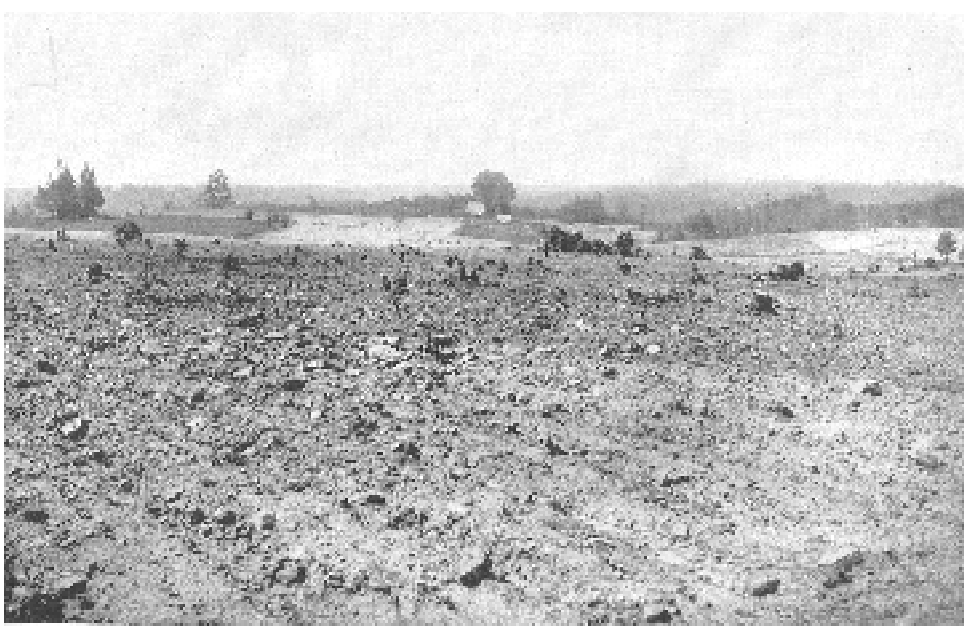

Figure 6. Cecil sandy loam.

SOILS: Cecil Clay

The Cecil clay is a red clay soil, with sharp quartz sand intermixed, 6 inches deep, containing from 10 to 30 per cent of quartz and rock fragments in both soil and subsoil. It is underlaid by a tenacious red clay subsoil, which is reached by ordinary plowing. This soil is locally known as "red clay land."

The soil is derived from the decomposition of granite, gneiss, and other crystalline rocks. The quartz fragments are derived from the quartz intrusions of the original rocks. While the presence of these fragments makes the soil and subsoil more friable and facilitates drainage, they obstruct plowing a great deal and are wearing on all soil implements.

The red clay subsoil possesses a peculiar coherency sufficient to make well curbing unnecessary; yet it is sufficiently porous to absorb rainfall and to allow a steady percolation of water through it into wells and streams. The red clay subsoil of the Cecil clay is very important, as it forms also the subsoil of sandy deposits in the Raleigh and Durham areas.

It is a fertile soil, well suited to cotton, grain, and grass. The yield of cotton ranges from three-fourths of a bale to 1 bale per acre, depending on the cultural methods employed.

The following table shows the mechanical analyses of the upper 6 inches and the underlying tenacious red clay subsoil. While distinctively a clay soil, the surface shows an infusion of sand that makes it more friable than the material beneath, which has nearly double the amount of clay possessed by the surface soil. It must be borne in mind that the quartz and rock fragments, which are not included in the table and vary from one-half inch to 4 inches in diameter, tend also to make the soil more friable. They vary in amounts from 10 to 30 per cent.

Mechanical analyses of Cecil clay (%) [Fine earth]

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5219	2 miles S. of Raleigh	Dull red sandy clay loam, 0 to 6 in	6.34	9.10	10.89	7.48	14.61	6.85	21.37	22.42
5220	Subsoil of 5219	Stiff red clay, 6 to 36 in	8.03	6.04	7.88	4.78	8.68	4.59	19.90	39.80

SOILS: Cecil Sandy Loam

Cecil sandy loam is a brown sandy loam soil from 6 to 10 inches deep, containing from 10 to 30 per cent of quartz and rock fragments. It is underlaid by a red clay, containing quartz and rock fragments similar to the subsoil of the Cecil clay. It is locally known as "brown land."

Cecil sandy loam differs from Cecil clay in possessing a much larger percentage of sand in the soil. It is more friable than Cecil clay and more easily tilled, though the quartz and rock fragments have a wearing effect on plows and other soil implements.

This type of soil is found in large areas in the vicinity of Raleigh and in smaller areas at Clayton and Wilsons Mills. There are some large and gently rolling fields of this soil, but generally it is quite hilly.

Cotton, small grain, and corn do well on this soil, the cotton production averaging from one-half to three-fourths of a bale per acre where fertilizer is used. Bright tobacco is grown to some extent on this soil. Because of the moist, retentive character of the subsoil this type of soil withstands drought quite well. The forest growth is like that common to the plateau section, differing from the Coastal Plain forest growth in that it possesses a larger proportion of hardwood than pine.

The following mechanical analyses of the soil and subsoil of the Cecil sandy loam show a large and uniformly proportioned infusion of sand in the soil, while the red clay subsoil analysis is almost identical with that of the Cecil clay subsoil:

Mechanical analyses of Cecil sandy loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5223	2.5 miles S. of Raleigh	Brown sandy loam, 6 to 10 in	3.58	6.03	18.14	12.76	26.73	10.49	12.20	9.35
5224	Subsoil of 5223	Stiff red clay, 16 to 30 in	7.63	4.94	8.40	5.77	11.36	3.94	19.37	37.92

SOILS: Durham Sandy Loam

Durham sandy loam consists of a gray, rather coarse sandy soil from 12 to 15 inches deep, generally overlying a yellow clay subsoil. Like the two preceding types, quartz and rock fragments are found to the extent of from 10 to 30 per cent in both soil and subsoil. The quartz and rock fragments seem to have been derived from the Piedmont formation, since the Durham sandy loam is always found in or close to the plateau area. The soil is easily tilled except for the presence of the fragments, which have the same wearing effect on soil implements noted in the two preceding types.

The origin of the subsoil is in part sedimentary, as is shown by the occasional presence of gravel and in part residual.

The largest development of Durham sandy loam is found south of Raleigh, and from here on to its eastern limit it occurs in small and irregular patches. Like, the two preceding soils it ceases to appear beyond Wilsons Mills in the area surveyed. It also partakes of the hilly surface characteristic of the Piedmont Plateau.

The Durham sandy loam is better adapted to corn, bright tobacco, and truck than it is to cotton or small grain. However, with sufficient application of fertilizers, about one-half of a bale of cotton per acre may be grown. Because of its sandy character and low per cent of clay, this soil is more subject to leaching and drought than the preceding soils.

The following mechanical analyses show a larger proportion of sand and less of clay in both soil and subsoil than are found in the preceding types. It may be mentioned in passing that the analysis of the soil of the Durham sandy loam would not suggest the marked difference between it and the Cecil sandy loam that is evident in the field. The former is rather loose and leachy, while the latter is moist, retentive, and spongy, because of the slightly larger proportion of clay.

Mechanical analyses of Durham sandy loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5225	3.5 miles S. of Raleigh	Gray stony sandy loam, 12 to 15 in	3.12	7.33	12.21	11.22	33.30	13.70	12.86	5.51
5226	Subsoil of 5225	Yellow or red clay, stony, 12 to 36 in	6.51	3.92	8.74	6.69	18.88	6.44	23.96	24.00

SOILS: Norfolk Sandy Soil

The Norfolk sandy loam varies from a coarse, sharp, gray, sandy soil to a gray, sandy loam, 10 to 20 inches deep, overlying a yellow clay. It is sedimentary in origin. No rock or quartz fragments are present in either the soil or subsoil, but occasionally gravel is found in the subsoil. The soil is easily tilled, the natural drainage is good, and, because of the clay subsoil, it withstands drought fairly well. It is found to a large extent east and south of Raleigh, as well as in the vicinity of Clayton and Wilsons Mills and to the north of Princeton.

The surface of the Norfolk sandy soil is more level and the areas larger and more uniform than any of the preceding soils, yet when it occurs near streams it is hilly. About 5 miles north of Clayton, along the Neuse River, this soil occurs as a rather thin deposit (4 to 8 inches), which is eroded in places, exposing the yellow clay subsoil. In this locality when the plow strikes the subsoil, a soil of a somewhat heavier character is formed.

This soil is well suited to bright tobacco, corn, and truck, and to some extent to cotton.

The following analyses show some striking resemblances in the proportion of sand, silt, and clay to that of the Durham sandy loam, but since it contains no rock fragments or gravel it has a field characteristic quite different from any of the preceding soils. The lower percentage of organic matter (only 1 per cent, as against 3 per cent in the preceding soils) accounts for the gray, bleached appearance that marks this soil in the field as compared with the dull color of the other types.

Mechanical analyses of Norfolk sandy soil (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5229	4 miles S. of Raleigh	Gray sandy loam, 0 to 15 in	0.76	8.56	22.23	12.13	33.73	10.88	9.08	3.30
5230	Subsoil of 5229	Stiff yellow clay, 15 to 36 in	4.68	8.90	12.38	5.39	15.10	8.08	15.67	29.81
5231	4 miles N. of Princeton	Gray sandy loam, 0 to 15 in	1.18	2.74	27.22	20.28	24.18	9.40	10.12	4.88

SOILS: Susquehanna Gravel

Susquehanna gravel is a deposit of gray sandy soil from 12 to 15 inches deep, overlying a yellow clay subsoil. From 10 to 25 per cent of gravel of a diameter of from one-fourth of an inch to 2 inches is found in the soil and often a like amount is also found in the subsoil. If the gravel were eliminated this soil type would be identical with the Norfolk sandy soil, which it resembles in possessing a sharp, bleached-looking sand as well as having a similar sedimentary origin. The gravel in some places obstructs tillage very much, and is quite wearing on soil implements.

The crops suited to this soil are the same as are adapted to the Norfolk sandy soil—bright tobacco, corn, and truck and cotton to some extent. This soil is slightly given to leaching, but because of the clay subsoil it holds fertilizers and withstands drought quite well. The distribution of this soil is limited to a few small areas in the vicinity of Clayton and Auburn, amounting to about 3 square miles.

The following analysis of the fine earth portion of the Susquehanna gravel shows it to be similar in texture to the Norfolk sandy soil, the principal difference as before noted being the gravel content of from 10 to 25 per cent. No analysis of the yellow clay subsoil was deemed necessary, as it is so similar to the Norfolk sandy soil.

Mechanical analyses of Susquehanna gravel (%) [Fine earth]

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5233	10 miles S. of Raleigh	Gray sandy soil, 0 to 15 in	1.57	12.70	17.76	12.62	26.17	15.22	9.64	4.73

SOILS: Garner Stony Loam

Garner stony loam is a sandy loam containing from 40 to 60 per cent of rock fragments and gravel. At a depth of from 6 to 15 inches it overlies a red tenacious brick-clay subsoil, which often contains a trace of sand, rock fragments, and gravel. This type is found along streams and doubtless owes its origin to the extraction of clay and silt during a period of the rapid flow of the streams which it generally borders. It is found north of Clayton along the Neuse River and south along Crabtree Creek. This type packs firmly over the clay substratum, affording to all the roads that traverse it a firm roadbed almost equal to macadam.

Tillage is almost impossible, but in cases where cotton is once rooted good crops are secured because of the clay subsoil. These areas, however, are generally given to the growing of commercial pine and to cattle and hog pasture runs.

The following table shows the mechanical analyses of the soil and subsoil. The soil would be a good friable sandy loam were it not for the presence of the large amount of rock fragments and gravel that makes this soil almost useless for tillage purposes.

Mechanical analyses of Garner stony loam (%) [Fine earth]

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5234	3 miles S. of Clayton	Stony, gravelly soil, 0 to 15 in	4.03	17.04	13.72	7.86	17.86	17.80	14.07	7.39
5235	Subsoil of 5234	Stiff, yellow and red clay, 15 to 40 in	6.62	3.65	4.30	2.35	5.77	8.76	22.37	45.91

SOILS: Selma Silt Loam

This is a gray silty loam mixed with fine sand 18 inches deep, overlying a mottled yellow clay subsoil, which sometimes contains fine sand and small gravel. It is a large and important area, found in its greatest extent in the vicinity of Selma and Princeton and to a lesser extent about Goldsboro. The surface is gently rolling, the natural drainage is good, only a small portion possessing rather poor natural drainage; artificial drainage is possible in nearly all such cases.

The Selma silt loam area is characterized by numerous fine sandy knolls and ridges from 2 to 6 feet high and from 5 to 40 acres each in extent. With their silty clay subsoils at a depth of 18 inches these ridges and knolls are especially suited to the growing of bright tobacco, corn, or truck, while the lower-lying more silty portion is well suited to cotton, which it yields at the rate of from three-fourths of a bale to one bale per acre. Both the sandy knolls and the lower-lying portions, however, admit of being used for cotton, corn, tobacco, or truck, and are so used. Both phases of this type are choice soils, easily tilled, and respond well to fertilizers.

The clay subsoil, while possessing some sand and occasionally gravel the size of beans, is sufficiently coherent to make the use of well curbing unnecessary. Wells from 20 to 40 feet deep are commonly found here, as in the other areas discussed. There is, however, a movement toward the use of drive pumps, which furnish water freer from contamination. In this area a water-bearing sandy stratum underlying the yellow silty clay is reached by drive pumps at a depth of from 30 to 60 feet.

The forest growth consists largely of pine, oak, and gum. Several small wild fruits are found; while of the domestic fruits the peach and cider apple are common. Many domestic varieties of grapes, such as the Delaware, Concord, and Scuppernong are grown.

The following table shows the analyses of the soil and subsoil of the Selma silt loam.

Mechanical analyses of Selma silt loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5237	1 mile W. of Princeton	Gray silt loam, 0 to 18 in	1.52	8.72	23.92	12.82	26.62	11.90	13.25	3.72
5238	Subsoil of 5237	Mottled, yellow clay with base of fine sand and gravel, 18 to 40 in	2.65	10.21	14.66	11.62	17.70	9.68	11.57	21.26

SOILS: Selma Heavy Silt Loam

This is a rather heavy gray silty loam, from 10 to 20 inches deep, overlying a stiff mottled clay. It is often spoken of as “stiff land” or “clay land.” Like the preceding soil, it is of sedimentary origin and represents a large and important area. It is found as large flat areas in the vicinity of Selma, Princeton, and to the north of Dover. There is no sharp line of demarcation between the soil and subsoil, one gradually merging into the other. The subsoil is, however, much stiffer than the soil.

The knolls and ridges spoken of in the preceding soil type very seldom occur in the Selma heavy silt loam. Natural drainage is poor; artificial drainage is possible and nearly always necessary, to insure a good crop. Fertilizers are well retained. This soil is suited to

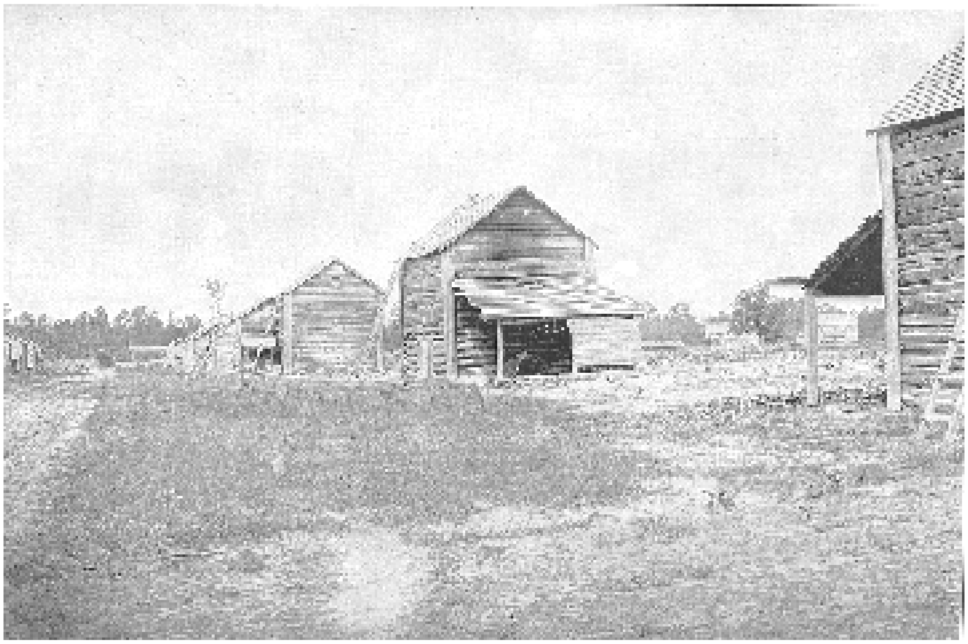

Figure 7. Group of Bright tobacco barns where tobacco is cured by artificial heat.

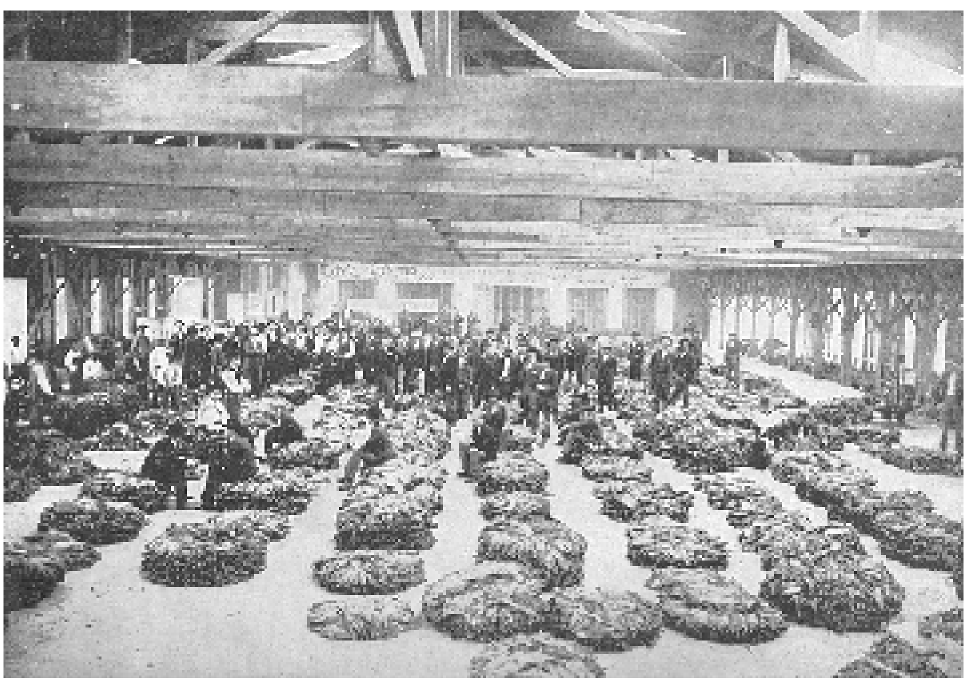

Figure 8. Bright tobacco being sold on warehouse floor in Goldsboro.

cotton, which it yields at the rate of from three-fourths of a bale to little more than one bale per acre. Under good drainage conditions, however, corn, vegetables, and small fruits are successfully grown.

The following analyses of three soils and two subsoils show the heavier character of this soil as compared with the immediately preceding type. The marked difference between the soil and subsoil is in accord with the observations in the field. No. 5242, representing the heavier phase of this area, is locally known as “clay soil.” Nos. 5240 and 5244 represent the area of largest extent.

Mechanical analyses of Selma heavy silt loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5240	2 miles NE. of Kinston	Heavy gray silt loam, 0 to 10 in	3.82	2.01	4.16	4.40	37.80	21.40	22.29	4.26
5241	Subsoil of 5240	Stiff gray mottled clay, 10 to 36 in	2.33	1.22	3.38	3.92	29.97	21.38	21.56	15.94
5242	3 miles N. of Tuscarora	Stiff mottled gray clay loam, 0 to 10 in	2.16	1.74	4.76	5.30	35.84	9.49	23.04	17.30
5243	Subsoil of 5242	Stiff gray mottled clay, 10 to 36 in	3.17	1.88	4.17	3.92	23.24	6.38	19.90	37.31
5244	0.25 mile SW. of Selma	Heavy gray silt loam, 0 to 8 in	1.86	0.52	1.56	1.79	13.34	34.96	37.44	7.96
5245	Subsoil of 5244	Yellow silty clay, 8 to 36 in	3.14	6.38	11.02	8.62	21.44	11.48	11.39	26.46

SOILS: Goldsboro Compact Sandy Loam

This is a soil type which comprises several variations in texture, all consisting, however, of gray, ashy, sharp, generally compact sand. Usually it has no distinctive subsoil, though it often grades gradually into a sandy clay substratum. It is a sedimentary soil varying in color from a bleached gray to black, the color being due to organic stains. This type is generally found in lower lying flat areas along the Neuse River at Kinston and extending into and around the Dover Pocoson area. The lower lying portions, containing the black sandy features, were once subjected to swamp conditions. When these are drained and an application of lime used, good crops of cotton and corn are secured.

The gray or bleached phase lies somewhat higher, but it generally requires considerable artificial drainage. In the gray phase occur compact spots from 5 to 20 acres or more in extent, which, on account of their compactness, suggest the possible presence of some cementing material. These spots are undesirable and are locally known as "stiff gray land," which when partially dry can scarcely be plowed. Instances are noted where a good application of barnyard manure seems to have made, these compact or seemingly cemented areas more friable.

Cotton and corn are generally grown with fair success on all the variations of this soil type where drainage is practiced and suitable cultural methods are employed.

The following table of analyses is given to show the peculiar sandy-clay character of both soils and subsoil. No. 5250 represents the coarse phase, while the other three (soils) represent the finer phase.

Mechanical analyses of Goldsboro compact sandy loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5246	2.25 miles E. of Cove post office	Fine gray compact, sandy loam, 0 to 15 in	1.29	0.94	2.50	1.70	12.98	37.39	31.76	11.27
5247	Subsoil of 5246	Yellow-mottled clay, with fine sand, 15 to 40 in	2.09	0.68	1.74	1.18	9.92	26.35	31.57	26.20
5248	0.75 mile SW. of Kinston	Fine gray compact, sandy loam, 0 to 20 in	3.76	11.22	17.18	15.30	18.94	5.90	10.19	16.80
5249	3 miles N. of Lagrange	Gray, very compact loam, 0 to 16 in	1.38	7.26	14.46	11.14	20.56	14.22	19.25	10.77
5250	1 mile E. of Goldsboro	Coarse, compact, sandy loam, 0 to 20 in	3.09	31.68	23.38	7.22	9.22	4.22	11.65	9.37

SOILS: Norfolk Sand

The Norfolk sand is a deep sandy soil 3 to 6 feet or more in depth. Often the first 6 inches is gray or bleached in color, while the underlying portion is a brown or yellow sand of the same texture. In different localities it varies from a fine sandy soil to a coarse sandy soil, all the variations having, however, the same general character as regards the production of crops.

The Norfolk sand is an extensive and important type. It is a truck soil, suited to the early maturity of crops because of its warm, dry nature. It occurs to a large extent along the Neuse River at Lagrange, Kinston, and Newbern, and also in some places 2 or 3 miles from the river. Immediately south and southwest of Lagrange is found a large area of the coarse phase, at Newbern occurs the medium phase, and 3 miles south of Lagrange, bordering the Neuse River, is the fine sandy phase (soil 5251), on which cotton does well.

The surface of the Norfolk sand is generally flat or gently rolling, possessing good drainage. Occasionally spots are met which are often subject to drought because of the great depth to the water table.

The following table shows the mechanical analyses of two samples of the Norfolk sand:

Mechanical analyses of Norfolk sand (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5251	3 miles S. of Lagrange	Fine sandy soil, 0 to 10 in	1.75	Tr.	1.84	8.90	72.86	8.95	2.43	2.52
5252	1.5 miles N. of Newbern	Brown, sandy soil, 0 to 40 in	0.76	0.60	3.80	8.22	68.62	12.84	2.74	2.30

SOILS: Sandhill

The Sandhill soil is a gray, sharp, incoherent sand of considerable depth—from 10 to 50 feet or more—found usually in the form of high flat ridges or hills. The first 6 or 9 inches is generally bleached, while the underlying portion is of a brown or reddish color and of the same texture as the soil. Its origin appears to have been a sandbar deposited by coastal waters and modified by wind action.

In the area surveyed only a small margin of this extensive Sandhill soil of the Coastal Plain occurs about 2 miles south of Goldsboro. It was sufficient, however, to correlate it with the great sand ridge that extends from about this point southward through North and South Carolina, Georgia, Alabama, Mississippi, Louisiana, and terminating in Texas.

It is a dry, barren soil, as it lacks sufficient moisture for crops. In wet seasons or when irrigated, truck does well. The natural growth is pine and scrub oaks. Stone fruits and small fruits, such as peaches, apples, grapes, and the blackberry, which are able to extend their roots deep, do well if they get started and are well cared for.

From the foot of the Sandhill type, even during dry seasons, a constant flow of pure water generally comes. The roads, as a matter of course, that traverse this soil are very loose and sandy, except in wet weather, when they are more easily traveled.

The following table of analyses shows a similarity of this type to the soil of the Norfolk sand, which is in keeping with the field observation as to texture and origin. The low percent of organic matter and small clay content tallies also with the loose, leachy character of this soil noted in the field.

Mechanical analyses of Sandhill (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5255	2.5 miles SW. of Goldsboro	Gray, loose, incoherent, sandy soil, 0 to 40 in	1.47	3.86	9.62	18.96	40.74	15.78	5.02	4.12
5256	3 miles W. of Goldsboro	Gray, loose, incoherent, sandy soil, 0 to 40 in	1.78	2.16	32.22	28.30	23.90	4.66	4.06	2.75

SOILS: Norfolk Fine Sandy Loam

This type consists of a mellow, fine, sandy loam from 10 to 15 inches deep, overlying a yellow, rather stiff clay subsoil. The soil and subsoil are of sedimentary origin. This type represents a large and important area in the eastern part of North Carolina. In the present survey it occurs to a large extent at Kinston and from thereon to Newbern.

This soil is peculiarly adapted to a wide range of crops, being well suited to the growing of cotton, corn, truck, and bright tobacco. Cotton yields from one-half to three-fourths of a bale per acre. Fertilizers are retained and drought is withstood quite well because of the clay subsoil. Open wells 20 and 30 feet deep are quite common in this area; a water-bearing stratum of sand is reached by drive pumps at a depth of from 60 to 80 feet. The test farm at Tarboro, Edgecombe County, is located on this important soil type.

The following table of analyses shows the distinctive character of the Norfolk sandy soil, namely, a fine, rather mellow sandy soil underlaid with a rather stiff yellow-clay subsoil containing a trace of fine sand. No. 5253 represents a variation of this type where it grades into the Norfolk sand near Newbern, and where it is used largely as a truck soil. No. 5259 represents the heavier phase of this type, and Nos. 5257 and 5261 represent the lighter phase as well as the largest area. The subsoils for all the variations are rather stiff, except No. 5254 of the truck soil, which is sometimes quite sandy and incoherent.

Mechanical analyses of Norfolk fine sandy loam (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5253	2.25 miles W. of Newbern	Medium fine sandy loam, 0 to 15 in	1.55	Tr.	3.18	4.24	46.56	21.15	6.91	16.00
5254	Subsoil of 5253	Yellow sandy clay, 15 to 40 in	1.33	Tr.	2.70	5.38	54.86	17.16	4.81	13.13
5257	4 miles NE. of Kinston	Fine, sandy loam light phase, 0 to 15 in	2.03	1.14	4.36	7.28	43.30	26.52	11.91	3.32
5258	Subsoil of 5257	Yellow sandy clay, 15 to 36 in	3.36	1.55	3.51	5.28	31.43	15.01	9.70	29.57
5259	2.67 miles W. of Newbern	Fine, sandy loam, heavier phase, 0 to 10 in	2.40	0.64	9.32	21.10	16.92	7.94	27.77	13.75
5260	Subsoil of 5259	Stiff, mottled gray clay, 10 to 40 in	3.57	Tr.	5.62	11.04	9.53	3.83	22.44	43.70
5261	3 miles W. of Tarboro (test farm)	Fine, sandy loam, lighter phase, 0 to 18 in	0.90	0.00	Tr.	1.26	54.10	26.15	12.49	4.79
5262	Subsoil of 5261	Stiff, yellow clay with trace of sand, 18 to 40 in	2.81	Tr.	0.64	0.52	40.32	20.06	13.10	23.12

SOILS: Neuse Clay

The Neuse clay is a stiff silty or fine sandy loam, from 10 to 20 inches deep, gray in color, and underlaid to a great depth with a stiff, mottled-clay subsoil. In the present survey it occurs along the Neuse River near Kinston and in and around Tracy Swamp, about 2 miles north of Dover station. Along the Neuse River it is known locally as mud-bottom land, and is there subject to overflow; here it is generally left to a dense growth of cypress, gum, ash, alder, vines, and rank grass, and is used as a pasture run for hogs and cattle.

Tracy Swamp is subject to standing water to a depth of from 3 to 6 feet during periods of much rainfall. It is used in dry seasons as a pasture run. Attempts are being made to reclaim this area by ditching and draining it into the Neuse River, which, if successful, will open up some fine cotton land. The forest growth of cypress, gums, etc., is the same as that described for this type along the Neuse River.

To the north of Tracy Swamp, separated off on the map by a dotted line, lies a large area of Neuse clay elevated high enough not to be so much subject to standing water, making tillage to some extent possible. Here the area is quite flat, but drainage is possible by ditching. The forest growth is largely long-leaf pine. Cotton and corn do well when once rooted in this soil. On account of the soil becoming so dry and hard during droughty seasons that the plow can scarcely turn it, or so sticky in wet seasons that implements can barely move through it, this soil is generally difficult to till and does not possess a very good reputation among the local farmers. When loosened and dried out this soil dusts about under the feet like flour. The addition of barnyard manure or green crops plowed under would tend to make the soil more friable and productive.

The following table shows the mechanical analyses of the samples as follows: No. 5265 represents the large area of stiff-clay phase north of Tracy Swamp, near Dover station; Nos. 5266 and 5267 represent the lighter and friable phase found in Tracy Swamp and along the Neuse River, which areas are not much tilled at present on account of the poor natural drainage and frequent overflow.

Mechanical analyses of Neuse clay (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5265	5 miles N. of Dover	Very stiff, gray silty clay, 0 to 20 in	2.54	0.32	2.46	2.26	12.68	10.60	41.46	26.12
5266	4.5 miles W. of Kinston	Stiff, mottled silty clay, 15 to 40 in	9.51	0.00	1.38	4.30	13.36	7.52	35.04	28.84
5267	2 miles W. of Dover	Stiff, mottled gray clay, 0 to 20 in	9.87	Tr.	2.72	3.35	20.16	14.46	37.80	10.80

SOILS: Savanna

The Savanna land is a type due to location instead of soil character. It is a flat area surrounding the Pocoson land near Newbern, subject to from 6 to 20 inches of standing water during rainfall, but artificial drainage is possible over most of this area. The natural forest growth consists mainly of long-leaf pine, gum, and oak. In this area occur numerous depressions, from 3 to 8 feet deep and from 100 to 300 feet or more in diameter, which generally contain standing water and a dense growth of water cypress. The openings left by the removal of the lumber pine support a dense growth of rank grass and shrubbery, which seems, to furnish good pasture nearly the entire year.

The soil is similar in texture to that of the Norfolk fine sandy soil at a depth of 8 or 12 inches, and is generally underlaid with a mottled, rather stiff yellow-clay subsoil. Where the Savanna land borders the truck soils, it possesses from 8 to 12 inches of rather loose, gray, sandy loam, which grades quickly into the stiff clay subsoil. Where the Savanna land is well drained it is very productive for cotton, corn, and grass crops.

The following, mechanical analyses of samples of soils and subsoils show the similarity in texture of this type to that of the Selma heavy silt loam (5268) and the Norfolk fine sandy soil (5270), both phases at a depth of from 8 or 12 inches, grading rapidly into a heavy clay subsoil.

Mechanical analyses of Savanna (%)

No.	Locality	Description	% Organic matter and loss	% Gravel, 2 to 1 mm	% Coarse sand, 1 to 0.5 mm	% Med. sand, 0.5 to 0.25 mm	% Fine sand, 0.25 to 0.1 mm	% Very fine sand, 0.1 to 0.05 mm	% Silt, 0.05 to 0.005 mm	% Clay, 0.005 to 0.0001 mm
5268	3 miles W. of Newbern	Heavy, gray silt loam, 0 to 8 in	2.76	1.30	1.48	2.18	32.54	20.38	27.42	11.53
5269	Subsoil of 5268	Stiff, mottled gray clay, 8 to 36 in	4.31	Tr.	0.72	0.72	11.76	11.11	22.80	48.24
5270	4.5 miles W. of Newbern	Loose gray sandy loam, 0 to 8 in	4.24	0.34	4.13	8.35	42.45	13.21	19.27	7.07
5271	Subsoil of 5270	Yellow mottled clay, 8 to 36 in	3.30	Tr.	1.71	5.95	28.68	8.91	16.50	34.25

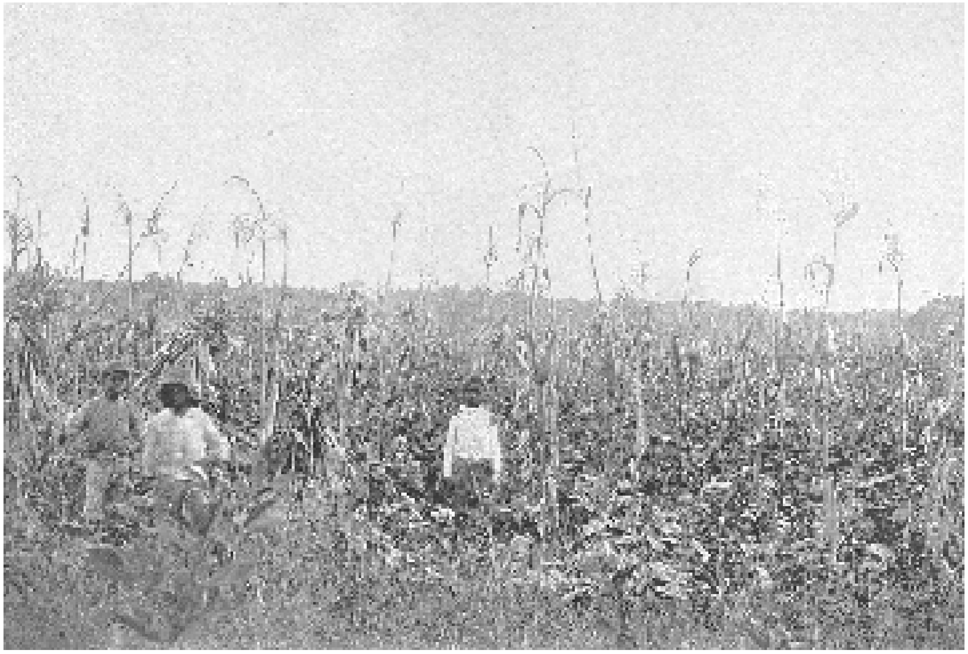

Figure 9. Corn and cowpeas showing method of pulling fodder.

Figure 10. Characteristic growth on pocoson.

SOILS: Pocoson

The Pocoson area possesses a character distinctively incident to location. Generally speaking, it is a swampy area, depressed from 2 to 10 feet below the surface of the surrounding land. The typical Pocoson consists of a black, spongy, mucky soil, supporting a scattering growth of scrub pine, a dense undergrowth of gallberry shrubs, wire grass, and broom sedge, and all woven together with brier vines. During moderately dry seasons this affords a pasture run for cattle and hogs—after they learn to get through the almost impassable matting. The scrub pines are 6 or 8 inches in diameter and from 20 to 30 feet high, and are useful for firewood, fence posts, and a poor grade of timber. During dry seasons these areas are sometimes subjected to fire, rendering them useless for a long time for cattle and hog runs because of the almost complete burning of the muck soil and the shrub and grass growth. Generally, however, these areas are subject to standing water, especially in the winter season.

Through these Pocoson lands extend extensive ridges and knolls, from 3 to 6 feet higher than the mucky area just described. These generally possess a soil similar in texture to that of the Goldsboro compact sandy loam, supporting a strong growth of commercial long-leaf pine. On the margin of these ridges often occur small spots of gum and cypress swamps and irregular strips of canebrakes. At a depth of from 10 to 15 inches the soil of these ridges generally grades into a sandy clay subsoil. When drained and tilled these ridges yield good crops of cotton, corn, and grass.

The Pocoson land of the present survey consists of a large tract between Dover and Cove post offices, known as the Dover Pocoson. There are also small areas of this land near Newbern, Goldsboro, Lagrange, and Kinston. About one-half of the Dover Pocoson consists of the knolls and ridges of the gray sandy loam above mentioned. At Goldsboro, Lagrange, and Kinston these areas have also a soil similar to these ridges—a gray sandy loam which is capable of tillage when drained. Three miles south of Lagrange, in the Pocoson area, there is about 2 square miles of the black spongy soil above mentioned, known locally as "huckleberry soil." A portion of this soil is cultivated and yields well of corn, cotton, grass, and some vegetables when well ditched. All crops tend to a rank growth, because of the large amount of humus present in the soil.

SOILS: Muck

The muck soil consists of varying amounts of vegetable mould, mixed with fine sand and clay, generally underlaid at a depth of from 2 to 6 feet, with a substratum similar in character to the adjacent land. In the present survey it occurs generally along the upper courses of small slow-moving streams, which are usually headed in large flat areas. Where drained, some of these soils yield large crops of hay, as well as corn and truck. The natural growth consists of cypress in the very wet swampy phases and alderbush, gum, willow, broom sedge, and rank grass on the more elevated and tillable phases.

SOILS: Meadow

This term, as used in the present survey, stands for a low-lying flat, usually poorly drained, land along the larger streams. It figures mostly as a narrow margin along the Neuse River and its larger branches from Raleigh to Goldsboro, where it ceases to appear any more, because of the soil admitting of being classified with other types having a more specific texture. The meadow soil is a river deposit 3 feet or more deep, varying from a clay to a sandy loam. As used here, however, it generally consists of a rather deep, fine sandy or silty loam. It is a fertile soil, easily tilled, and adapted to grass and pasturage and occasionally to general farming where drainage is possible. The forest growth consists largely of willow, alderbush, and gum.

1979–1999: Two Decades of Progress in Western North Carolina Soil Surveys

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Historically, the first soil surveys in western North Carolina were cooperative endeavors "to classify soils according to their characteristics, both internal and external, with special emphasis on the features that influence the production of crop plants, grasses and trees" (Goldston 1948). The United States Department of Agriculture in cooperation with the North Carolina Agricultural Experiment Station and the Tennessee Valley Authority conducted most of the initial soil surveys in the 1940s and 1950s. Most of these soil surveys were published at a 1:48,000 scale (Perkins 1947). The soil classification system of this era had a strong agricultural bias, and most of the soil scientist's field time and effort were spent classifying, mapping, and interpreting the agricultural soils in valleys and along the major streams in western North Carolina.

Modern soil surveys, beginning in 1981, are very different documents from soil surveys produced in the 1940s and 1950s. The major areas of difference are kind of photography, scale of photography, in-depth study of geology and geologic behavior, shading phenomena, new series creation, and innovative soil map unit design.

Soil maps in western North Carolina are being produced on 1:12,000-scale ortho photos. These maps are true to scale and are compatible with the soil-digitizing product that most soil survey users are requesting. The 1:12,000 scale allows the field soil scientist to delineate significant areas, as small as one acre. Small areas of landscape features, such as prime farmland, hydric soils, and rock outcrops, can be accurately located on 1:12,000-scale soil maps. In addition, the 1:12,000-scale ortho photos allow field soil scientists to delineate narrow ridgetops. Top of ridges are common sites for roads and are desirable areas for home sites. Some ridgetop delineations are covered with old-growth forests that have little commercial value but which are quite valuable to groups wanting to preserve old-growth forests. Ridgetop delineations also help map users orient themselves correctly on the map (Figure 1).

In-depth studies of common geological formations in western North Carolina are part of the modern soil surveys. Three major separations based on the type of rock are made in most new soil surveys. These geologic groups are crystalline rocks high in mica content, crystalline rocks low in mica content, and metasedimentary rocks.

Crystalline rocks, such as mica schist and mica gneiss, are high in mica content. This rock tends to produce soils and saprolite high in mica content. Soils and underlying saprolite erode easily and are difficult to compact when used as earthen foundation material. Soils such as Fannin and Chandler have a high mica content and are poor as engineering materials (Figure 2). Micaceous rock tends to weather deeply. Most micaceous saprolite commonly extends tens of feet below the soil surface.

The relationship of soils to metasedimentary rock formations in western North Carolina is difficult to interpret. Metasedimentary rocks generally are composed of thin beds that dip at some angle from the horizontal. When slopes parallel the bedding dip, soils are very susceptible to landslides. Some thin beds contain sulfur compounds and produce a yellowish leachate during road building. This leachate is very acid (Figure 3). When this leachate enters nearby streams, fish kills and other aquatic damage commonly occur. The map unit descriptions in modern soil surveys discuss this soil/geologic problem and discuss possible solutions.

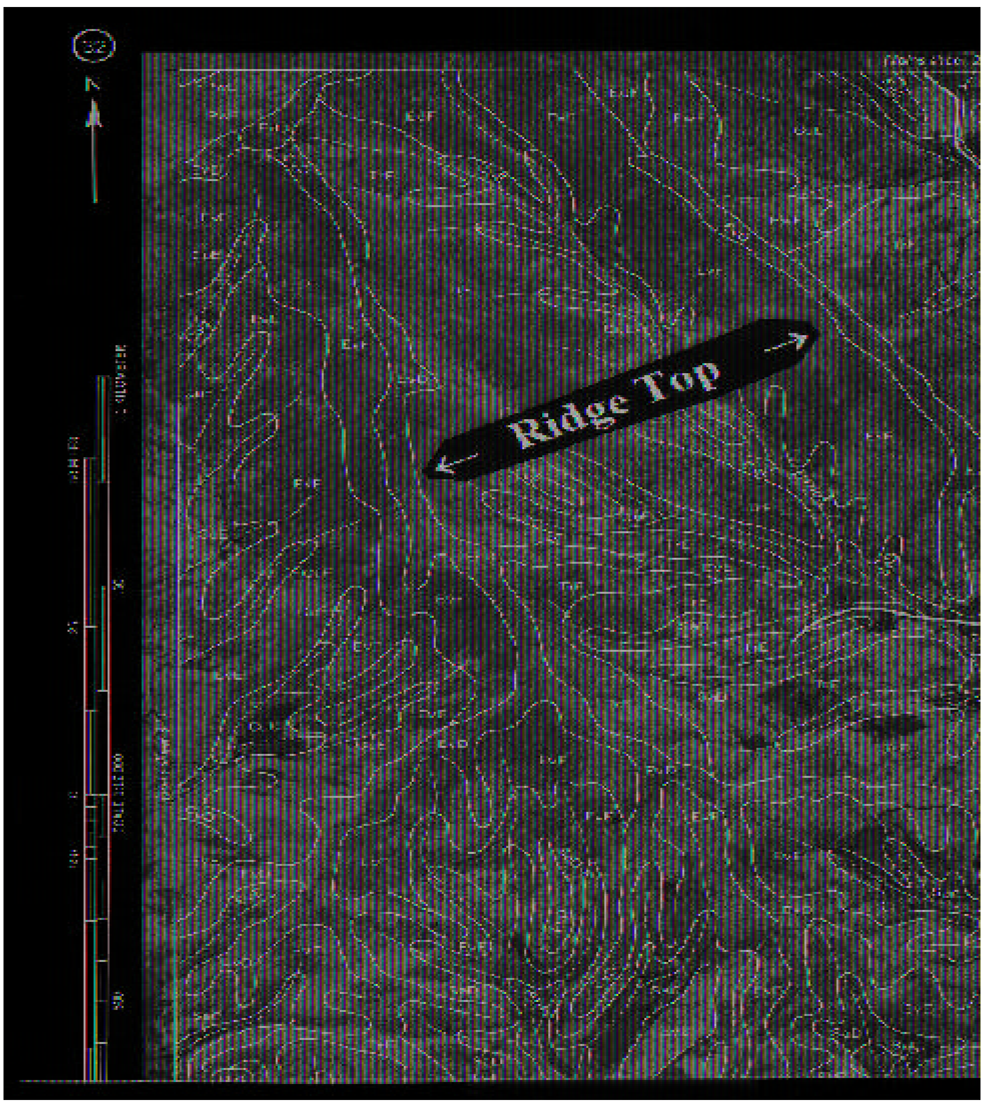

Figure 1. Section of soil map 32, Jackson County, North Carolina, June 1997.

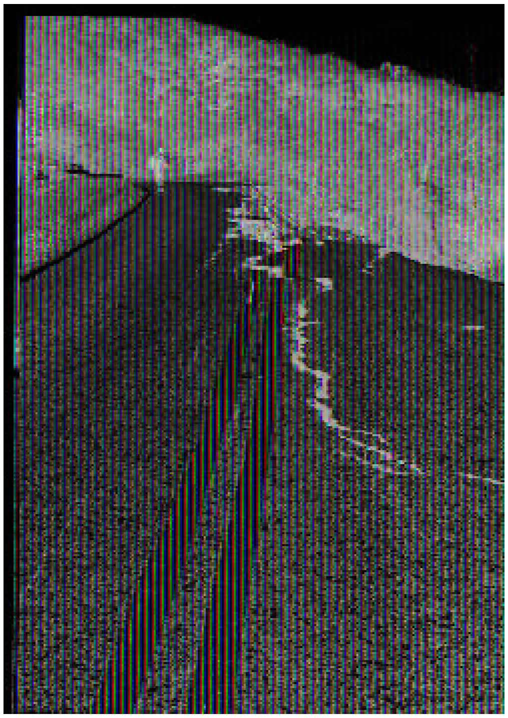

Figure 2. Roads built of micaceous soil materials are subject to landslides.

Figure 3. Acid leachate stains of metasedimentary rock.

Generally in western North Carolina, soils on south- to west-facing slopes have surface layers that are lighter in color and contain less organic matter than north- to east-facing slopes. In certain areas, the phenomenon of shading occurs when a higher mountain to the west casts a shadow on mountains of lower elevation to the east (Figure 4). Shading from the direct rays of the afternoon sun on south- to west-facing slopes of lower mountains lowers the maximum daily soil temperature, slows biological activity and causes more organic matter to accumulate. These shaded areas have tree species and productivity similar to north- to east-facing slopes. This is important information to foresters in timber management and road building. Roads on unshaded south- to west-facing cut slopes are more difficult to vegetate and expensive to maintain due to the frequent freeze-thaw cycles during the winter. Shaded south- to west-facing slopes are not as frequently subjected to freeze-thaw cycles and are less difficult to vegetate and maintain.

Modern soil surveys conducted from 1983 through 1990 established 50 new soil series in an attempt to classify, map, and interpret soils encountered in western North Carolina. Soils such as Nikwasi and Hemphill in the floodplains near toeslopes are subject to wetland preservation regulations. Ellijay soils are formed from an ultramafic rock that is very high in magnesium content. Ellijay soils have a calcium-magnesium imbalance and are difficult to manage for crops. In the high mountains, the Wayah soil series was accurately classified as an Inceptisol. However, its high content of organic matter in the surface layer also gives this soil properties shared with Andisols. The taxonomic establishment of new soil series, along with old established soil series, gives the soil scientist in western North Carolina the basic information needed to develop soil map unit names, descriptions, and other interpretive materials.

Soil map unit designation can be a challenging task in some areas of western North Carolina. Soil scientists quickly observed that in some areas of the same soil series, trees of commercial value grew, though in other areas the timber is of very poor quality. This contrast is related to meteorological events. The west side and ridgetops of north-south–trending mountains are barriers to the prevailing westerly wind. During the winter season, trees on these sites experience tremendous ice damage and wind shear. A map unit modifier, “windswept,” has been established for the west side and ridgetops of prominent north-south trending mountains where tree growth is severely affected by wind and ice (Figure 5).

The “windswept” map unit helps foresters identify noncommercial forest areas. Summer home owners quickly learn that ice and wind shear also remove shingles from rooftops as well as tree limbs.

Soil survey work in the mountains is not yet complete. In 1998, a memorandum of understanding was signed by the National Park Service and the Natural Resources Conservation Service to produce a detailed soil survey of the Great Smoky Mountains National Park at a 1:24,000 scale. Many of our established series will be used in the park, but we also know that this 550,000-acre piece of real estate also contains soils that will require establishing additional soil series and some unique map unit designs. We have learned that some high mountain areas burned repeatedly in the early 1900s did not revegetate with forest cover. These areas, known as “balds,” lack the thick dark surface layers common in nonburned areas. Burned areas are easily identified on color infrared aerial photography as pale green (Figure 6). To accurately identify these areas, and thus enhance the value of our soil maps to National Park managers whose primary interest is vegetation, we may need the soil map unit modifier “burned” added to our growing list of map unit modifiers.

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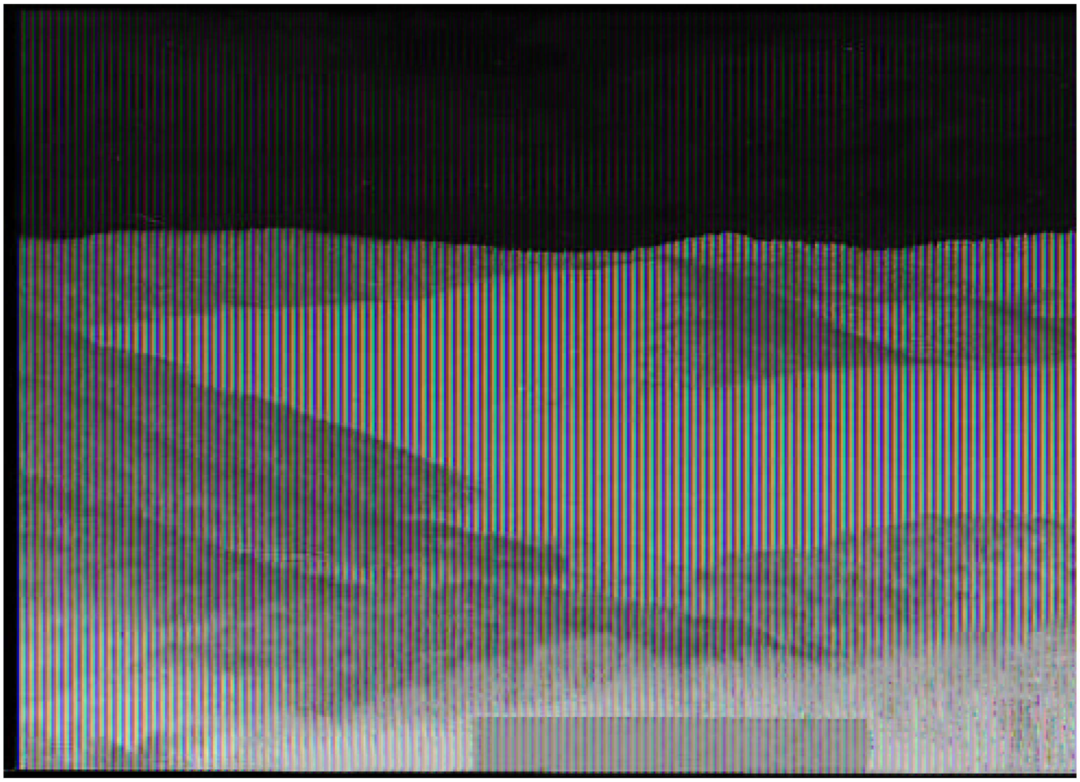

Figure 4. Shading effect of higher mountains.

Figure 5. Trees severely damaged by wind and ice.

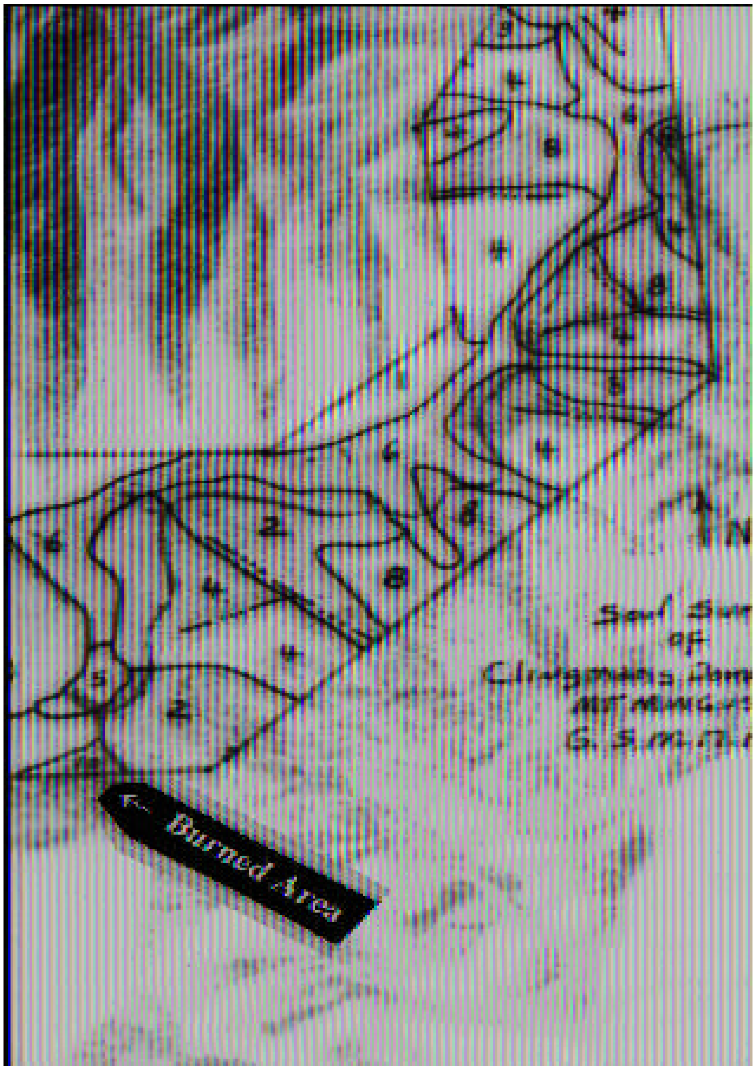

Figure 6. Burned area near Clingman's Dome.

Formation of Soils in North Carolina

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Soils in North Carolina can trace their ancestry to the formation of planet earth. As the molten magma cooled that portion of the earth's surface that was destined to be politically designated as North Carolina acquired a chemical composition that determined the proportion of chemical elements available within the material that we now call soil. The basic ingredients that formed most of the soils in North Carolina were acid igneous rocks. By earth-wide standards these rocks are rich in silicon and aluminum but poor in the life essential elements of phosphorus, calcium and magnesium. Geologic ages before the land surface acquired any similarity to that of the present, the cooling crusts were twisted and turned to reshape portions of the original granitic rock structure into metamorphosed masses of gneiss. Melting and solidifying processes concentrated certain elements into potassium-rich mica schists, silica-rich quartz dikes, and iron- and magnesium-rich mafic dikes within the crustal lithosphere.

Additions were made via volcanic activity that spread ash and molten flows over some of the gneiss and granites. These materials were eroded, redeposited and compressed into shales, slates and limestones. The surface plates of the earth continued to shift and what is now the western part of the state was thrust upward to form the Appalachian mountains. Wide basins were formed to the east of the mountains and sediment from eroding surfaces settled into them forming the Triassic Basins. Tectonic upheaval subsided, and erosion became the major influence shaping the land surface of what was to become North Carolina. Over the millennia, soil materials eroded off the piedmont and mountains. The Blue Ridge formed the highest point in the eastern part of the United States. Erosion to the west of the Blue Ridge was carried toward the Mississippi basin. To the east of the Blue Ridge eroded sediments were deposited to form the continental shelf of the North American continent. As the relative elevation of land continued to rise, the position of the Atlantic Ocean receded to the east, and broad nearly level areas of sediment became exposed as land surface, now known as the coastal plain. Sea level fluctuated over 400 feet in the last 5 million years creating seven levels of sediment surfaces, separated by scarps (escarpments) that are markers of the former coast line within the coastal plain.

The most significant aspect of geologic history on soil formation within North Carolina is a legacy of material that is chemically poor with respect to chemicals such as phosphorous, calcium and magnesium needed to support life. Most of the limestones which contained the calcium- and phosphorus-rich materials of dead organisms were thrust westward into what is now Tennessee or eroded and deposited deep within the sediments under the coastal plain. The slates, granites, and gneiss exposed on the eroding slopes of the piedmont and mountains are acidic and contain only small amounts of phosphorus, calcium and magnesium, with potassium being in relatively good supply.

North Carolina was untouched by the massive continental glaciers that pulverized the limestones and granites of what is now Canada. With the aid of flowing waters and dusty winds, that fertile silty material was deposited over vast areas in the Midwest of the United States. The materials on the coastal plain, most of which were chemically poor at their origin, were exposed to further chemical depletion as they were eroded and transported to their present location. Only the relatively basic sediments in the Triassic Basins and basic gabbro and diorite rock exposures can be considered chemically fertile soil forming material.

Graced with appropriate temperature and moisture North Carolina has climatic conditions that are amenable to many plant species and ample water is available during the long frost-free season. Paleoclimatic evidence does not indicate extreme differences within the recent past. Although cooler climatic conditions have been present no glacial activity has been detected in North Carolina.

Most of the state averages about 45 inches of precipitation each year. Average precipitation is slightly higher near the coast, decreases to about 35 inches in the Asheville basin and reaches about 80 inches in some of the mountains in the southwest part of the state. Temperatures over most of the piedmont and coastal plain dictate evapotranspiration requirements of about 30 inches of water each year. Cooler temperatures in the mountains dictate somewhat less evapotranspiration. Although yearly weather conditions fluctuate around these averages there is an average annual surplus of about 15 inches of water if all the precipitation infiltrates into the soil. Most of this surplus water comes during the winter months, percolates through the soil and recharges the ground water.

Change with time is intrinsic to the concept of soil formation. If soil composition could not be changed in response to ambient conditions all soils would have only properties of the geologic material from which they form. Several soil properties are dictated by the composition of the parent material and several soil characteristics common in other areas of the world can not develop in North Carolina simply because the ingredients necessary for their development are not present. For example, the redistribution of carbonate to form calcic horizons is a significant feature of soils formed in material that contains abundant amounts of carbonate. Calcic horizons are not found in North Carolina.

Base Saturation Patterns

The interaction of water and plants redistributes chemical elements within the soil profile in addition to both adding and removing some elements. Plants obtain hydrogen and oxygen from water. Almost all other chemicals in plant tissue, except carbon, are taken up through their roots.

Carbon enters the plant as CO_2 through the stomata of the leaves and combines with nitrogen, phosphorus, calcium, magnesium, iron, copper, zinc, sulfur, boron, etc. extracted from the soil to form organic compounds of these elements in the plant tissues. Potassium, extracted from the soil, does not form organic compounds but is retained in the cytoplasm and vacuoles of the plant cells. Plants combine these inorganic elements from the soil with the CO_2 from the air to form organic compounds in their roots and above ground parts.

Most of these organic compounds are deposited as organic litter on the soil surface not to the total soil volume from which the plant roots extracted the essential elements. Potassium quickly leaches from the dead plant cells as an inorganic ion. As microbes consume the plant tissues and respire the carbon as CO_2 the other essential elements are released from their organic compounds as inorganic ions. The result of this "biocycling" is a concentration of life essential elements in topsoil despite the leaching effect of the percolating water.

When biocycling and leaching processes are imposed on infertile parent materials soil profiles are formed within which exchangeable base cation contents decrease with depth, i.e. Ultisols. When these processes are applied with equal vigor to fertile parent material a vertical pattern of decreasing, then increasing, base saturation with depth develops, i.e. Alfisols. In North Carolina, major examples of these processes in identical climatic, topographic, vegetative and age settings are the formation of Ultisols such as Cecil soils formed in acid parent materials and Alfisols, such as White Store soils formed in basic Triassic Basin parent material.

Clay Movement

Vertical water movement patterns within soil offer an explanation for the formation of subsoil clay accumulation, i.e. Bt, argillic and kandic horizons. Most rainfall events are of a limited duration during which water passes rapidly through the larger pores in the uppermost layers of the soil. After rainfall ceases the velocity of the percolating water slows and eventually ceases as it is drawn by capillary action into the smaller (less than 0.01 mm diameter) voids. It is from voids with diameters between 0.01 and 0.0002 mm that plant roots extract water between rainfall events. Water held in pores less than 0.0002 mm in diameter retain water at such great tensions that it can not be extracted by plants. The energy of the rapidly moving water as it percolates through the surface horizons has the ability to suspend clay-sized particles and carry them downward. As plants extract water the suspended clay does not pass into the root and is concentrated into the smallest pores where subsequent water flow rates of high velocity can not again suspend it.

In most soils the amount of clay suspended in each rain event is extremely small, but over several years, perhaps centuries, enough clay is translocated from the upper part of the soil to form argillic or kandic (Bt) horizons. If the clay translocation process (lessivage) is rapid, visible coatings of oriented clay (clay skins) are formed on root channels and ped faces in subsoil horizons. If lessivage is slow, as when little clay is present in the surface horizons, mixing (pedoturbation) processes destroy the fragile clay skin structures, and the clay is mixed into the matrix, but the greater clay content of the subsoil remains.

Clay depletion in the surface horizons and accumulation in the subsoil is a feature common to almost all soils formed on stable landscape positions in North Carolina. It has been hypothesized that this should not occur in poorly drained soils, but it does. The reason appears to be that even if the water table is within the Bt horizon for much of the year there are periods of time during most years, usually during the summer, when subsoils are not saturated and conditions are present for the lessivage process to take place.

Soils with thick sandy surfaces, primarily the Typic and Arenic Kandiudults of the coastal plain, have almost no clay skins within the upper Bt horizons. It is probable that the lessivage process is slow because surface horizons lack both clay and weatherable minerals from which clay can form. In sandy, quartz-rich materials like those is the Sandhills region little clay is accumulated in the subsoil. The lessivage process is slow and soils on rapidly eroding surfaces, like the slopes in the mountains, do not accumulate enough clay to form argillic horizons although clay skins are often present in Bw or cambic horizons.

Soil Organic Matter Distribution

The content and distribution of organic matter in soils results from the interaction of plants, water and temperature. Since there is no organic carbon in geologic rock, except that derived from plants and buried by sedimentation, the organic carbon we find in soil owes its existence to carbon dioxide extraction from the air via plants. Organic carbon is usually the only element determined to estimate organic matter content of soil. Soil organic matter is also the major source of nitrogen in the soil.

Nitrogen, like carbon also comes from the air. Although 78 percent of the air is nitrogen it is present as N_2 and not directly available to plants. Plants secure almost all the nitrogen they need as nitrate (NO_3^-) or ammonium (NH_4^+) from the soil. Small amounts of nitrogen are converted from N_2 by electrical discharges, lightning, and added to the soil in rainwater. Nonsymbiotic microorganisms living in the soil are capable of converting N_2 and incorporating it into their cells. As these microbes die and their bodies decompose the nitrogen they contain is released into the soil solution mainly as nitrate. Precipitation and nonsymbiotic microbial fixation together contribute approximately 20 pounds of nitrogen per acre to the soil each year. Leguminous plants have a symbiotic relationship with nitrogen fixing microbes (Rhizobium) that “fix” N_2 and pass it along to the legume plant. Plants readily consume nitrogen, and it becomes a component of their tissue subsequently to be released as that dead tissue is decomposed. Nitrogen, released as organic tissue decomposes, moves as nitrate (NO_3^-) in oxidized water but is reduced in anaerobic soil water and returns to air as N_2 and other nitrogen gases.

Organic matter in soils is transient. Microbes in the soil consume the organic carbon of the dead plant and animal tissue. Of the carbon consumed, about 25 percent is incorporated into microbial cells, and about 75 percent is released as CO_2, which escapes the soil and returns to the air. Individual microbes have a short life expectancy and with each generation the 75 percent conversion of organic carbon to CO_2 takes place as a new generation of microbes decomposes the cells of the dead microbes. The only new supply of organic carbon is the cells of plants that extract carbon from the air, or of animals which have eaten plants to obtain carbon and other nutrients for their cells. Organic carbon decomposition releases the mineral nutrients that the plants have taken from their total rooting volume and concentrates them in the surface layers of the soil. This results in the spatial association of fertility (N, P, K, etc.) and organic matter in the topsoil horizons.

Temperature and moisture conditions are satisfactory to produce abundant plant growth in all parts of North Carolina. Therefore the availability of organic carbon via plant litter appears not to be limited. To explain the different soil organic carbon contents we find among soils we need to examine those factors that control the rate at which organic carbon is destroyed and returned to the air as CO_2. Soil microbes use O_2 to decompose soil organic carbon. In soils that are saturated with water for much of the year O_2 within the soil is often in short supply. In poorly drained soils, much higher contents of organic carbon are maintained than in well-drained, better-aerated soils.

There are over a million acres of organic soils (Histosols) in the state. They are formed where during recent geologic time organic production has exceeded organic matter decomposition and a thick layer of almost pure organic matter overlies the mineral substrate. We have to say “almost pure” because trees, partially rooted in mineral substrata have been uprooted by wind and mixed mineral material upward into the organic layer and some deposition of mineral dust has occurred. Histosols form when saturated and anaerobic conditions are present throughout most of the year and organic carbon oxidation is slow and nitrate reduction is rapid. As a result much of the organic material in the uncultivated Histosols in North Carolina has carbon:nitrogen ratios well above the 32:1 ratio considered necessary to allow plant available nitrogen to be released during slow decomposition.

Soil microbes respire more slowly when cool, and therefore, it takes longer for each generation of microbes to decompose the plant tissue and organic remains of the past microbial generation. The residence time of each organic carbon atom in the soil is thus longer, and organic carbon contents in cool soils are greater than in warm soils. In the cooler soils of the high mountains, organic carbon contents are greater than in the warmer areas of the state. Soils on the south-facing slopes in the mountains contain less organic carbon than soils on the north-facing slopes because they receive direct sunlight and surface horizons become warmer for longer periods of time each cloudless day.

The temperature to which a given amount of radiation will heat soil depends upon the heat capacity of the soil. Heat capacity is the number of calories needed to raise the temperature of a substance 1^{o} C. Water has a much higher heat capacity than air, thus water content in the soil is the major determinant of a soils heat capacity. Dry soil has a lower heat capacity than moist soil, therefore maximum daytime temperatures near the soil surface are higher than those in moist soil. Sandy soils retain less water than finer textured soils when dried to the point that plants begin to wilt. Therefore, they warm to higher surface temperatures and organic carbon contents are lower than in finer textured soils. Lower maximum temperatures are also present in the surface horizons of more poorly drained soils where higher water contents keep their maximum temperatures below those of surface horizons in adjacent well-drained soils.

Farming operations cause daily maximum surface soil temperatures to increase. Simply removing the shade and surface litter present under native tree vegetation reduces soil organic carbon contents about 30 percent after only a few years. Where drainage has been installed to lower the seasonal high stand of the water table even greater organic carbon content reductions are experienced. Extreme reduction in soil organic carbon content has resulted in parts of the eastern North Carolina “Blacklands.” Since European settlement, drainage and fires have combined to oxidize some of the organic soils (Histosols) and expose the mineral substrate where farming is now conducted.

Erosion and Sedimentation

Natural geologic erosion and deposition processes have shaped the characteristics of most soils in the state. Over geologic time the surface of the land (soil) is not stable. The surface of the land at any given site is either rising in response to deposition or lowering in response to erosion and dissolution of the mineral materials. From measurements of the constituents dissolved and suspended in the major rivers of the Atlantic coast it is estimated the land surface is lowering at a rate of 1.6 inches per 1000 years. Approximately 55 percent of the materials are lost by dissolution of minerals and 45 percent as suspended load in the rivers.

Average rates are extremely misleading because the erosion and deposition processes are localized both in space and time. The spatial arrangement of these processes has created extreme contrasts in soil properties within North Carolina. Erosion is most intense on steep slopes and along major rivers where the kinetic energy of flowing water suspends and moves soil material. Dissolution losses have the most impact on soil properties where soil surfaces are stable and mineral alteration and lessivage have produced the thick, quartz-rich sandy surfaces and kaolinite-rich kandic horizons of the upper coastal plain. On the steep slopes of the mountains, physical removal by surface erosion and physical displacement via landslides change the absolute position of the soil surface so rapidly that the impact of lessivage is minimal with only Bw or cambic horizons being formed in the soils. Argillic and kandic horizons are present only in areas of stable landscape. In the piedmont, with lesser slope gradients, the rate of erosion is less than in the mountains. The soil surfaces are being lowered at a slower rate, and argillic (Bt) horizons are present in all soils except those on the most erosive sites. The level upland surfaces in the coastal plain experience little erosion and are sites for the thickest soils with the most contrasting “textural” profiles, i.e. Kandiudults and Paleudults.

Alternating erosion and sedimentation has created extreme spatial contrast of soil properties in the flood plains and low terraces of the major river systems within the coastal plain. These alluvial areas are subjected to extreme contrasts of erosive energy as floodwater reshapes the channels by cutting new channels while filling old channels with sediment. Floodwater velocities differ greatly both in time and space. Therefore the texture of the deposited sediment contrasts greatly within small distances. Long-term deepening of the major river channels has left former floodplains as stable terraces upon which soils with argillic (Bt) horizons have formed. However, spatial variations in texture, a result of the past sedimentation and stream bank erosion processes experienced during the time the terrace was in a flood plain landscape position, remain. As the river channels deepened, the water tables under the adjacent terraces deepened. Differential settling of the contrasting textures has resulted in the formation of small depressions, often called “potholes,” of more poorly drained soils interspersed within the well-drained soils of the terraces. The intimate spatial mixture of textures and depths to water tables force even detailed soil surveys to represent these areas with map units that have high percentages of included contrasting soils.

Erosion processes remove more than surface soil material. In the mountains, landslides scour linear slopes and pile colluvium at the base of slopes. Landslides and the slow creep of soil material down the slopes result in the formation of shallow soils, and often rock outcrops, near the crest of the ridges and deep soils on the lower part of the slope. Except along major rivers, little deposition remains in the flood plains irregularly eroded in flash floods. On the coastal plain, where river gradients decrease, broad flood plains are present. The piedmont has intermediate flood plain width.

Mineralogy and Particle Size

Most soils in North Carolina contain less silt than soils in the glaciated areas of the Midwest of the United States. Low silt content has profound influence on the available water holding capacity of soils. When silt-sized particles are packed together in soil, pores ranging from 0.0002 to 0.01 mm in diameter are formed. Pores of this size are responsible for retaining water for plant use between rain events during the growing season. Low silt content soils in North Carolina retain approximately 0.1 inch of available water per inch of soil depth. Silty soil in the Midwest retain double that amount.

The granitic nature of most rock, and sediment derived from that rock, precludes high silt content in the soils of North Carolina. The major component of the granitic rock is quartz that weathers by dissolution. Dissolution rate per unit weight of quartz is dependent upon the surface area of the individual particles. Sand-size particles dissolve very slowly while silt- and clay-size particles of quartz dissolve at a relatively rapid rate. Almost no quartz of clay size is present in soil.

Silt contents are greatest in the slate belt and the northeastern part of the coastal plain but seldom exceed 50 percent. Soils formed in the Midwest commonly exceed 60 percent silt, the abundance of silt-size particles resulting from physical crushing by glacial ice and concentration by wind, i.e. loess.

Most soils in the coastal plain are Siliceous. The sand and silt in Siliceous soils is 90 percent or more quartz (SiO_2) and less than 10 percent weatherable minerals. A distinct boundary between Mixed and Siliceous mineralogy exists at the Suffolk scarp at an elevation of 20 feet. To the east and below the Suffolk scarp the soils contain more than 10 percent weatherable minerals and are recognized as having Mixed mineralogy. The weatherable minerals are thought to be derived from sediment originating from material dislodged from areas to the north by glaciation during the last ice age and deposited when the ocean edge was at the Suffolk scarp.

The mineralogical composition of soils within the flood plains in the coastal plain depends upon the area being eroded by the watershed of individual rivers. The flood plains of rivers with headwaters in the piedmont usually have Mixed mineralogy resulting from saprolite material eroded from some areas within the piedmont. The flood plains along rivers in the coastal plain that have headwaters only within the coastal plain usually have Siliceous mineralogy.

Granitic and gneissic rocks form a large portion of the piedmont and mountain areas of the state. Quartz is the most abundant mineral. The second most common minerals are feldspars and micas. Feldspars weather by rearrangement of the silica and aluminum into clay minerals such as gibbsite and kaolinite. On the more stable slopes in the piedmont this alteration takes place at the contact of the saprolite and bedrock, usually well below the soil profile. The upward sequence of alteration within the saprolite is from feldspar to gibbsite, gibbsite to halloysite, then halloysite to kaolinite very near the bottom of the argillic horizons. Gibbsite and halloysite are usually found only within a few inches of the hard rock. The gibbsite appears to rapidly acquire silica, from percolating water to form the halloysite. The halloysite appears unstable when subjected to drying and alters to plate-like-shaped kaolinite in the upper part of the saprolite.

In the mountains where there is a rapid exposure of feldspar minerals by the erosive action of creep and landslides considerable feldspar of sand size is often incorporated into the soil. Gibbsite, apparently forming directly from feldspar weathering, is a significant component of both the silt and clay fractions in cambic horizons. Kaolinite is the dominant clay in most soils in the mountains. Kaolinite forms from both feldspar and biotite. Alteration of sand-size biotite to sand-size kaolinite, with both minerals being present in the same particle, has been observed. Sand-size kaolinite is rigid and easily fractures to smaller silt- and clay-size particles.

In the acid soil environment of almost all soils in North Carolina aluminum ions are abundant. This leads to the formation of a secondary mineral known by several names: soil chlorite; hydroxy interlayered vermiculite (HIV); pedogenic chlorite; with hydroxy interlayered mineral (HIM) being the preferred designation. In its formation Al^{3+} and OH^- ions precipitate as $Al(OH)_3$ and AlOOH in the interlayers of 2:1 minerals like montmorillonite and vermiculite forming a very stable 1.4 nm (14 A°) mineral. HIM is a minor, but consistent, clay-sized component of nearly all soils in North Carolina.

The basic materials of the Triassic Basins and smaller bodies of gabbro, metagabbro and diorite alter to montmorillonite when exposed to weathering in and below the soil. In the Triassic Basins the montmorillonite may have been formed prior to deposition. The presence of appreciable quantities of montmorillonite in clay textured subsoils renders these horizons quite impermeable when wet. The shrink-and-swell characteristics of montmorillonite produces physical movement as the soil wets and dries creating angular blocky structure with slickenside features on the ped faces. Base saturation percentage in and below these horizons is usually much higher than horizons formed from acid igneous rock and many of these soils are Alfisols.

Soil Color

Most soil colors are related to the distribution and composition of iron and organic carbon compounds in the soil. Iron is a constituent of most initial materials in North Carolina, and its movement in response to site specific conditions often differentiates soils within the state. Most often iron is present in silicate minerals but can occur as iron oxides. Iron oxides are particularly visible in soil because of their red and yellow color. Organic carbon is visible as black color in soil material. Most silicate minerals, quartz and kaolinite being the most common in North Carolina, are gray or nearly white in color. Most micas and feldspars are also gray except iron-bearing biotite mica that can be brown to black in color and some pink feldspars.

As previously discussed, organic carbon is derived from the air, and after a brief sojourn darkening the surface A horizons of the soil, most—but not all—returns to the air as carbon dioxide. Organic carbon can also translocate within soil and leach to surface waters especially in sandy materials. Iron, however, is translocated both vertically within the soil profile and laterally among soils on the landscape. To be translocated iron must first be free of its silicate parent mineral. This requires dissolution of silica. Iron silicates are most abundant in basic rocks such as gabbro and diorite. Biotite is a common iron-bearing mineral in gneiss. Under warm conditions, percolating water dissolves silicates more rapidly than under cold conditions. During the eons of time that iron-bearing minerals in North Carolina have been exposed to percolating water considerable iron has been released from the iron bearing silicates of the geologic material. If the environment into which the iron is released contains O_2, the iron forms a ferric (Fe^{3+}) oxide of red or yellow color. Particles of oxide precipitate on the gray-colored quartz and kaolinite minerals. Small amounts of iron oxide, acting as paint, impart a red or yellow color to the soil.

In an absence of O_2, iron is reduced to a ferrous (Fe^{2+}) form which is soluble in water and thus able to move with the water. Water exposed to air contains dissolved O_2. For water to loose its dissolved O_2, microbes need to be actively respiring. Under the deciduous vegetation that once covered North Carolina, the leaves deposited each autumn blanketed the soil surface. Coarse texture surface horizons overlying more clayey and less permeable subsoils of well-drained soils may become saturated for short periods of time mainly in the winter when plants are not transpiring. During warm winter days, the sun warms the surface, and the sugars, carbohydrates and starches of the decomposing organic litter provide an ample source of available carbon to microbes. Respiration is rapid; oxygen is consumed; and nitrate, manganese and iron are reduced as long as the soil is saturated. The nitrate is liberated as N_2 and other gasses. The manganese and iron are reduced to soluble ferrous and manganous forms and free to move as water percolates deeper into the soil with each subsequent rainfall. After each rainfall event some water drains from the soil, the larger pores empty of water and fill with air. Oxygen from the air filled pores diffuses into the reduced water, and the ferrous iron oxidizes to a ferric iron. Red ferric iron is mainly hematite, and yellow ferric iron is geothite. Most soils have a mixture of the two. Manganese, being less readily oxidized than iron, is often observed as black ped face coatings somewhat below the main horizon of iron accumulation.

This process is sporadic and suitable conditions for iron reduction in the surface horizons may occur only a few days each year, or be lacking in many years. The result is low iron content and gray-colored E horizons near the surface of most of the well-drained soils and yellow- to red-colored B horizons. The gray color of the iron poor surface horizons seldom extends to the surface because organic carbon of decomposing plant material added to the surface forms dark colored A horizons.

Plinthite

Of particular interest is the behavior of iron within landscapes on the coastal plain. Sediments on the coastal plain contain relatively few iron bearing silicates because of silicate weathering prior to erosion and movement from the piedmont. Depositional environments are anaerobic so most iron oxides were reduced and removed at the time the sediments were deposited. Most soils in the coastal plain have relatively low iron oxide contents. However, continued desilication of the few remaining iron silicates in the sediments releases some iron, and perhaps some iron is imported as aerosol dust.

Centers of the broad, nearly level interstream divides are saturated for long periods of time each year, some for the entire year. Abundant plant litter supplies fresh carbon each year. There is an inadequate O_2 supply for microbes to quickly decompose the annual additions of plant litter so organic carbon contents are high, and oxygenated rain water is quickly reduced after it enters these poorly drained soils. As the reduced water near the top of the water table moves toward the river valleys between rainfall events, plant roots extract some water from the top of the water table. As air replaces that water in the soil pores ferrous iron oxidizes and precipitates as red or yellow ferric oxide. The result is a "rim" of moderately drained to well-drained soils with yellow- to red-colored, iron-enriched subsoil horizons at the edges of the interstream divides and gray-colored, iron-depleted poorly drained soils in the interstream centers.

Often the subsoils near the edge of the interstream divides that have been stable for long periods of time acquire rather high amounts of iron oxides that partially cement the other soil particles forming a feature called plinthite. Once substantial masses of iron cemented material have formed they restrict water movement and are not easily dissolved by future reduction. To a lesser extent these same features are observable in the piedmont, but the more rapidly changing landform associated with ongoing geologic erosion of the steeper slopes probably precludes complete plinthite formation. Only "red and gray reticulate mottling" is observed in the lower B and upper Cr horizons of soils formed on the lower side slopes.

Spodic Horizons

Some of the organic compounds added as plant litter or formed as the litter is decomposed are soluble or suspendable and move with water in the soil. Such organic compounds are not easily decomposed by microbes, and most seem to be organo-mineral complexes containing short-range-order (amorphous) aluminum oxides. It is probable that such complexes move out of the surface horizons in all soils, but they appear to be retained and decomposed by microbial activity in the Bt horizons of soils that have appreciable amounts of clay.

In sandy soils, especially those with water tables near the surface, a high concentration of these organo-mineral complexes move to surrounding streams and rivers imparting a black or "coffee" color and acidity to the water. Some of the mineral-organic complexes are retained in a subsoil horizon at the upper surface of the seasonally fluctuating water table to form Bh or spodic horizons. A layer or horizon that is repeatedly saturated and aerated for extended periods of time during the year seems to be necessary for these features to form. Spodic horizons seldom occur in well-drained or excessively drained sands but may be extremely thick in some locations with large water table depth fluctuations. Iron oxides are associated with spodic horizons in some soils that have an abundant supply of weatherable iron silicates, but the Spodosols in North Carolina are in iron-poor sandy sediments of the coastal plain and most contain little iron oxide.

Dispersive Soil Material

Sodium-rich soil material is uncommon in humid areas. Sodium is a hydrated ion and when present in sufficient quantity causes soil material to disperse. Sodium is quite mobile in soil, and with appreciable amounts of leaching water, the sodium released upon feldspar weathering is usually removed, ending up in the oceans. Sodium-rich feldspars (plagioclase) are a component of several geologic materials, but little exchangeable Na^+ is present in most soils in North Carolina. Some mafic materials present in the Triassic Basins, diabase and other mafic rocks release Na^+ and Mg^{2+} upon weathering in the saprolite. When sodium-rich saprolite material is weathering below slowly permeable Bt horizons and on convex portions of the landscape, it is protected from leaching, and exchangeable Na percentages approach the 15 percent usually considered necessary for dispersion. In the very low salinity soil water in North Carolina it has been found that exchangeable Na^+ saturation as low as 5 percent, if accompanied by about 15 percent exchangeable Mg^{2+}, is sufficient to induce dispersion if this material is used in earthen dams. Only rare occurrences of this material have been found where all of the above conditions are present.

Sulfur Rich Soil Material

Prolonged contact of sulfur and iron in a reduced environment can produce insoluble iron sulfides. Such conditions occur in clay textured materials saturated with brackish water which are also receiving ferrous iron from fresh water sources. When these materials are drained and become oxidized sulfuric acid is produced. The resulting material is extremely acid, often too acid for the growth of plants. Commonly known as “Cat Clays” or “Acid Sulfate Soils,” they are identified as Sulfaquents in soil taxonomy. Only very limited areas of such soils are known to exist in North Carolina. Most are on islands and clayey beaches near the mouth of the Cape Fear River where fresh waters of the river enter the Atlantic Ocean. Apparently because the other major rivers from the state enter sounds within which the salt concentration is much lower than in the ocean, occurrence of sulfuric horizons in North Carolina is rare compared to occurrences in South Carolina and Maryland.

Human Influence

Intensity of human habitation has increased greatly since European settlement started about 300 years ago. Human evaluation of the soils in North Carolina was well expressed by Professor Mitchell in 1822 when he said:

> “The soil of this State is pronounced, by those who have traveled extensively on both Continents, to be of a middling quality. It is of that kind which seems most to demand the employment of science and skill in its cultivation, and to promise that they shall not be employed in vain. Our grounds are neither so fertile that they will produce spontaneously what is necessary to the sustenance and comfort of our citizens, not so sterile that we have reason to abandon them in despair.”[1]

With few exceptions all the soils in North Carolina are composed of mineral material derived from acid igneous rock containing scant quantities of the life essential elements calcium and phosphorus. Blessed with near ideal temperature and moisture for abundant plant growth, the limited supply of these and other life essential elements that plants must obtain from minerals were concentrated in the surface horizons of the soils, but even the

[1] Quote from a speech by Professor Mitchell to the North Carolina Agricultural Society in 1822 and printed in the North Carolina Department of Agriculture Monthly Bulletin No. 15, 1882.

richest of surface horizons contain very limited amounts. These amounts were quickly removed and transported from the fields in food and fiber crops grown and sold to urban areas.

The first European settlers practiced what is now known as "slash-and-burn" agriculture. After the trees were cut and burned, the land was cultivated for a few years harvesting the stores of essential nutrients contained in the ashes. The organic carbon in the soil rapidly oxidized in response to the removal of the cooling shade further releasing essential elements. As these stores of organically bound elements became exhausted, land was abandoned, and the farmers moved to clear yet uncultivated lands. In the words of Professor Mitchell (*ibid*),

> "But, in the process of time, as this system goes on, the planter will look down from the barren ridges he is tilling, upon the grounds from which his fathers reaped their rich harvest, but which are now desolate and abandoned and enquire whether he can restore them to their ancient fertility at a less expense than he can cultivate those lands of an inferior quality with which he is now engaged."

Fortunately natural concentrations of phosphorus and calcium were available and could be mined from some near surface sediments in the coastal plain. As farming intensified and spread across the state, resupplies of essential nutrients via fertilizer and lime became available. Over the history of farming in North Carolina, considerable amounts of lime and phosphate have been added to the soils that were cultivated, and today the cultivated soils are more fertile for the production of food and fiber crops than they were in their natural condition.

Calcium and magnesium from the liming materials have moved downward in the soil and replaced some of the natural acidity in the subsoil. This enables the roots of crop plants to extend to greater depths in subsoils, naturally too acid and calcium poor to permit their elongation, and extract more available water during rainless periods in the growing season. Phosphorus contents of the plowed surface horizons have been increased, but being insolublized by iron and aluminum, phosphorus has not migrated downward in most agricultural soils and subsoil contents are very low. Potassium supplies have been maintained by fertilization.

Annual supplements of nitrogen are placed on cropland and pasture to bolster the amounts naturally extracted from the air by rain and N-fixing bacteria. Liming and fertilization have taken place for approximately 200 years in many parts of the state. This is but a short time in the formation of the soils in North Carolina. However, these practices have significantly improved the soil's ability to produce crop yields per acre that are now approximately three to four times greater than obtained by the first cultivators.

As farming became more mechanized, many areas—primarily those of steeper slopes—were no longer cultivated and have been occupied by forest. Even land abandoned by early slash-and-burn farmers as infertile still has enough fertility to support the growth of pine and hardwood trees, which have a much slower rate of nutrient uptake from the soil than food crops. Forest regrowth occurs naturally on abandoned cropland in the state, but landowners wanting high rates of tree growth often find it profitable to add lime and fertilizer.

Summary

Soil is what soil does. At the interface between the lithosphere and atmosphere on the land mass of planet earth, soil directs the exchange of water and heat, supplies most of the essential elements of life, and holds plants upright so they can utilize the energy of the sun to produce organic compounds necessary to all life on the planet. Soil becomes a mixture of organic and mineral materials within which the organic and inorganic chemistries interact with a multitude of life forms. Each soil is located at a site where a unique array of environmental and human activities combine to create features and functions that identify that soil as different from all other soils. No two soils are exactly alike. People have attempted to group soils of similar function and form thereby facilitating human understanding. Within North Carolina, over 300 kinds of soil have been identified by these human efforts, but in reality each identified kind of soil encompasses many soils, each somewhat unique and different.

Many known species of soil are not represented in North Carolina. Limited by the composition of the geologic materials from which they form and moderate climatic differences, soils in North Carolina may be considered monotonously similar. Most have features and functions that only slightly differ. Although soil differences in North Carolina may be small when compared to the total spectra of soils on earth, many of these differences are critical to human uses. Science is required to understand these soil differences. Skill is required in the application of science to assure continued formation and function of soils in North Carolina.

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History of Soil Survey in North Carolina

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Abstract

The Raleigh to New Bern survey, published in 1900, at a scale of 1 inch per mile is the oldest known soil survey in North Carolina. Milton Whitney, then chief of the Bureau of Soils, had been the first superintendent of the research farm in West Raleigh before being appointed to the Federal position. In 1909, W. E. Hearn completed a unique soil survey of approximately 50,000 acres in Lake Mattamuskeet while it was under water, later to be pump drained in the 1920s only to become a lake again in 1933–34 when the pumping was abandoned. Hugh H. Bennett entered the soil survey of his native state in 1903, became an inspector in 1910, and spearheaded the formation of the Soil Erosion Service in 1933. Of the 100 counties in the state, 98 have published soil surveys, and the remainder have completed surveys awaiting publication. Fifty-six counties have two published soil surveys and five have three published surveys. Tales of ’bacca spittin’, moonshin’, and “ya’ll can’t get there from here” have contributed to the soil surveys of the “Old North State.”

Introduction

Perhaps it would be a bit presumptuous to claim that North Carolina was where soil survey in the United States started, but it is a fact that in 1886, Dr. Milton Whitney was appointed the first superintendent of the research farm in West Raleigh. While the research farm was to become North Carolina State University, Dr. Whitney was to become the first Chief of the Bureau of Soils in the USDA and establish the soil survey program and the first systematic classification of soils in the United States (McCracken 1989).

Whitney was well known for his ever present cigar and his allegations that he could determine the kind of soil in which a tobacco was grown by the aroma of the smoke

(Simonson 1986). His contention that the content of sand, silt, and clay had more to do with soil productivity than the soil's nutrient status or fertility put him at odds with the chemists and soil fertility specialists of that day (McCracken 1989). Also, oral history indicates that not all of his associates shared his enthusiasm for cigars.

Early Soil Survey Program in North Carolina

North Carolina became one of the first six states to begin a program of systematic classification and mapping its soils, with accompanying interpretations of use potentials. The USDA soil survey program began as a cooperative effort with the North Carolina Agricultural Experiment Station (now North Carolina State University) and the State Board of Agriculture (now the North Carolina Department of Agriculture). The first soil survey in North Carolina was the "Raleigh to New Bern Area," started in 1900 (Lee 1984). The survey was to be used as the basis for systematic investigation of the fertilizer requirements of different crops through a series of substations to be established on some of the principal soil types. The first surveyor was William C. Smith, a USDA employee. With the U.S. Geological Survey base maps previously prepared along the railway right-of-way, he mapped 1000 square miles in eight months. This is a rate of 5.6 square miles per day traveling by foot, horse- or mule-back, cart, buggy, or train. The cost of the survey was $1.10 per square mile.

In 1901, a second soil survey was started in the Statesville area. This survey was in one of the most eroded areas in the state. The report stated that farming practices resulted in "washing and small gullies . . . with many fields having gullies with a depth of greater than 40 feet" (Lee 1984). The remedy suggested was that "gullied fields in a few years would be entirely reclaimed by a judicious use of ditch and terraces and the filling in of the larger gullies by means of pine boughs and logs" (Lee 1984). The fast-growing area around Cary was surveyed in one summer month in 1901. The survey area covered 63 square miles and included the present site of N.C. State University. The Mt. Mitchell area was mapped to find soils suitable for apple orchards in 1903. Other area soil surveys are listed in Table 1.

Table 1. Soil surveys by area

Year Published	Name of Survey
1900	Raleigh to New Bern area
1901	Statesville area
1901	Cary area
1902	Mt. Mitchell area
1902	Hickory
1903	Craven
1903	Asheville
1904	Greenville
1909	Lake Mattamuskeet
1977	Outer Banks [1" = 1000 feet]

Alamance County was selected, because it was alphabetically first among the counties, for a survey in 1901. Duplin County was surveyed to consider land suitable for vegetable and grape production. Chowan County soil survey marked the first State Department of Agriculture employee, G. M. MacNider, to join with USDA soil scientist W. Edward Hearn. These two men also mapped Transylvania County at the same time. The state contributed $188.10 to the Chowan County survey and $737.80 to the Transylvania County survey. From 1900 to 1910, the base maps were 1-inch-per-mile U.S. Geological Survey (USGS) maps, many of which were 15 to 25 years old and out of date due to new roads, etc. Soil surveyors were geologists or chemists with little training in agriculture (Lee 1984).

In 1904, Hugh Hammon Bennet joined the North Carolina soil survey, became an inspector in 1910, and in 1933 formed the Soil Erosion Service, later to become the Soil Conservation Service and the Natural Resources Conservation Service.

In 1910, Professor Curtis Marbut was placed in charge of the Bureau of Soils, USDA. Base maps were then made with a plane table (15- x 15-inch board) equipped with compass and mounted on a tripod. An alidade was used to sight and measure. Transportation was by mule- or horse-drawn carts. An odometer fastened to the front wheel served to measure distances along roads. Churches, schools, cemeteries, and dwellings along the road were carefully identified on the base maps. About 1905, a 36- to 42-inch-long screw auger became the standard tool to examine soils.

In 1917, S. F. Davidson became the first college-trained soil scientist to join the soil survey, followed in 1918 by W. A. Davis. In 1918, the automobile entered the survey to transport the soil surveyor and his plane table.

The first airplane entered the survey in North Carolina in 1920. W. B. Cobb, a World War I pilot, assisted by W. A. Davis, flew over the swamps of Tyrrell County to locate points later to be traversed on foot. A few photos from the plane were used to aid the ground work, but total photo coverage was not used at that time. Complete aerial photo coverage was not used for soil survey in North Carolina until 1934 (Lee 1984).

A Few Statistics

North Carolina contains 100 counties. In recent years, soil surveys have been made and published by county or, in some cases, two counties.

As of this writing (June 1998), 182 county soil surveys in North Carolina have been published (Table 2). These surveys cover all 100 counties. More than half of the counties have two published soil surveys, and seven have three published surveys (Table 3).

By 1911, B. W. Kilgore had written *A preliminary report of mountain soils* based on soil surveys and field experiments. In 1915, C. B. Williams wrote a report on the piedmont soils, and in 1918, he wrote a report on coastal plain soils.

Table 2. Number of soil surveys published in each decade (USDA-NRCS 1995).

Decade	**No. Published**
1900–1909	22
1910–1919	33
1920–1929	31
1930–1939	10
1940–1949	8
1950–1959	11
1960–1969	4
1970–1979	14
1980–1989	26
1990–1997	23
total	182

Table 3. Coverage of the 100 counties in North Carolina [excluding the area surveys listed in Table 1].

No. Times Published	**No. Counties**
1	31
2	62
3	7

Three North Carolina Agricultural Experiment Station bulletins have been published that have summarized the soil survey data for the entire state (Williams and others 1934, Lee 1955, Daniels 1984).

The estimated cost for conducting soil survey field work in North Carolina is $1.50 per acre (September 1995). In 1995, 14 counties were contributing a total of more than 1.6 million dollars in cost-sharing funds for soil surveys. Most county cost-share agreements call for the county to contribute one-third of the survey cost for the privately owned land in the county. For their cost-share support, local governments receive both a published and a digital version of the modern soil survey. It should be noted that this support is perhaps strongest in, but not limited to, some of the least wealthy counties in the mountains of the state. Twelve counties in the sparsely settled mountain area have cost-shared surveys at a scale of 1:12,000. At first glance, the need for increased resolution in mountainous areas may not appear justified. However, soil suitable for home sites, horticultural crops such as Christmas trees, apples, ginseng, and tobacco are often in very small units that are not possible to delineate on smaller scale maps. This is but one indication that the soil survey program in North Carolina has been, and is still, serving the people.

In addition to the support from the North Carolina Agricultural Research Service at North Carolina State University and North Carolina A&T University at Greensboro, the state of North Carolina presently supports nine N.C. Department of Environment and Natural Resources soil scientists active in field mapping. This support has been ongoing since about 1975 and several of the state supported soil scientists are party leaders in our present surveys. Although they receive their paychecks from the State of North Carolina, they work side by side with federally funded soil scientists of the Natural Resources Conservation Service and the Forest Service.

In 1994, a major reorganization in the USDA resulted in the formation of a Major Land Resource Area (MLRA) office in Raleigh. This office is responsible for providing assistance to nine states, which include parts of North Carolina, New York, Alabama, Georgia, Florida, New Jersey, Delaware, Maryland, and all of South Carolina.

There is a professional bond among the soil scientists in North Carolina that is strengthened by almost universal membership in the Soil Science Society of North Carolina, which meets annually. With strong leadership from among the soil scientists that work in the National Cooperative Soil Survey, a North Carolina Registry of Certified Professionals in Soils was formed and recently has succeeded in their efforts to establish State licensing of soil scientists in North Carolina.

Some Unusual Surveys

Perhaps the most unusual soil survey was conducted in North Carolina. In 1909, some wealthy individuals had the bright idea that a shallow body of water known as Lake Mattamuskeet could be drained with the aid of pumps, and the lake bed could be used to produce crops. The lake was approximately 1 to 5 feet deep and covered about 50,000 acres. The surface of the lake was only 30 inches above sea level and is located approximately 10 miles from Pamlico Sound. A base map at a scale of 1 inch per mile was compiled by the Office of Experiment Stations and the USDA. Mr. W. Edward Hearn, one of the most experienced soil surveyors, was placed in charge of surveying the lake and surrounding area for a total of 112,640 acres.

To keep located during the survey of the lake, the surveyors first ran guide strings across and then followed the strings in wide, flat-bottomed boats to make the auger borings. Obtaining auger samples from under water was a severe problem. A 60-inch auger was used. The auger was inserted in a bicycle inner tube that had been severed at the valve. This "waterproof" casing was carefully fastened to the auger in such manner that the soil samples could be drawn and retained from any depth to 3 feet below the lake bottom.

Although the survey was completed and published in 1909, it was not until the 1920s that a definite attempt was made to drain the lake completely. This was done with huge pumps and the digging of a network of canals and ditches. Extensive tracts were cultivated with large machinery and used to grow corn, soybeans, and oats. Smaller areas were used for white potatoes and some vegetables. According to observers, yields were "fair" but despite the rather sandy nature of most lake bottom soils, they apparently did not achieve uniform drainage, and some sections of crops often "drowned out" rains. By 1933–34, the owners decided that it was not possible to crop the area of the former lake; the pumps were removed; nature took its course; and today Lake Mattamuskeet contains some fine bass fishing and hosts vast flocks of migratory waterfowl (Lee 1984).

As development of beach homes and a boom in recreation demand greatly increased population and waste disposal problems on the Outer Banks of North Carolina, there was an urgent request for a special soil survey. With strong support from all cooperators, mapping the soils of the coastal strip from Virginia to South Carolina was completed in 1977. A special report for each of the seven counties that have land on the Outer Banks was released to provide information on soil suitability and limitations for development. The map scale was 1 inch per 1000 feet (1:12,000) with many of the published sheets containing more water than land.

In 1984, the U.S. Environmental Protection Agency initiated a multi-level research project to address concerns regarding potential soil and water acidification by atmospheric deposition. During this study, 13 watersheds covering 53,000 acres were surveyed by North Carolina soil scientists. In addition to mapping, pedon data were collected on 80 statistically selected transects and complete laboratory characterization was provided on 54 pedons. The work provided several unique experiences such as helicopter transport of samples from remote mountaintop locations.

All in a Day's Work

W. D. Lee (1984) reported that in the early days dogs, bulls, wild boars and snakes occasionally objected to a soil surveyor's passage. However, the most disturbing incidents occurred when an irate farmer appeared with a pitchfork or shot gun and vehemently proclaimed he "didn't want no gov'm't men messing on his land" and "get the blankety-blank outer here."

In the early days when soil surveys were being made with a plane table and alidade base map, there was a soil surveyor by the name of Red Stryker. Red was able to take care of himself and was known for punching out any farmer who challenged him for crossing the farm. Because soil surveyors had to move frequently in those, they would rent a room in a house and take their breakfast and supper in the local restaurant. Seems Red ate a lot of bran flakes washed down with prune juice and had to relieve himself at frequent intervals. He had the practice of picking up napkins at breakfast. In one place, one of the waitresses caught on to what he was doing. One morning she asked Red why he always was taking napkins with him, to which he replied that they were to wipe his alidade. The waitress laughed and said she had never heard it called that before. During the rest of the stay, she would routinely ask if he was able to keep his alidade clean—shouldn't he take more napkins?

Then there was the legendary Billy Ligon. Billy was the principal correlator while the surveys were being made of the mountain counties of the state. If any comment was made about his driving on inspection trips, he would slam on the brakes and turn over the driving to the individual making the comment. One soon learned not to sit in the back seat on the same side of the car where Billy was driving on a hot day because tobacco juice frequently drenched that position.

While making reviews of the area, the review parties usually stayed in Waynesville, N.C. In Waynesville, there was one exceptionally good restaurant for breakfast each morning. In this restaurant worked an exceptional waitress. This lady would never take a note and was able to remember and correctly return with several orders. Billy, like all of us, was greatly impressed with her ability. Upon returning a year after one of these reviews, he inquired if they would eat at the same restaurant and remarked how he remembered the waitress. Billy always ordered eggs over easy, grits, and biscuits for breakfast. Louie Aull, party chief and outstanding joker, make it a point to catch the waitress before she took the order from the several soil scientists at their table. Being duly armed with Louie's coaching, she approached the table and received the verbal order from each, leaving Billy until last at which time she declared, "Oh, I remember you . . . you always order eggs over easy, grits, and biscuits," leaving Billy with his mouth open in amazement at her ability.

Ralph McCracken reports his personal account of a rather frequent scenario experienced by soil surveyors in the mountains of North Carolina. One day when Ralph was walking down a dirt path in the woods, a person stepped out from behind a tree and asked where he was "started for"? Being astute and acquainted with the locale, Ralph concluded immediately that he was a representative of the local moonshin' industry. Seizing the opportunity to teach a potential student, he carefully explained how he was surveying the soils and making a map. Upon receiving Ralph's excellent lecture, the fella' replied, "I'll save you some trouble . . . ain't no soils down this way so you can turn about and go back." Being a firm believer in the wisdom of indigenous people, Ralph accepted the help and, to this day, there is a map unit delineation in North Carolina entitled "Ain't No Soil."

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Licensing of Soil Scientists in North Carolina

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The year 1995 marked an important accomplishment in the recognition of soil scientists when the General Assembly passed an act to provide for the licensing of soil scientists. As of July 1999, over 230 soil scientists from 18 states have been approved for licensing and 25 are currently in an in-training status. North Carolina joined a select group of only seven states with legislated licensing recognition for soil scientists. Licensing over 200 soil scientists in less than four years is a significant accomplishment. Reaching this goal, however, did not come easily.

Discussions of licensing by soil scientists began in the early 1970s. Most of the initial deliberations were among members of the Soil Science Society of North Carolina. The minutes of the annual meetings of this group reflect this theme and strong desire to recognize the profession. A bill was finally drafted for such a statute in 1977. The timing for such a bill, however, proved to be wrong politically and otherwise. The Attorney General expressed concern for the proliferation of occupational licensing and challenged the documentation relative to the public need for such a statute. The bill could not be passed over objections from the Attorney General's office.

The interest in some form of certification program for soil scientists was not diminished by the initial lack of success in the legislature. Under the auspices of the Soil Science Society of North Carolina, plans were put into action to develop a certification program that would recognize the unique soil science training and expertise of the profession. In 1979, the North Carolina Registry of Certified Professionals in Soils was established, and the President of the Soil Science Society of North Carolina appointed a rotating board.

Over the next 15 years, this certification program served to elevate the soil science profession. A published directory of the membership was circulated to various state and local agencies that were responsible for implementing various regulatory programs where soil reports were required. The registry grew to over 50 members and provided a valuable resource for anyone needing the services of a soil scientist.

Since the registry was only a certification program administered by the Soil Science Society, it did not, however, meet the same standards of professional credentials as other professions that were recognized with a state statute. Impetus began to grow from a core of registry members for another attempt at a licensing statute. The effort was given important support and encouragement from related professional groups who felt that the soil science specialty should assume its own statutory responsibility.

In 1993–94, a major campaign was initiated to generate contributions for a fund to hire a lobbyist to assist in the effort of shepherding a bill through the General Assembly. Representative Arlie Culp, a former employee of the Soil Conservation Service, agreed to sponsor the bill in the House. Many people assisted in contacting their legislators and in attending committee meetings and hearings in the legislature. Support was gathered from the engineering and geology professionals. Documentation of examples relative to protecting the public welfare were developed and were especially focused on waste disposal issues. The existence of the 15-year registry of soil scientists organized by the Soil Science Society provided valuable support for the cause. The involvement of the State in the failure of a couple of large community-sized ground absorption septic disposal systems provided important fuel for raising the soil issue to a level that attracted the attention of the legislature. In 1995, the House bill was passed with only a few dissenting votes. Approval followed in the Senate and the statute was ratified July 11, 1995.

As defined in G.S. 89F, the practice of soil science means any service or work the adequate performance of which requires education in the physical, chemical and biological sciences, as well as soil science; training and experience in the application of special knowledge of these sciences to the use and management of soils by accepted principles and methods; and investigation, evaluation and consultation; and in which the performance is related to the public welfare by safeguarding life, health, property and the environment. 'Practice of soil science' includes, but is not limited to, investigating and evaluating the interactions among water, soil, nutrients, plants and other living organisms that are used to prepare reports for subsurface ground absorption systems, including infiltration galleries; land application of residuals such as sludge, septage and other wastes; spray irrigation of wastewater; soil remediation at conventional rates; land application of agricultural products; processing residues, bioremediation, and volatilization; soil erodibility and sedimentation; and identification of hydric soil and redoximorphic features.

The Governor, the Senate and the House appoint members of the North Carolina Board for Licensing of Soil Scientists in the statute. The seven members are affiliated as follows:

1. One member appointed by the Governor, who shall be a soil scientist employed by a federal or State agency.

2. One member appointed by the Governor, who shall be a soil scientist employed by a local government agency.

3. One member appointed by the Governor, who shall be a soil scientist employed by an institution of higher education.

4. One member appointed by the General Assembly upon recommendation of the Speaker of the House of Representatives, who shall be a soil scientist who is privately employed.

5. One member appointed by the General Assembly upon recommendation of the Speaker of the House of Representatives, who shall be a member of the public who is not a soil scientist.

6. One member appointed by the General Assembly upon recommendation of the President *Pro Tempore* of the Senate, who shall be a soil scientist who is privately employed.

7. One member appointed by the General Assembly upon recommendation of the President *Pro Tempore* of the Senate, who shall be a member of the public who is not a soil scientist.

In addition to the members described above, the President of the Soil Science Society of N.C., or a member of the Society appointed by its President, shall serve as a nonvoting *ex officio* member of the board.

Appointment of the first Board was completed late in 1995. The rule-making process was undertaken and after several attempts and adoption of temporary rules, Chapter 69 Board for Licensing of Soil Scientists Title 21 Occupational Licensing Board of the North Carolina Administrative Code was approved by the Rules Review Commission and became fully effective April 1, 1997. Under this clause, applicants who met the education requirements and the practice experience could be licensed.

The statutory opportunity for granting a license without a written examination kept the Board busy for the first year as many applicants took advantage of the grandfather clause. This opportunity ended in November 1996 after which written examinations were required of all applicants.

Development of a written examination was a major concern for the Board. Quite fortuitously, however, the Soil Science Society of America was simultaneously exploring the preparation of such an exam that could be used on a national basis. This society appointed a 30-member Council of Soil Science Examiners representing all the major subdisciplines of soil science. This group meets biannually to write exam questions. Three members are presently from North Carolina. The written examinations involve two parts. The fundamental exam is taken after completion of the B.S. degree and 15 semester hours of soil science course work. Successful completion of this exam allows an individual to be granted an in-training status. After three years of mentored practice in soil science, a professional practice exam must be successfully completed.

The Board meets quarterly to review applications and conduct necessary matters for implementing the statute. Written communication can be addressed to the North Carolina Board for Licensing Soil Scientists, P.O. Box 5316, Raleigh, NC 27650-5316. Information about the program can be found on the Internet at www.soil.ncsu.edu/ncblss.

Hugh Hammond Bennett: the Father of Soil Conservation

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Hugh Hammond Bennett must be included among the elite of North Carolina's most illustrious native sons. Appropriately described as "the father of soil conservation," he was also affectionately known as "Chief" and "Big Hugh." Dr. Bennett's contributions to soil science and to humankind have been far reaching. In fact, the impacts of his vision and his achievements are continually being recognized today.

Dr. Bennett perhaps is best remembered for arousing a nation to the potential perilous effects of soil erosion, which he called "a national menace." His efforts did not end with the awakening though. They were just a part of his exciting career that culminated in the establishment of a national soil conservation program. More than 60 years later, the beneficial impacts of that conservation program as it has evolved are seen and experienced daily.

It is impossible to document the life and works of Hugh Hammond Bennett thoroughly in this brief article. Several writers have already undertaken this monumental task. The aim of this commentary is to highlight a few major periods in his life and to validate his greatness as an individual and a dedicated public servant.

The Formative Years

Hugh Hammond Bennett was born April 15, 1881, in Anson County, North Carolina. Hugh's father operated a 1,200-acre plantation in the Carolinas. When he died in 1913, there was no indebtedness on the plantation he had directed since the Civil War. Hugh frequently cited this as an example of efficiency that characterized the management of many Southern cotton plantations at that time. This model of efficiency apparently made an indelible impression on him because efficiency was a trademark of Hugh Bennett in the various roles that he was destined to fill in the years that lay ahead.

Hugh remembers helping his father lay off terrace lines when he was about ten years old. A wooden 'horse' or bipod, later known as an A-frame, substituted for a transit and tripod in establishing level lines. Hugh's job was to dig small holes with a hoe to mark the successive points to form the plow line for turning up soil for terraces. Bennett recalled vividly asking his father why they were going to all that trouble. His father's answer seared deep into his memory: "To keep the land from washing away!"

There were nine children in the Bennett family. All nine had a fling at college, four going on to graduation. Hugh's early schooling was in Wadesboro. For seven years, accompanied by two brothers, he rode a mule to school using a fertilizer sack for a saddle. Sometimes when the mules were needed in the field, the brothers would walk to school and back, a distance of seven miles. At that he grew up with a sense of well being, for he was always well fed and well clothed. There were self respect and mutual respect, and security and close-knit family love and loyalty at home.

Hugh earned his university education the hard way. There were postponements and delays. He entered the University of North Carolina in the fall of 1897. By spring of 1899, funds were exhausted and he dropped out of college. He worked for two years in a pharmacy in Wadesboro to earn money to return to school. Later he would look back on those two years in the drug store as one of the most valuable parts of his education in that he learned much about human nature and some hard rules of business.

Bennett specialized in geology and chemistry at the university. A professor who influenced him greatly was Dr. Collier Cobb, who taught him geology. Hugh graduated from the University of North Carolina in the spring of 1903.

Bennett, the Scientist

Hugh Bennett had numerous job opportunities available to him as a result of his college degree and his pharmacy work experience. It was a sheer accident, so he said, that caused him to take a job with the old Bureau of Soils. While considering several offers, he saw an announcement of a Civil Service examination for chemist in the Bureau of Soils, U.S. Department of Agriculture. It was for a job that would pay one thousand dollars a year, and in those days that was considered good pay for a youngster fresh out of school. His grade on the examination was 89.10, a relatively high grade that earned him an appointment as chemist in the Bureau of Soils. However, the filling of the laboratory chemist position was delayed and Bennett was asked if he would object to a temporary assignment in soil survey field work. His quick response was, "No objection!"

The long and colorful career of Hugh Hammond Bennett began on July 1, 1903, in Davidson County, Tennessee. His assignment entailed the classification and mapping of soils by individual types, and observation of their productivity. He liked the work from the start, particularly because it was about 95 percent outdoor activity. He loved the land—the smell of it, the feel of it, its beauty, its variety. Soil surveying also afforded him an opportunity to learn the soils of this nation to an extent approached by few men before or since.

Unhurriedly and with infinite pains, he examined the flora and fauna as well as the soils of the United States from Maine to California. It was not an easy life, but it was a happy one filled with incidents, some profoundly significant. During his multiple careers, but especially that as a soil scientist, he worked in every state of the Union. In retrospect, the foundation of what was to come later in his life was laid in those early days as a soil scientist.

Bennett's many observations of soil erosion, originating with his home place in Anson County, were beginning to mold deep impressions in his thinking. Years later he would write, "The damaging effects of soil erosion were in evidence to right and left through the rolling farm country encountered in North Carolina, Tennessee, and Virginia during my first two years of surveying, but it was not until 1905 that I began to understand just what was taking place on the land." Bennett was referring to his assignment to Louisa County, Virginia, in 1905 to conduct a soil survey with the assistance of W. E. McClendon. He liked to relate the Louisa County experience, which he regarded as sort of an epiphany, i.e., an awakening or revelation about the processes of erosion:

> "Bill McClendon of Bishopville, South Carolina, and I were stirring through the woods down there in middle Virginia when we noticed two pieces of land, side by side but sharply different in their soil quality. The slope of both areas was the same. The underlying rock was the same. There was indisputable evidence that the two pieces had been identical in soil makeup. But the soil of one piece was mellow, loamy, and moist enough even in dry weather to dig into with our bare hands. We noticed this area was wooded, well covered with forest litter, and had never been cultivated. The other area, right beside it, was clay, hard and almost like rock in dry weather. It had been cropped a long time. We figured both areas had been the same originally and that the clay of the cultivated area could have reached the surface only through the process of rainwash—that is, the gradual removal, with every heavy rain, of a thin sheet of topsoil. It was just so much muddy water running off the land after rains. And, by contrast we noticed the almost perfect protection nature provided against erosion with her dense cover of forest."

As a result of this observation, Bennett and McClendon conceived the term "sheet erosion," in contrast with rill and gully erosion, which up until then had been the field clues for soil erosion. In seeing the effects of sheet erosion, the surveyors had recognized the process by what was not there or by what they could not see. By virtue of participating in a soil survey that required them to report on the soils of Louisa County, Bennett and McClendon were required to find the means to express what they saw, and their jobs and scientific reputations depended on it. Their 21-page report on the soils of the county included comments on evidences of soil erosion.

The 1905 experience in Louisa County, Virginia, was a turning point for Bennett, one that he referred to throughout his life. In his retelling of the event, he made it clear that the immediate situation, the juxtaposition of a good soil with forest cover and a "washed" soil of the same subsoil provided them the crucial clues to this discovery—soil versus no soil. They could see that the "washed" soil had no topsoil when the contrasting soil was friable and soft, with organic matter, among other things. He attributed the strong impression of the experience to the shock of recognizing the true nature of a process he had lived with all of his life.

A second turning point that helped define the future direction of Bennett's career occurred in 1908 when President Theodore Roosevelt held the Governor's Conference on Natural Resources at the White House. T. C. Chamberlain, Head, Department of Geology, University of Chicago, spoke on "soil wastage." Chamberlain confirmed for Bennett that he was right to be concerned about the soil body and the connection between soils and the survival of a people. Bennett often cited Chamberlain in his writings and credited him with giving legitimacy to erosion as a serious national issue.

Unfortunately, the Governor's Conference did not produce the results that Roosevelt sought, namely, the enactment of legislation for natural resource conservation and flood control. Congress, balking at Roosevelt's continuing efforts to prod them into action, refused to support any of the President's conservation meetings and committees. The Bureau of Soils and the soil science community were also not ready to adopt Bennett's view that soil erosion was a serious problem and that it should be dealt with actively. How Bennett fared at the Bureau is a measure of the lack of esteem in which he was held. In 1909, he was made Inspector of Soil Surveys for the Southern Division, a supervisory position of fieldwork in 18 states. While this was a promotion, it was not much for someone with Bennett's energy, initiative, and commitment.

Also in 1909, as a measure of the Bureau's view of the perishability of soils, whether by erosion, by chemical or physical degradation, or by these factors in combination, the Bureau of Soils published its Bulletin 55. In this Bulletin, Professor Milton Whitney, Chief of the Bureau of Soils, argued that the soil was of inexhaustible and permanent fertility: "The soil is the one indestructible, immutable asset that the Nation possesses. It is the one resource that cannot be exhausted; that cannot be used up." At a later time, Bennett reacted to Whitney's statement: "I didn't know so much costly misinformation could be put into a single brief sentence." While Whitney no longer censored discussions of erosion out of Bennett's reports, he apparently intended to "cool" Bennett down by sending him on surveys and projects in Alaska and Cuba, and in South and Central America.

Early in his career, Bennett worked hard to establish scientific credibility with a view to persuading his superiors to take initiative on the erosion problem. In the pursuit of this goal, he constructed a strong work ethic and a reputation as the foremost expert on soil erosion in the U.S. He also became the Bureau's expert on soils of the southern U.S., publishing *The Soils of the South* in 1921, and was the individual in the Bureau of Soils with the most experience of soils in South and Central America.

In his single-minded pursuit of a means of dealing with erosion, Bennett gained a reputation as a voracious reader of publications on geology and soils, and as a gargantuan worker, able to endure hardship and privation, as on his assignments to Alaska and to Honduras and Guatemala. Although Bennett was primarily motivated to do something about erosion, he continued to build his professional reputation by contributing to the primary, disciplinary focus of the period, namely, a sound basis for soil classification. Bennett's scientific prowess is often overlooked because of the large amount of publicity and emphasis given to his highly visible activities that occurred later.

Bennett, the Crusader

From his experiences in the field, Hugh Bennett had a conviction of the importance of erosion. But this conviction was not accepted nor appreciated in the Bureau of Soils, where Bennett's reports were received with indifference and skepticism. Soil conservation meant little or nothing to the public, including farmers. As Bennett later described it, "The term conservation had scarcely attained dictionary status." He also noted that, as a student at the University of North Carolina, no attention was given in textbooks or by the instructor to the role of land in economics or politics. The Bureau of Soils likewise had given no emphasis to erosion.

In the context of such a passive view of erosion, Bennett set out to make people aware of the process and its effects. From the time of the Louisa Count survey, Bennett went on to find and report on the staggering erosion problems he saw—and he saw them everywhere now. His surveys from around 1909 record the nature, extent and location of eroded conditions. In 1910, a field party consisting of three members of the Mississippi Geological Survey and two Bureau of Soils surveyors, Bennett and Howard C. Smith, completed a survey of Lauderdale County, Mississippi. This survey identifies an "erosion phase" of Orangeburg sandy loam, designating a soil not as a distinct soil type, but as a soil that is modified by erosion. They assert through classification that a soil difference was the result of erosion.

The Lauderdale report apparently was not edited in Washington, so its extended discussion of erosion effects and recommendations to remedy them was allowed to stand. Bennett carried on with survey work, describing erosion wherever he found it and raising awareness of it in the surveys and in his personal contacts. In 1911, as Inspector for the Southern Division of the soil survey, Bennett was responsible for the classic report on Fairfield County, South Carolina. There, by the account of his staff, 136,000 acres of formerly cultivated land had been ruined by erosion. The survey included three photographs taken in the county. The first two showed steep hillsides that had been cleared and planted to cotton and were highly eroded. A third photograph showed a field being reclaimed by the use of contour cultivation and terracing. This was the first survey to allocate a separate section to "Rough Gullied Land" as to a soil type. Bennett expected this report to arouse public opinion. It was met instead with massive indifference.

The Fairfield County report was followed in 1913 by a soil survey of Stewart County, Georgia. This survey featured a gully of thousands of acres named “Providence Cave” because it grew by undercutting that had begun where rain dripped from the eaves of a barn. This report was accorded the same cold reception as previous reports.

Bennett was disappointed that others would not see how erosion was hurting his native region so badly, but he was not discouraged. In order to create motion in the direction of erosion and its control, he concluded that he had to foster an interest in the subject among the public and among the members of his discipline. He was in a good position as Inspector for the Southern Division, and later for the larger Eastern Division, to bring interest within the discipline. He began to emphasize land use as a topic to generate more interest in erosion. He found more attentive audiences when he talked about land capability and management before warming up to his favorite topic of soil erosion.

Bennett seems to have been regarded by the Bureau of Soils hierarchy as a promising, but impetuous, young scientist. After his surveys of 1910, 1911, and 1913 emphasizing erosion, he was sent away on special assignments, as far away as possible it seemed. Whether or not he was intentionally sent away to distance him from his course of action, his publications trail shows him having worked in the Panama Canal Zone in 1909 and 1913, Alaska in 1914 and 1916, and the area bordering warring Honduras and Guatemala in 1919. In the latter assignment, he served with the international boundary commission. This intended diversion of Bennett’s energies had an opposite effect for the Bureau hierarchy because it gave him an opportunity to further hone his skills for the erosion fight that was to ensue.

Bennett was moved out of the field to Washington in 1918, and at that point began to speak and write more forcefully. His first significant presentation outside his traditional audiences was to the Southern Forestry Association meeting in Atlanta in 1921. He presented a paper that was later published in the Proceedings of the Association meeting. Recalling that the Division of Forestry had been established to conserve resources, Bennett said it was “singing to the choir” at the Forestry meeting when he could not get a hearing in his own Bureau. However, he persisted in working to establish a sound, scientific reputation by publishing extensively on soils in the South; conducting detailed technical investigations for his articles on the humid tropics; and with R.O.E. Davis, contributing suggestions for technical improvement in the textural triangle to simplify soil survey work. He also worked hard during this period to promote interest in erosion with scientists outside the Bureau of Soils and with the public in general.

Biographers comment that while Bennett was not being advanced in the Bureau of Soils, he was gaining substantial recognition outside his organization as an expert on soils and soil erosion. He had developed many contacts among the public through his soil survey work and he informally promoted erosion control with them. He also had many contacts among the state experiment station researchers because the soil surveys were carried out in cooperation with the states. In addition, erosion studies were initiated at several state experiment stations around 1916. Bennett kept in communication with researchers in the State Experiment Stations who were interested in erosion, and information was exchanged through this network. Station researchers likewise were receiving no support from their superiors in Washington for their work on soil erosion. It naturally followed that a strong esprit de corps developed among soil scientists working on erosion and Bennett was the major promoter of the contagious spirit.

In the mid-1920s, Bennett began publishing in the popular and farm magazines, such as *American Game*, *Country Gentleman*, and *Nature*, and he contributed a monthly article to *Farm Journal* from late 1925 through 1926. In total, he published at least 40 items between 1920 and 1930, despite having had several assignments in South and Central America and the Caribbean during that period. His best known publication from this period was the 1928 Circular 33: *Soil Erosion, A National Menace.* Written with the help of W. R. Chapline of the U.S. Forest Service, the circular was regarded as more effective than any of the preceding erosion bulletins in that it was not technical and did not discuss erosion control measures. Instead, coming shortly after the great Mississippi flood of 1927, the costliest in lives and property the nation had ever seen, Bennett and Chapline's bulletin emphasized only the damages caused by erosion and the need for action to stop it.

Soon after the publication of this circular, Bennett finally saw some federal funding approved for erosion research. This came about through his connection to A. B. Conner, Director of the Texas Experiment Station. According to a prearranged plan, Conner was to discuss erosion with Congressman Buchanan of Texas. When the congressman maintained, as they expected he would, that federal money was to be spent for defense, Conner would bring up the large expenditure for battleships, and then argue that protecting the soil that supports the citizenship protects the nation. This devious arrangement worked and, as a result, Bennett was soon asked to testify before Buchanan's subcommittee. An amendment was attached to the 1929 appropriation for the Department of Agriculture authorizing $160,000 over four years for soil erosion research. This money was to be used by the USDA "to investigate the causes of soil erosion and the possibility of increasing the absorption of rainfall by the soil in the United States."

Over a period of two years, Bennett established a network of ten erosion stations in various problem areas of the country: Clarinda, Iowa; Hayes, Kansas; Bethany, Missouri; Statesville, North Carolina; Zanesville, Ohio; Guthrie, Oklahoma; Temple, Texas; Tyler, Texas; Pullman, Washington; and La Crosse, Wisconsin. Of these ten, those at Bethany and Guthrie were already in existence, but experiments at these stations were adjusted to match a model so that all of the stations were controlling and testing the same variables. With this approach, for the first time, commensurable data on soil erosion from different locations in the U.S. became available. Bennett provided findings from these stations in "The National Program of Soil and Water Conservation" in 1930 at the annual convention of the American Society of Agronomy, the largest, longest established, and most prestigious body he had addressed up to that point.

More than 25 years after the Louisa County, Virginia, discovery of sheet erosion, Hugh Hammond Bennett finally saw some positive tangible results of his efforts to arouse the American public to act. The soil erosion peril was, for the first time in the nation's history, an official concern. His crusade was successful, but there was much more yet to come.

Bennett, the Administrator

President Franklin Roosevelt, in promoting his New Deal agenda, encouraged the Congress to establish a Civilian Conservation Corps (CCC). The Corps was envisioned as a means of reducing unemployment, making a positive contribution to the future state of the nation's resources, and instilling in the young men of the Corps a sense of a stake in that future. The CCC was established "to carry out reforestation and other conservation projects in the national forests and national parks." A five-million-dollar appropriation was made available for erosion control on private and public lands, with work to be administered by the Bureau of Agricultural Engineering in the USDA.

Bennett approached his superior, Assistant Secretary of Agriculture Rexford Tugwell, who represented the USDA on the Board of Public Works, about how the job was to be carried out. Bennett by this time had finally attained some degree of acknowledgment within the USDA. Tugwell, a new administrator with Roosevelt's administration, greeted Bennett as the nation's erosion expert. Thus, with Bennett's planning and Tugwell's support, the Soil Erosion Service (SES) was established in the Department of the Interior (DI) in September 1933. Predictably, the head of this new agency was Hugh Hammond Bennett!

Upon receiving the SES appropriation, Bennett lost no time in undertaking work that he had been trying to get done for decades. By mid-October 1933, there were twelve people on the payroll, and the erosion reconnaissance survey was started immediately. One of the first administrative actions affecting the SES was the transfer to it from the Forest Service of over 150 CCC camps.

Over the next two years, Bennett set up approximately 40 large demonstration projects, applying a wide array of soil conserving and restoring practices at the demonstration sites. The CCC participants were engaged in doing the actual work on the demonstration projects, e.g., planting trees, building erosion control structures, planting cover crops. This work was well received by the farming communities and the general public, and it attracted much favorable attention. In December, Henry C. Wallace, Secretary of the USDA, sent Harold Ickes, Secretary of the DI, a memorandum requesting the transfer of the SES to the USDA, a move reputed to have demonstrated the success and popularity of the SES research and demonstrations. The value of the SES work was soon to be realized as the forces of nature were about to act in a spectacular way to drive home the reality and devastation of soil erosion, a fact that Hugh Bennett had being preaching for 25 years.

In 1934, just as the first national survey of soil erosion was being completed, wind storms hit the drought-stricken Great Plains and the term "dust bowl" was born. On May

12, 1934, a major storm hit the plains, later to be described by Bennett as a turning point in the battle to get public attention to the erosion problem:

> "This particular dust storm blotted out the sun over the nation's capital, drove grit between the teeth of New Yorkers, and scattered dust on the decks of ships 200 miles out to sea. I suspect that when people along the seaboard of the eastern United States began to taste fresh soil from the plains 2,000 miles away, many of them realized for the first time that somewhere something had gone wrong with the land. It seems to take something like a disaster to awaken people who have been accustomed to great national prosperity, such as ours, to the presence of a national menace. Although we were slowly coming to realize that soil erosion was a major national problem, even before that great dust storm, it took that storm to awaken the nation as a whole to some realization of the menace of erosion."

That something had gone wrong with the land was indeed evident in 1934, and the resulting public concern led to a great deal of public and private effort to remedy the situation.

In March 1935, a bill was introduced in Congress to set up the Soil Conservation Service as a permanent agency of the government. It was one of many dropped in the hopper under the urgency of the Dust Bowl and its accompanying consequences of depression, unemployment, and hunger. Bennett was called by a Senate committee to argue the case for the proposed legislation. His appearance and what followed it are now legendary. A Bennett biographer, Wellington Brink, graphically describes the event:

> "The witness was not cheerful, but he was persistent, informed, and courageous. He told a grim story. He had been telling it all morning. Chapter by chapter, he annotated each dismal page with facts and figures from a reconnaissance he had just completed. . . .
> The witness did not hurry. He did not want to hurry. That extra ace he needed was not yet at hand. Well he realized that the hearing was beginning to drag. Out of one corner of his eye, he noted the polite stifling of a yawn, but Hugh Bennett continued deliberatively. . . .
> Bennett knew that a dust storm was on its way. He had newspaper items and weather reports to support this knowledge. But it seemed mighty slow arriving. If his delaying tactics were successful, the presence of the swirling dust—material evidence of what he was talking about—ought to serve as a clincher for his argument. Presently one of the senators remarked—off the record—'It is getting dark. Perhaps a rainstorm is brewing.' Another ventured, 'Maybe it's dust.' 'I think you are correct,' Bennett agreed. 'Senator, it <u>does</u> look like dust.' The group gathered at a window. The dust storm for which Hugh Bennett had been waiting rolled in like a vast steel-town pall, thick and repulsive. The skies took

> on a copper color. The sun went into hiding. The air became heavy with grit. Government's most spectacular showman had laid the stage well.
> All day, step by step, he had built his drama, paced it slowly, risked possible failure with his interminable reports, while he prayed for Nature to hurry up a proper denouement. For once, Nature cooperated generously."

The committee went back to the conference table no longer in doubt. This was the turning point. The 74th Congress passed without a dissenting vote Public Law 46, The Soil Conservation Act, the first soil conservation act in the history of this or any other nation. It was signed by the President on April 27, 1935.

With the passage of Public Law 46, the Soil Conservation Service (SCS) was established as a permanent agency in the USDA. The soil erosion and soil conservation activities that had been carried out in the Soil Erosion Service of the Interior Department were transferred to the Agriculture Department. The only logical choice to be the first Chief of the newly created Soil Conservation Service was Hugh Hammond Bennett. Bennett had mixed feelings about the transfer of the SES program into the USDA and its new agency, the SCS. He had high professional regard for Interior Secretary Harold Ickes and credited Ickes for much of the rapid progress of the SES. In addition, the SCS was not received warmly by sister agencies in the USDA. However, Bennett and his colleagues had strong agricultural constituents in farmers and they enjoyed close relations with members of Congress, many of whom were from agricultural areas.

Bennett was disturbed with the slowness of getting conservation on the ground. After two years of work, the SCS reported the completion of less than one million acres of treated land. One reason for the slow progress, thought Bennett, was the lack of involvement of farmers in the nationwide program. Out of this need for farmer participation came the idea of soil conservation districts, an idea credited primarily to Hugh Bennett. He modestly gave credit to others but he stated on many occasions: "I consider the soil conservation districts movement one of the most important developments in the whole history of agriculture. It has proved even more effective, I am convinced, than we had dared to expect."

Nearly a year of technical and legal work was required to develop an appropriate document to implement the concept of conservation districts. The completed document was called *A Standard State Soil Conservation Districts Law.* After much review, President Roosevelt sent a letter in February 1937 to all the state governors, enclosing the standard enabling act and recommending that each state adopt such a law as part of an effective national effort to conserve the soil. A total of 22 states had enacted the district enabling law by the end of 1937. The formation of local districts began immediately, starting usually with a local petition signed by 25 residents and a referendum election that established the district's boundaries. It was most fitting that the first conservation district in the nation, the Brown Creek Soil Conservation District, was established in Hugh Bennett's home county, Anson County, North Carolina, in August 1937.

Hugh Bennett officially concluded his career of distinguished public service on April 30, 1952, when he retired from the SCS. He died on July 7, 1960, after a long battle with cancer.

Epilogue

Hugh Hammond Bennett was a special man for a special time in history. However one wishes to explain it—be it divine appointment, planetary alignment, or extraordinary insight of the individual himself, the timing of Hugh Bennett's presence on the world stage was perfect. A major task at a critical time in America's history needed to be accomplished, and he was uniquely qualified as the man for the task.

Upon reviewing his career, which took many turns and produced many achievements, one can see how each stage of his life prepared him for the next. His boyhood life on a cotton plantation in North Carolina instilled in him the qualities of thrift, hard work, stamina, endurance, love, respect, and gratitude. All of these qualities would benefit him at one time or another in his dealings with people and in managing programs. His scientific training and experience provided a solid foundation for soil erosion research and interaction with scientists. His soil survey experience provided him an understanding of the soils of the U.S. unmatched by anyone else of his time.

Also, through his soil survey experience, he developed strong professional associations with soil scientists and endearing personal friendships with people all across the land. These personal and professional relationships stood him in good stead as he assumed leadership responsibilities in the government. Even the cooling-off assignments to distant lands served to strengthen his scientific credibility and extend his interpersonal ties across political and cultural lines. All of these experiences equipped him for his finest hour, namely, his courageous response to one of the worst crises in American history, the Dust Bowl and all its concomitant human misery and distress.

A man of the soil, Hugh Bennett left a rich legacy for all who follow in the soil science profession. He left an enviable publication record: five books; more than 400 technical, semi-popular and popular papers; hundreds of soil survey reports, magazine articles and miscellaneous materials not officially totaled by the USDA. It is estimated that Bennett's signed production exceeds 1,000 items.

He struck out many times. He continued to call soil erosion a national menace in the face of official rebuffs. He risked the laughs and the jeers of the academic intelligentsia. He reached his 30th, 40th, and even 47th birthdays before any influential scientists would take him seriously. Although Hugh Bennett received many scars, none of them ever dampened his sense of humor, his sense of humanity, or his sense of scientific simplicity.

Hugh Hammond Bennett was many things—visionary, scholar, strategist, politician, tactician, realist, prophet, naturalist, to name a few. He had the uncanny ability to wear the right hat for the right issue at the right time. He was a man who loved the land, but who loved mankind even more. He was a man's man! A tribute by Louis Bromfield, a well-known conservationist and Bennett contemporary, sums it up well: "Hugh Bennett deserves the greatest honor from the American people as one of the greatest benefactors since the beginning of their history."

Micronutrient Research in North Carolina

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The micronutrient research covered in this essay is that concerning soil fertility and plant nutrition. These nutrients, once called minor or trace elements, are copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), which occur as cations in the soil; and boron (B) and molybdenum (Mo), which occur in anionic form. Chlorine (Cl), another micronutrient, has never been a problem for crop production, other than excesses being detrimental to tobacco quality, and will not be discussed. Also, other research has been conducted on Fe and Mn in soil genesis and morphology, especially by students of S. W. Buol, that will not be covered in this presentation. The following is a chronology of research by micronutrient. Specific citations are not given in the text, but a list of references is appended for the reader's reference.

Manganese

L. G. Willis, who was with the Agronomy Department from 1925 to 1945, was a soil chemist with an interest in micronutrients. In 1928, he reported manganese deficiencies in oats and soybeans, primarily in spots in the coastal plain. He associated this problem with very high soil pH, and thus this observation was likely the first evidence of "overliming." Although overliming is still noticed today, it may have been more prevalent then as lime was first spread by hand from wagons or piles, and the highest pH was always closest to the spot from which it was spread.

In the late 1950s and through the 1960s, there were a number of investigations on manganese. Adolf Mehlich added some detail on the effect of pH on lime-induced manganese deficiencies. Dr. Mehlich was in the Agronomy Department working in soil chemistry from 1938 to 1970, and in 1953, developed the Mehlich-1 extractant. This extractant has been called the "North Carolina extractant" and the "double acid extractant," and its original publication was by Nelson, Mehlich, and Winters.

During this period, Sanchez and Kamprath also looked at the effects of lime and organic matter on manganese availability. W. L. Rivenbark conducted some excellent soil chemistry research on rates and mechanisms of manganese retention and release in soils.

Also in this period, F. R. Cox worked on a soil test interpretation for manganese. The Soil Testing Division, North Carolina Department of Agriculture (NCDA) would, on request, determine manganese in the Mehlich-1 extract at that time. In 1968, Cox used both extractable manganese and soil pH and developed a yield response prediction and manganese soil test interpretation for soybeans. The yield response prediction was later transformed into an "availability index" by NCDA, and manganese levels have been measured and interpreted routinely since.

In the 1980s, H. J. "Rick" Mascagni conducted a host of field studies on manganese in corn and soybean. He reported on sources of materials, rates of fertilization, plant response, residual effects, and soil test interpretation. His work provides the latest calibration of a manganese availability index, which included both manganese concentration in the soil and soil pH, for the current extractants. At this time the Mehlich-3 extractant was in use, and Rick's work with manganese was the first direct calibration work for that extractant.

Also during the 1980s, work by G. S. Miner showed how the acidifying effect of starter fertilizer could affect manganese uptake in corn and tobacco. The only recent work on manganese has been that by Mikkelsen who used hydrophilic polymers to improve uptake of manganese.

Manganese has been the most extensively studied micronutrient for several reasons. The soils in the coastal plain are inherently low in manganese, especially the more poorly drained ones, since manganese can be reduced and leached in the soil-forming process. Interveinal chlorosis is a clear symptom of manganese deficiency, and its association with overliming shows a strong association with or dependency on pH. Extractable concentrations at the critical level, which varied from 3 to 9 with Mehlich-1 depending on pH, were sufficient to be measured readily. For these reasons, considerable knowledge has been accumulated on soil reactions, rates of application, sources of materials, residual effects, and soil test interpretation for manganese.

Copper

In 1930, when also serving as department head and vice-director of the experiment station, C. B. Williams noted that crops grown on muck soils often responded to copper application. This observation was researched in detail by L. G. Willis who moved his laboratory from the university campus to the research station at Castle Hayne in 1935 to be near the problem. Much of his research centered on the aspect that copper may be a catalyst in oxidation-reduction processes in soils.

Work continued on copper in the 1950s. J. T. Pesek studied the equilibria of copper with various soil colloids and evaluated the results with plant uptake. P. C. Butler determined the complexing of a number of heavy metals, including copper, by organic matter.

In the early 1960s, there was a resurgence of work on copper that included field evaluation. R. P. Patterson evaluated the response of wheat and soybeans to copper on high organic soils, and R. E. Hanes found copper responses on mineral soils as well. S. E. Younts reported on this work and established the rates of copper recommended on soils varying in organic matter for the recommendations that exist today. In the late 1960s, D. W. Eaddy, who later became the Director of the NCDA Agronomic Division, included copper absorption when studying the relation between drainage class and certain chemical properties of organic matter.

It has been difficult to analyze for copper by routine soil testing methods because of such low concentrations extracted. Adolf Mehlich, who later worked with the NCDA Agronomic Division, developed a hydrochloric acid extractant especially for copper in 1975. Later, in 1984, he added a complexing agent to an acetate-based solution to create the Mehlich-3 extractant, a more universal extractant. Although concentrations of copper were still very low, analyses were now more accurate in the Agronomic Division because of better glassware cleansing with an aluminum chloride solution, another of Dr. Mehlich's contributions.

Makarim evaluated the need for copper with several soil extractants, including the Mehlich 3, in 1983, and his work provided the background for the establishment of the current critical levels and soil test interpretation for copper. His work at that time did not include the Modified Olsen, which is a more universal extractant than Mehlich 3 in that it may be used on high pH soils. In 1988, Rohman determined copper, manganese, and zinc critical levels with the Modified Olsen extractant.

Although progress has been made in most aspects of copper nutrition and its role in the fertility of soils, the concentration extracted is still extremely low. Its critical value has been placed at only 0.5 mg/dm^3, so the accuracy of copper analysis in the extractant is quite variable.

Boron

J. R. Piland, who was with the Department from 1929 to 1968 and was also the first person in charge of the Service Laboratory for the College of Agriculture, was best known for his work with boron. In 1937, he reported how borax improves the seed set of alfalfa. He worked with a number of legumes and reported on his work in the mid-1940s.

Piland's research is responsible for the boron recommendation on alfalfa that continues today, but it also set the stage for further work by C. M. Wilson and A. C. McLung about 1950 on response to boron and on born behavior in soil. In the mid-1950s, T. B. Hutcheson, advised by W. G. Woltz, reported on boron fertilization of flue-cured tobacco, and A. C. McLung reported on boron in relation to foliar and fruiting abnormality of peach.

Further work was done on boron in the mid-1960s, too. F. R. Cox found one form of concealed damage in peanuts, "hollow heart," related to a lack of boron. Boron, a highly mobile anion, is not evaluated in the soil testing process, but Cox's work led to a general recommendation for boron on peanuts.

E. W. Stoller evaluated the possible role of boron in nucleic acid metabolism in peanut. J. F. Luke studied the effects of high rates of boron in the field, one of the first studies on a potential toxic effect for a micronutrient. In the late 1960s, Zeiger and Shelton reported on internal bark necrosis, a symptom of manganese toxicity in apples, and recently Miner evaluated several sources of boron for cotton and soybean.

Zinc

In 1977, a regional study on diagnosis and correction of zinc deficiency chaired by F. R. Cox was published as Southern Cooperative Series Bulletin 222. This reference provides a comprehensive account of the status of zinc in the soils of the Southeast and serves as a primary reference for zinc soil test evaluation, fertilization, and residual effects for North Carolina. This work—as well as others by Edwards, Junus, Lins, Borkert, and Cox—showed the dependence of zinc availability on soil pH.

The effect pH on zinc availability is not as striking as with manganese, but it is still a factor to be considered in the soil test evaluation. Even though the effect has not been quantified in detail, it is being accounted for in the zinc soil test interpretation given by the Agronomic Division. The Division changes the critical level for each soil class—mineral, mineral-organic and organic—as the optimum pH for each class differs.

Zinc deficiencies were noted early by Willis but have never been a severe problem in the state. Symptoms occur primarily in corn grown after another crop and are not as severe in crops grown after corn. Therefore, locating sites and conducting zinc research difficult.

Molybdenum

There has been little research reported on molybdenum in North Carolina, but in the late 1970s and early 1980s, two papers by Karimian evaluated the extractability of molybdenum and a means to predict molybdenum availability. Routine soil test extractants do not remove sufficient molybdenum for analysis, so an oxalate extraction, as for amorphous aluminum and iron, was used. The status of aluminum and iron, and notably the pH, gave an indication of availability. Legumes grown on soils that need lime are now known to be likely to respond to molybdenum.

Physiological studies

In the mid- and late-1950s, micronutrient research centered on plant nutrition was conducted. M. E. Harward and his student, D. P. Moore looked at some of the interactions of aluminum, iron and manganese and those of copper, iron and molybdenum. This started a plant nutrition focus in soil science research that continues today.

There were a number of plant physiology papers on micronutrients in the 1970s. Edwards and Kamprath evaluated zinc accumulation by corn as affected by temperature and light. The effect of temperature on manganese accumulation was studied both by Rufty with tobacco and Ghazali with soybean. Cox summarized some of these effects in Southern Cooperative Series Bulletin 281.

Heavy metal toxicities

In the 1980s, L. D. King had a number of papers on the heavy metal content of municipal and industrial sewage sludge and swine manure lagoon sludge. Some of these materials are quite high in copper and zinc and cause a buildup of the elements in the soil, increasing the threat of toxicity. His student L. M. Hajjar studied the residual effect of sewage sludge on metal content of tobacco and peanut. The several reports by King during this period gave a foundation for later studies on micronutrient accumulation and potential toxicity to the environment.

Research in the 1990s has continued to center on the environmental threat of toxic levels of micronutrients. Fontes published several papers on physiological effects of zinc toxicity and reported a unique symptom of zinc toxicity in soybean. Borkert evaluated the effects of high concentrations of both zinc and copper; he also evaluated a range in pH on several crops grown in the greenhouse. Miner looked at soil factors affecting plant concentrations of these elements in sludge-amended soils. When concentrations of heavy metals are high, knowledge of their solubility becomes important. Hesterberg modeled this chemistry for copper and zinc.

Summary

These are some of the highlights of micronutrient research that have occurred over the last 70 years. In this period, we have not only gained a lot of knowledge on the subject but also applied it to the betterment of agriculture and our environment in general. North Carolina has indeed been a leader in micronutrient research.

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Soils and Forests in North Carolina

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In North America until about 1900, forests were not considered scarce, and thus, the study of forest soils was very limited. At the turn of the century, Carl Alwin Schenck, at the Biltmore Forest School near Asheville, was concerned about severe soil erosion in the Southeast. He investigated the feasibility of halting erosion by reforesting abandoned farm land with appropriate tree species on different soils.

The first major effort to learn about forest soils and their management came following World War I. An enormous amount of timber had been harvested to support the war effort. This was done in haste and the stripped land left bare. Starting in about 1920, there were studies of these soils with the intention of repairing the damage that had been done. This work was slow in getting started, but in 1933, the combination of the Great Depression and the Dust Bowl of middle America, resulted in President Roosevelt establishing the Civilian Conservation Corps (CCC).

Many forest conservation projects were undertaken across the nation and a need for much information on forest soils was evident. Forest soils research received much emphasis at that time. During World War II, massive cutting of forests was repeated. Following the war, the need for information on forest soils again became evident.

Through the 1930s and 1940s, centers for teaching and research in forest soils were limited mostly to Duke University, the University of Wisconsin, and Yale University. Limited work was also underway at other institutions, such as the Black Rock Forest, Cornell University, and at The Harvard Forest. Also, the U.S. Forest Service had some work ongoing at most of its regional research centers, including especially the Southeastern Forest Research Station in Asheville and the Coweeta Hydrologic Laboratory in Otto, N.C.

The Biltmore Forest School operated from 1898 until 1913, when Dr. Schenck returned to Germany. From then until 1929, there was no formal forestry education in North Carolina. In 1929, Dr. Julian V. Hofmann established what is now known as the College of Forest Resources as a Division within the College of Agriculture, at North Carolina State University. A separate School of Forestry was established in 1949. The first position funded to specifically teach and do research in forest soils was established in the Department of Soil Science in 1962. From the initiation, this position was jointly appointed in both Soil Science and the Department of Forestry.

Beginning in the 1950s, forest soils became a much larger focus in research and teaching. Numerous universities, federal and state agencies, and several forest industries got involved in relating forest growth to soil properties. In 1952, T. S. Coile of Duke University, published a monograph entitled *Soil and the Growth of Forests* (Advances in Agronomy 4: 329–98).

Over the years, subjects of emphasis have changed. This evolution of emphases is best seen in the proceedings of the North American Forest Soils Conferences (NAFSC). Dr. Charles Kellogg, keynote speaker at the first conference in 1958, stressed the importance of multiple use of forest soils, soil management in relation to forest productivity, soil engineering applications in forestry, land use patterns, and soil classification and mapping in forest environments. The second conference stressed soil survey of forest lands. The third conference, held in North Carolina in 1968, emphasized soil biology, tree roots, and forest fertilization. Operational fertilization was obviously coming of age because in that same year, the Tennessee Valley Authority published a book on the theory and practice of forest fertilization.

Subsequent conferences have stressed land classification and land-use planning, geology and landscape stability as related to forest management activities, acid rain and its impacts on forest ecosystems, recovery of mined lands, and soils information needed for intensive forest management. The more recent conferences have stressed sustainable forest productivity and economics of forest soil management, carbon forms and functions in forest soils, humus forms and their relation to soil management, forest health, and microbial ecology in forest soils, especially the study of mycorrhizae.

Because forests are expected to serve the multiple uses of wood production, recreation, range, wildlife habitat, and watershed protection, the soil that supports these forests must also serve many purposes. All of these functions have been subjects of teaching and research in North Carolina. As the century ends, the major emphases in North Carolina are on tree nutrition (forest fertilization on an operational basis); the forms and functions of mycorrhizae on tree roots; nitrogen dynamics, fixation, and transformation in forest soil; wetlands restoration and management; hydrology and watershed management; and forest ecology, especially as influenced by atmospheric inputs. As history will show, North Carolina has had a pivotal role in forest soil science for the entire century. The natural occupation of North Carolina lands is the growth of trees. Even in our present highly developed condition, two-thirds of the land of the State of North Carolina is forested.

Nutrients in North Carolina Soils and Waters

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Both surface and subsurface drainage waters from all land contain some nutrients. These nutrients are necessary for life in surface waters but can become a problem when they are present in excessive amounts. The nutrients of most concern with regard to water quality are nitrogen and phosphorus in surface water and nitrate nitrogen in ground water.

North Carolina soils were originally low in both nitrogen and phosphorus so these nutrients had to be added to soils to grow a good field crop or lawn. The addition of these nutrients to soils for increased plant growth increases their concentration in the water that drains from the land and increases the nitrate concentration in the shallow groundwater below most fields. This is accepted as scientific fact now, and modern soil textbooks contain a discussion of factors controlling losses of both nitrogen and phosphorus to water from soils. However, this was not the situation in the late 1960s when the first research designed primarily for water quality purposes was conducted in the Soils Department at North Carolina State University (NCSU).

In 1968, Ralph McCracken, who was then Department Head of Soil Science, suggested that research on effects of fertilizer usage on water quality was needed. The director of the newly initiated Water Resources Research, Dr. Howells, and others were making “unfounded” statements that agricultural fertilizers were causing water quality problems. The Tennessee Valley Authority (TVA) and NCSU had paired watersheds in western North Carolina that could be used for a joint research project.

I intended to run the one experiment to show that Dr. Howells was wrong in his statements about fertilizers. However, the research did not fit my preconceived ideas, and it showed that addition of fertilizer nitrogen to grazed bluegrass pastures in the North Carolina mountains did result in a very significant increase in nitrogen in the runoff water. When the experiment was completed and the results ready for publication in a scientific journal, I was shocked to learn that TVA did not want the information published because of the effect it might have on fertilizer sales. It is interesting to note 30 years later that TVA’s research program is totally for environmental protection.

During the past 30 years, water quality research in the Soils Department at NCSU has increased from part time for one faculty member to the largest single area of endeavor. We now understand most of the factors controlling losses of nutrients from soils and have developed many best management practices (BMPs) to minimize their losses and maintain the quality of the receiving waters.

Nitrogen

Because nitrogen in fertilizers and animal waste is present in very water-soluble inorganic forms or is converted to these forms when added to soils, the nitrogen moves into the soil with rain or when applied as irrigation from a lagoon. Because of its solubility and tendency to move into the soil with the first rainfall, only small amounts of inorganic nitrogen are usually present in surface runoff water. The inorganic nitrogen in the soil can be utilized by plants, move vertically to ground water, move laterally toward surface waters or be converted to a gas under special conditions. Nitrogen normally does not accumulate in North Carolina surface soils that are sufficiently well drained to for crop production.

The efficiency of utilization of nitrogen fertilizers by grain crops is about 50 percent: that is, a little over half of the fertilizer nitrogen added to crops is ultimately harvested with the crop. Up to 80 percent of the applied nitrogen may be harvested in forage crops used for hay. However, with forage crops that are grazed, the percentage of nitrogen harvested is much lower than that harvested by grain crops.

If fertilizers are added in excess of recommended rates, the utilization efficiency decreases. It should be understood that productive agricultural systems tend to be very leaky with regard to nitrogen even when the best management practices known are utilized. It is sometimes difficult for producers to understand that even if they follow all of the recommendations of the Cooperative Extension Service or the Natural Resources Conservation Service and have a good crop year, there will still be a significant amount of fertilizer nitrogen that can get into the shallow groundwater.

It has also been difficult to convince strong proponents of conservation tillage that this very good BMP for reducing sediment and phosphorus losses has very little effect on reducing nitrogen losses. The only way that conservation tillage reduces nitrogen losses to water is for it to increase yields, which increases the amount of nitrogen harvested with the crop. Research here by Wagger and his students has generally shown no effect of conservation tillage on yields in the coastal plain.

The unharvested nitrogen applied as fertilizer generally moves with the water to the shallow ground water. Thus the nitrate-nitrogen concentration in the shallow groundwater below most agricultural fields fertilized according to agronomic recommendations is 10 to 20 milligrams per liter. The World Health Organization states that 10 milligrams per liter is maximum for drinking water.

When fertilizer applications exceed the recommended rates, nitrogen concentrations in shallow groundwater increase proportionately. Under North Carolina's climatic conditions, a general guide for estimating the nitrate concentration in shallow groundwater under land receiving fertilizers is that "there will be 1 milligram per liter of nitrate-nitrogen for every two pounds of nitrogen not harvested by the crop."

North Carolina is fortunate to have soils that have a clay layer at 10-30 feet below a large percentage of the fields in the coastal plain, which is the area receiving the highest applications of nitrogen fertilizer. This clay layer prevents the nitrate in the shallow groundwater from moving into the deeper aquifers where most drinking wells are located.

Most of the nitrate present in the shallow groundwater is transported via lateral flow to streams protected by riparian buffers. We have sampled below many fields where the shallow groundwater contained more than the drinking water standard for nitrate but have never found more than 1-2 milligrams of nitrate nitrogen in water below a significant aquatard (clay layer nearly impermeable to water). This is the reason that North Carolina has some surface water quality problems but few drinking water wells contaminated with nitrate.

Phosphorus

It has been historically stated by soil scientists that phosphorus does not leach except in very sandy or organic soils because of the chemical interactions between phosphorus and clay minerals. Thus, phosphorus applied to the soil as fertilizer tends to stay in the topsoil and not be lost to either surface or subsurface drainage waters. Large applications of phosphorus to soils tend to accumulate in the topsoil.

The large majority of nonpoint-source phosphorus lost to surface waters is attached to eroded soil particles. However, even small amounts of soluble phosphorus lost in runoff can contribute to problems in the receiving waters. Data collected over the past two decades show that the higher the concentration of phosphorus in the topsoil, the larger the amount of phosphorus lost via surface runoff. Until recently, we have not been concerned with phosphorus losses through leaching and lateral flows.

In recent years, the concentration of farm animals in large production units has caused large amounts of animal waste to be at one location. This has resulted in land applications of animal waste near the maximum rate governed by the limiting nutrient. Historically nitrogen has been the limiting nutrient so animal waste has been applied to the land using the maximum rate of nitrogen allowable. Applications of both swine and poultry wastes have resulted in more phosphorus being applied than is needed for agronomic purposes.

The high concentrations of phosphorus present in soils that have received animal waste applications for many years have resulted in widespread environmental concern because the limiting nutrient for eutrophication in most fresh water is phosphorus. There is concern not only that more phosphorus will be lost via surface runoff but also that it will move through subsurface drainage systems to surface waters. This problem has really been of concern in the Delaware–Maryland eastern shore area where the soils are very sandy and there are very high concentrations of poultry. These two states and several others are in the process of making regulations for application of animal waste based upon phosphorus as the limiting nutrient.

Recent research by Ham, a graduate student in the Soil Science department at NCSU, has shown that some sandy soils that have received animal waste for many years have significant increases of phosphorus to a depth of 4–5 feet. We have no indication that this phosphorus is moving laterally to streams, but there are questions as to how much phosphorus can be added to soils before this kind of movement becomes significant. As of this date, North Carolina soil scientists have not determined a recommended level of soil phosphorus on which waste applications should be based.

Value of Riparian or Planted Vegetative Buffers

A prominent feature of most North Carolina landscapes is the forested area present as narrow bands on either side of small streams. These forested areas (riparian buffers) are usually present because they were either too wet or too steep to conveniently clear for agricultural crops or urban development.

Riparian areas are extremely important for water quality protection in North Carolina. Nitrogen from nonpoint sources most often enters streams through subsurface flow of nitrate from agricultural fields. When the subsurface flow passes below a wooded riparian area, greater than 90 percent of the nitrate is frequently removed from the water before it enters streams.

In North Carolina, data show that drainage water from agricultural fields containing 10–20 milligrams per liter of nitrate nitrogen contains less than 1 milligram per liter when it enters the stream because of nitrate removal by riparian buffers. The removal is largely the result of a process called denitrification that occurs in wet soils containing organic matter—just the kind of conditions one finds next to streams. Denitrification converts the nitrate, which can contaminate surface and ground water, to a harmless dinitrogen gas that already makes up 80 percent of the air.

Since we do not know how to grow crops with sufficiently high yields to feed our population without loss of nitrate to groundwater, it is important that we take measures to prevent this nitrate from reaching surface waters where it may cause eutrophication problems. One of the best methods of preventing the nitrate from reaching streams is riparian buffers. Scientists and water quality regulators are currently searching for reasonable buffer requirements in North Carolina to achieve water quality goals. It is clear that buffers are a reasonable choice in many locations, but many questions about ideal width, location, etc. are unanswerable at this time.

Riparian buffers are also very effective in controlling sediment and pollutants associated with the sediment. Removals of greater than 90 percent are common. However, it is important that flow into the buffer approach not be in a channel because little sediment is removed from water flowing in a channel through the buffer. Riparian buffers are not as effective for phosphorus removal from surface runoff as they are for sediment, but average phosphorus removals of 50 percent can be expected from well-maintained buffers.

It is my opinion that riparian buffers are the single most important factor controlling nonpoint source pollution in North Carolina. If most of the drainage water from agricultural fields in the piedmont and middle and upper coastal plain did not flow through riparian buffers, the water quality in our streams would be much lower.

Controlled Drainage

In the Tidewater area of North Carolina, controlled drainage replaces natural riparian buffers as the management practice that can best be utilized to minimize nitrogen and phosphorus losses from agricultural fields to surface waters. This practice can reduce nitrogen losses to water by 50 percent. On approximately 300,000 acres of North Carolina cropland, controlled drainage is used as an approved BMP.

Use of controlled drainage as a BMP is reducing the entry of nitrogen into North Carolina surface waters by about 3,000,000 pounds annually. The practice is well liked by farmers because it increases corn and soybean yields by about 10 percent. Thus farmers can use the practice to improve the quality of water leaving their farm while increasing their profits.

In areas where controlled drainage has been recommended and been accepted by the agricultural community, the slope of the land is less than 0.5 percent. It is probable that controlled drainage can be used to improve quality of agricultural drainage water in areas where the land slopes are larger. However, the cost of using controlled drainage in these areas would be greater per unit area of land, and yield benefits to the farmer would be less or nonexistent. These circumstances do not rule out the possibility that controlled drainage might still be a BMP of choice in some areas where it has not been routinely recommended.

Soil Acidity and Liming

by Eugene J. Kamprath
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Surface horizons and most subsoils in North Carolina are inherently acid. The rocks and minerals from which the soils are formed contain relatively low amounts of calcium (Ca) and magnesium (Mg). The soils have a low capacity to retain cations and since rainfall in the state exceeds evapotranspiration, Ca and Mg tend to be leached from the soil. In their natural state most North Carolina soils have pH values less than 5. Thus unless soils are limed crop growth is quite limited.

When the first settlers came to North Carolina, forests covered the land. Pine was the predominant species in the coastal plain while oak and hickory were the principal trees in the piedmont. Slash-and-burn was the procedure used to clear the land. This practice added Ca and Mg to the soil in the form of oxides that neutralized acidity and raised the pH of the surface soil. The ash also contained other recycled nutrients. The liming and nutrient effect lasted several years after which time the cleared area was abandoned and a new area cut and burned. For many years this was repeated throughout North Carolina as a means of overcoming soil acidity and adding nutrients in the surface horizons.

As agriculture production became more intensive, farmers started using lime. Along coastal areas there were shell deposits which were burnt to form calcium oxides and then applied to the soil. Marl deposits in the eastern part of the coastal plain also were a source of lime. Farmers observed that where burnt shells and marl were applied crop growth improved.

Initial research on liming by the North Carolina Agricultural Experiment Station was limited primarily to field studies. These studies showed that application of lime and animal manures increased yields. Since soil acidity was a primary factor limiting crop growth in North Carolina, basic research on soil acidity and liming was started in the late 1930s and early 1940s. Data from the Midwest indicated that the ideal pH for crop production was 7, which gave a base saturation of 80 percent for these soils with montmorillonitic (2:1) clays. Soils in North Carolina, however, had mostly kaolinitic (1:1) clays and the question was whether the results from the Midwest applied to North Carolina soils.

The relationship between pH and percent base saturation was studied for pure clay systems and North Carolina soils representative of 1:1 and 2:1 clays. A much higher base saturation was required to raise the pH to 6 with montmorillonite than with kaolinite.

White Store soils (fine, mixed, thermic Vertic Hapludults), representative of soils with 2:1 clays, had to be 80 percent base saturated to give the same pH as the Durham soils (fine, loamy, siliceous thermic Typic Hapludult) (1:1) clays at 40 percent base saturation as determined by the sum of cations, pH 8.2 CEC method (Table 1).

Table 1. Soil pH and percent base saturation for soils with different clay mineralogy (*Mehlich and Cowell, 1943*)

Soil	Type of Clay	% Base Saturation[1] (1:1 H_2O)	Soil pH
Durham	Kaolinitic (1:1)	40	6.0
White Store	Montmorillonitic (2:1)	80	6.0

[1] Base saturation is of CEC pH 8.2

Growth of cotton and soybeans was maximum at 40 percent base saturation on the Durham soil and 80 percent base saturation on the White Store. Calcium was held much stronger by the montmorilloni-tic clay than by the kaolinitic clay and for this reason a much higher base saturation was required in order to supply adequate Ca in soils with 2:1 clays. Laboratory and greenhouse studies also showed that organic soils (Histosols) only needed to be 40 percent base saturated for optimum growth. The research dealing with pH and percent base saturation established that for mineral soils in North Carolina the lime recommendation was based on adjusting the pH (1:1 H_2O) to 6.

In the early 1950s researchers challenged the idea that acid soils contained exchangeable hydrogen. Soil chemists had developed the concept that acid soils behaved similar to weak acids rather than strong acids. This, however, raised questions as to whether acid soils actually contained exchangeable H^+. Soil scientists at NCSU had a major effort in this research which established that acid soils contained exchangeable aluminum (Al^{3+}) rather than exchangeable H^+.

It was found that when H^+ was added to soil the aluminum silicates clays decomposed releasing aluminum which went on the cation exchange site of the clay. The acid reaction of the soil as measured by pH was due to hydrolysis of the Al ions in the soil solution which formed H^+ ions. This is illustrated by the reaction Al^{3+} + HOH ® $AlOH^{2+}$ + H^+. It was now established that acid soils have exchangeable Al on exchange sites and that a major cause of poor growth in acid soils is due to aluminum toxicity.

Another major finding was that the CEC of Ultisols and Oxisols was pH dependent. The CEC of soils with Fe-oxide-coated clays and 2:1 clays with hydroxy Al interlayers increases as the pH increases. The OH^- ions associated with Fe and Al hydrous oxides and interlayer hydroxy Al release H ions as the pH increases and a negative charge develops.

Therefore, in Ultisols and Oxisols, the CEC of the soil is not constant but is variable depending upon the soil pH. Thus measurement of CEC at pH 8.2 did not reflect the chemical environment that roots encountered in our Ultisols. The effective CEC (ECEC) of these soils has been defined as the sum of the exchangeable Ca, Mg, K and the exchangeable Al extracted with an unbuffered salt solution such as KCl. The amount of Al in the soil solution is related to the percent Al saturation of the effective CEC.

When 60 percent or more of the effective CEC is occupied by exchangeable Al, there is a very sharp increase in the Al concentration of the soil solution (Table 2). A marked decrease in plant growth results.

Table 2. The exchangeable cations, ECEC, Al saturation of a Norfolk fine-loamy (siliceous, thermic Typic Kandiudults) soil at various pH values (Kamprath 1970)

Soil pH	— meq / 100 g Al	Exchangeable — Ca + Mg + K	ECEC 100 meq / 100 g	% Aluminum Saturation
		0.20	1.11	82
		0.55	1.15	27
		1.20	1.37	13
		1.50	1.70	6

$$\frac{Al^{+3}}{(Al^{+3} + Ca^{+2} + Mg^{+2} + K^{+})} \times 100$$

Mineral soils with variable charge mineralogy are 100 percent base saturated at pH 5.8 to 6. However, organic soils above pH 5 were found to have very little aluminum in the soil solution and essentially have their active exchange sites essentially occupied by basic cations. Organic matter holds Al quite strongly and liming organic soils to pH 5 reduces Al in the soil solution to very low concentrations. At pH 5 organic soils contain adequate Ca to overcome the H ion effect on cation uptake.

The knowledge that acid soils contain exchangeable Al brought about a new concept for making lime recommendations. The concept was to apply the amount of lime required to neutralize the Al that was extractable with a neutral unbuffered solution such as KCl. The amount of lime required to neutralize the exchangeable Al is given by the following equation.

$$\text{tons } CaCO_3 \text{ per acre} = 2 \text{ (meq Al per 100 grams of soil)}$$

The factor of 2 takes into account the pH-dependent charge of the soils, which results in a portion of the nonexchangeable acidity being ionized as the pH increases and reacting with the added lime.

The procedure for measuring exchangeable Al^{+3} is not well suited for routine soil testing procedure. For this reason a buffer solution pH 6.6 is used to measure extractable acidity (Ac) in North Carolina soils. The buffered solution extracts both exchangeable Al^{3+} and the pH dependent acidity (H^+) which becomes ionized up to pH 6.6. The lime rate to apply is calculated with the following equation.

$$\text{tons } CaCO_3 \text{ / acre} = \text{Ac} \left[(\text{desired pH} - \text{soil pH}) / (6.6 - \text{soil pH}) \right]$$

The desired pH for a soil is the pH at which the activity of Al^{+3} is neutralized. The effect of soil organic matter in decreasing the activity of Al^{+3} has been taken into account by establishing desired pH for each of three classes of soils (mineral, mineral-organic and organic) based on their organic matter content. The desired pH at which exchangeable Al^{+3} is essentially neutralized is 6 for mineral soils, 5.5 for mineral-organic soils, and 5 for organic soils.

Many years of high-input management, including liming, of Ultisols in North Carolina has improved the chemical properties of the subsoil. Increases in exchangeable Ca^{2+} and corresponding decreases in exchangeable Al^{3+} have created a favorable environment for root growth in the subsoil. This has resulted in utilization of subsoil moisture and reduced the detrimental effects of short-term moisture stress.

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The Early History of Soil Survey in North Carolina[1]

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This brief compilation of data and personal insights on the history of soil survey in North Carolina was prepared by Professor William D. Lee, whose career as a soil scientist spanned over 50 years. W. D. "Bill" Lee was involved in soil survey and related classification and land use projects in North Carolina and five other states during the period 1920 to 1934. From 1934 to 1936, he was in charge of soil conservation surveys in North Carolina for the Soil Conservation Service and during the period from 1940 to 1956, he was in charge of the North Carolina soil survey program with North Carolina State University. In 1955, he authored a technical bulletin entitled *The Soils of North Carolina — Their Formation, Identification and Use*. This publication has served as the main source of soil geographic and classification information for nearly 30 years. He has maintained his contact with fellow soil scientists through his continued involvement in the Soil Science Society of North Carolina and participation in the State High School Land Judging contests.

When the Soil Science Society of North Carolina learned that Professor Lee had prepared this history of soil survey, it strongly voiced its support for a publication that would share these memories and insights with all soil scientists. The Society is proud to play a role in preserving these historical highlights as shared by W. D. Lee.

The discipline of Soil Science in general and more specifically the field of soil survey and classification owes a great debt to the dedication and just plain hard work of early soil scientists like William D. Lee. Their efforts and accomplishments required considerable personal hardship and sacrifice, but their zeal for understanding and inventorying our valuable soil resources was not to be denied. Much has been accomplished and many changes have occurred in soil classification and soil science since the early fifties, but we can always learn a great deal and renew our dedication by listening to those who blazed the trails before us. We thank you, Professor Lee, for sharing these memories.

—H. J. Kleiss, editor
Soil Science Society of North Carolina

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[1] This article is a reprint of the original paper: Lee WD. 1984. The early history of soil survey in North Carolina. Raleigh (NC): Soil Science Society of North Carolina. 28 p.

Background

Soil Survey—by the first definition recorded in the 1900 report of the United States Bureau of Soils—is the systematic classification and mapping of soils. Soil Survey in North Carolina was initiated in 1900 in cooperation with the State Board of Agriculture (later the State Department of Agriculture). Thus, this state became one of the first six states to make an orderly arrangement of its soils on the basis of their characteristics. The purpose of a soil survey, as stated more fully by Prof. Milton Whitney, Chief of the Division of Soils, United States Department of Agriculture (USDA), in an early report, also 1900, was: "to construct maps in the field showing the area and distribution of the soil types; to explain as fully as possible from geological considerations the origin of the soil, and to have the soil chemist and physicist study the differences in the soil types." [2]

Whitney, a chemist himself, recognized that "chemical and physical properties of the soil are so complex and difficult that it may take many years to explain them through laboratory investigations, but pending this complete investigation, the maps themselves will be of the utmost value to the agriculturists in indicating the areas over which certain soil conditions are found to prevail . . . climate has much to do with the relation of soils to crops . . . and that certain economic conditions, frequently local, have a controlling influence upon the relative crop values of a soil . . . also, the most pressing demands for a soil survey arise from a consideration of special problems." Among these are "the introduction and spread of new industries, the improvement in the development of different types of tobacco, of fruit production, truck growing, and other special crops; also, in the improvement of certain soil areas by the use of fertilizers, and by the introduction of underdrainage." The Division "cooperates with State experiment stations, State geological surveys, and State boards of agriculture to promote the interests of the work." It is worth noting that in his second annual report (1901), Prof. Whitney stated, "The purpose of a soil survey is to provide an accurate basis for the adaptation of soils to crops." What a prophet he was!

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[2] Prof. Milton Whitney on Feb. 15, 1894, became director of a Division of Agricultural Soils in the U.S. Weather Bureau of the Department of Agriculture. On July 1, 1895, this division became an independent unit, and in 1897 was designated as the Division of Soils. As of July 1, 1901, it became officially the Bureau of Soils by act of Congress. Prof. Whitney, and associates, while he was with the Maryland Agricultural Experiment Station has made extensive studies of the soils of Florida and elsewhere on the Atlantic seaboard; and of soils in the arid regions of the United States " . . . from which might be learned the extent and comparable physical and chemical character, climate relationships, and adaptation to crops and soils of the U.S. For years the Geological Survey had been mapping and studying economic minerals; so why should a survey of the soils upon which the economic life of the country is dependent be neglected? The soils would be mapped, studied, and described in reports for public distribution."

Realizing the deficiencies in training of his personnel, Prof. Whitney, in 1903, arranged with Cornell University for detailing Dr. J. A. Bonsteel to that institution as Professor of Soil Investigations. There, for two years, Dr. Bonsteel, representing the Bureau, developed a course in soil science and soil surveying. From Crisscross Trails (1949) by Macy H. Lapham, who was on active field service in the USDA Soil Survey 1899–1944, and correlator 1944–1949.

The history, progress and extent, and value of the soil survey in North Carolina from its beginning is definitely linked to the character of the base map upon which the several soil units were delineated. In addition, the quality of each soil survey reflects clearly the training and experience of the individuals conducting the survey. Thus, we may indicate these progressive states in the State.

Stage 1: 1900 to 1910

1. Base Maps. The only maps suitable as the basis for Soil Surveys were made by the United States Geological Survey (USGS), usually at a scale of one-inch-to-the-mile. Many of these maps were 15 to 25 years old, some quite out of date due to changes in roads, etc.

2. Soil Surveyors. The men conducting the surveys were geologists or chemists; none had training in Agronomy (soils and crops). Little detail was shown on the maps.

3. The Raleigh to New Bern Area. The first soil survey in North Carolina was begun in late April 1900. The area selected was along the line of the Southern and the Atlantic and N.C. Railways from Raleigh to New Bern, a distance of 105 miles. The territory surveyed was about 9 miles wide and contained approximately 1,000 square miles.

An "accurate map of the region along the railways had been completed by the USGS." The survey was to be used as a basis "for systematic investigation of the fertilizer requirements of different crops through a series of substations [then termed test farms] to be established [by the State Board of Agriculture] on some of the principal soil types." (There were two of these substations already in operation, one at Tarboro and the other at Red Springs, and "the soil on the farm at Tarboro was correlated with a similar type of the area surveyed.") The first surveyor in charge was William G. Smith, a USDA employee. Again, it is interesting to note that the scale of mapping would be one-inch-to-the-mile. "On this basis a square of 10 acres represents an area 1/8 inch square on the map, and is to be taken as the unit in soil mapping" (Whitney, USDA Report, 1901). Even though he had an "accurate base map already prepared in detail," it is remarkable that Surveyor Smith did not waste any time in the eight months he was surveying the 1,000 square mile area, because transportation facilities were poor or almost nonexistent. Travel was by any means available—foot, horse- or mule-back, cart, wagon, buggy, or train. The rate of mapping per day was 5.6 sq. mi., at a cost of $1.10 per sq. mi. These soils were recognized and mapped: Cecil clay and sandy loam; Durham sandy loam; Norfolk sandy loam; Susquehanna; Garner; Selma sandy loam and heavy silt loam; Goldsboro compact sand; Sandhill; Neuse; Savanna; Pocoson; Muck; and Meadow. (Prof. Whitney stated that soil names, in practically all instances would be of the counties, or other geological features or places where the soils were first recognized. The type designations would depend upon the texture of the surface or first six inches of soil.) Mechanical analyses were made in the USDA laboratory of one or more 'representative samples' of all of the above except Muck and Meadow. As an aside, we may note that a survey made in 1975 of this same strip from Raleigh to New Bern would probably list over 100 soil types and some 300 map units.

As a result of this survey, the North Carolina Board of Agriculture established the Upper Coastal Plain Test Farm (now Research Station) at Rocky Mount in 1902.

4. The Statesville Area. In early 1901, a soil survey was begun of the Statesville area "in close cooperation with the North Carolina Board of Agriculture, which bore all of the expense of the survey, exclusive of salaries" (Whitney, 1901 report). This was the farthest east of the U.S. Topographic (USGS) sheets, and the soils were considered representative of the upper Piedmont region. This area survey also was used to train seven young men in the methods of soil survey work. It may be noted that not one of these men had had specific studies in soils and crops while in college, but were primarily trained as geologists or chemists. Of course, there were no established departments of soils in the southern Land Grant colleges in 1901. The report of the area brings out this information: "In the survey of the soils of the Statesville area some attention was given to the various rock formations . . . This was necessary on account of the direct relation between the soils and the underlying rocks. The soils are the direct results of the decomposition and disintegration of the rocks upon which they rest." As a further note it may be mentioned that the two men "in charge of the Statesville area had had considerable experience in soil mapping" (all of three years at the most). One of the purposes of this survey was to determine the feasibility of establishing a test farm or research station in the upper Piedmont. However, only seven "types of soil" were indicated. (Contrast this to the 31 soil types indicated in the 1960 soil survey of Iredell County and the 109 actual soil map units.)

It should be brought out here that the report of the Statesville area emphasizes the fact that farming practices resulted in "washing and small gullies . . . with many fields having gullies with a depth of greater than 40 feet." However, a remedy was suggested: "gullied fields in a few years would be entirely reclaimed by judicious use of ditches and terraces and the filling in of the larger gullies by means of pine boughs and logs." Thus we learn that soil erosion was a recognized problem in North Carolina at the beginning of the century and that some efforts were suggested for control.

In 1903, a test farm was established near Statesville to determine the best usage of the red clay soils of the Piedmont. Due to encroachment of urban development, the farm, in 1954, was relocated (as the Piedmont Research Station) to a site in Rowan County near Salisbury where the soils are similar to those at Statesville.

5. The Alamance County Area. The record is not clear, but some time early in 1901, the N.C. Board of Agriculture and the Bureau of Soils, USDA, entered into a cooperative program in Soil Survey. Apparently, it was concluded that a proper procedure for a soil survey would be to select political units with established boundaries, such as counties. Because Alamance County was the first on the alphabetical list with a geological survey (1891), it was chosen and "two experienced surveyors" (one with two years, the other in his first year) assigned. This was a somewhat hurried and generalized soil survey on the "enlarged and redrawn base map." Only six soil separations were made (as contrasted to the 25 soil series and 194 map units indicated by the 1956 survey of the county). The author states that the establishment of several cotton mills in the region resulted in the "taking of many laborers from the fields" and the consequent loss of much farm land "with many washed and abandoned fields." However, no recommendations were made for the control of washing.

6. The Cary Area. The smallest and fastest cooperative soil survey in the state was that of the Cary area. As noted in the Bureau of Soils report: "About one month in the summer of 1901 was spent in making a soil survey of an area between Raleigh and Cary . . . of approximately 63 sq. mi. . . . and including within its boundaries the farm of the North Carolina Experiment Station. The work was done at the request of the N.C. Board of Agriculture on a base map which was surveyed for the purpose." This was a means of determining the soil resources of the area, with the possibility of expanding the limits of the experimental area for greater research. Only four soil types were included, of which Cecil sandy loam comprised 64.7% of the area. (Today, due to accelerated erosion and much urban construction in the same boundary, probably less than 35% of the area is sandy loam in surface texture.) In the 1966 soil survey of Wake County, there were eight soil series and over 30 mapping units shown on the identical 63 sq. mi. area.

7. The Craven Area. Apparently the soil survey was moving too rapidly in 1902 because "the Craven area base maps were not entirely satisfactory, making necessary some revision in 1903" (Whitney, 1903 report). However, the total cost of surveying this 897 square mile area was listed at $644.30. Perhaps this reflects not only the comparatively low salaries of surveyors (a small fraction of the salary of a present day soil scientist surveyor), but also the ten very moderately low printing and publishing costs.

8. Other Early Surveys. Upon completion of the Craven area survey, there followed, in somewhat rapid succession, area surveys in 1902–04 of the USGS quadrangles of Taylorsville, Hickory, Mt. Mitchell, Asheville, Saluda, and Greeneville, N.C.–Tenn. All the base maps were scaled one inch to the mile. The maps of each, except that of Greeneville, served as possible regions in which to locate agricultural test or experimental farms. One such farm was established at Swannanoa in 1908, but this was relocated at Waynesville (as the Mountain Research Station) approximately 32 years later when the U.S. Army took over the site for a hospital. Evidently the Mt. Mitchell area survey was looking forward to possible locations for test work with apple orchards or for suitable areas for 'mountain pastures' and beef cattle management. It is rather remarkable that, according to published dates, one man in one field season (1903) made the surveys of three of the areas listed. That was the year man learned to fly, although at the other end of North Carolina.
It should be noted that Hugh H. Bennett, a native of the State and a graduate of the University, entered the Soil Survey in 1904. However, until he became an inspector in 1910, his first assignments were in several other states. His observations as surveyor and supervisor in areas of the Piedmont region and elsewhere, plus his experience on his home farm in Anson County, gradually led to his formation of the Soil Erosion Service in 1933.

9. The Duplin Area. Beginning in 1905, there was a rather abrupt change in mapping procedure in North Carolina. Because the USGS base maps were quite old, or did not cover an entire county, it was necessary to do considerable plane table surveying, which is a painstaking and time-consuming procedure as described under section 2, in Stage II, later in this paper. Duplin was the first county in the State where it was necessary to conduct some plane table base map surveying. As this survey of soils proceeded, the Coastal Plain Horticultural Crops Test farm was established in 1905 at Willard, close to the Duplin County border. The farm was considered representative of the lands in Duplin that were used for vegetables and grapes (scuppernong). For the record, it should be mentioned that the vegetable research portion of the Willard farm was transferred to similar soils on a tract near Faison in 1949, and both stations were combined in a larger farm near Clinton in 1970 as the Horticultural Crops Research Station.

Solely as a matter of passing interest, it may be noted that the surveyor in charge of the Duplin area—although interested in and working with soils—later turned his talents to the study of medicine. He became a prominent pediatrician in Raleigh, and one of the city schools bears his name.

10. The Chowan County Area; Others in 1906–1908. Perhaps this county survey indicates that the State and USDA officials were interested in balancing east against west in number of soil surveys, since most of the earlier work was in the west. Without doubt, the most interesting factor listed in the Chowan survey report is the subtitle: "By W. Edward Hearn, assisted by G. M. MacNider, of the State Department of Agriculture" thus marking the beginning of a state employee in field work of the soil survey. Incidentally, this same year—1906—these two men literally jumped across the state to make the survey of Transylvania County. It is worthy of note that the cost per square mile of the Chowan survey was $3.01; that of Transylvania, $4.34, no doubt reflecting the greater difficulty of covering the mountainous county over that of an almost flat Coastal Plain area. Whitney states (1906 report) that these figures included salaries of the men while in the area and their subsistence expenses, but not the cost of transportation to and from the area. The state of North Carolina contributed $188.10 to the survey of Chowan, and $737.80 to that of Transylvania.

Again, two widely separated counties were surveyed in one year (Henderson and Edgecombe, 1907) by the same two men. Fast workers.

Additional Cooperation. Beginning in 1908, the NCDA employed a second individual, thus putting two soil surveyors in the survey of Robeson County to work with the USDA men. However, both state men soon dropped out, but later another man was employed. A second surveyor was added in 1909. Apparently some men considered the work too difficult.

11. Lake Mattamuskeet Survey. By far the strangest "soil survey" of all time in North Carolina was that of the Lake Mattamuskeet area in 1909. Some wealthy individuals and others had the bright idea that this shallow body of water (approximately 50,000 acres in extent and 1 to 5 feet in depth) could be drained (pumped dry) and the lake bed used to produce abundant crops. The surface of the lake was then only about 30 inches above sea level. W. Edward Hearn, one of the more experienced surveyors, made the survey. The base map was compiled by the office of Experiment Stations, USDA, and Mr. Hearn, on a scale of one inch to the mile. Included in the drainage area surveyed was "the lake bed and a belt of country bordering the lake from 1 to 3.5 miles wide; thus giving the area surveyed (upland and lake) a total of 112,640 acres. To keep located—in addition to definite “sighting points” on land—the surveyor first ran guide strings across the lake which he followed in a wide flat-bottomed boat. The soil borings were a real problem. The long—60-inch—soil auger was inserted in a bicycle inner tube that had been severed at the valve. This waterproof casing was carefully fastened to the auger in such manner that the soil samples could be drawn and retained from any depth to 3 feet below the lake bottom. This required considerable ingenuity and skill. Incidentally, practically all the lake bottom soils were chiefly sands ranging in texture from medium to very fine.

According to available records, it was not until the 1920s that a definite attempt was made to drain the lake completely. This task was accomplished by the installation of huge pumps, reportedly the largest developed anywhere. There were many cross canals and ditches to increase the probability of drainage and to aid in removing water from the areas to be cultivated or in some crop. Water was pumped from the lake late in the 1920s, and large machinery was used to prepare the soil for crops. There were extensive tracts in corn, soybeans, or oats, and small fields of white potatoes and some vegetables as cabbage. Yields were reasonably fair, according to observers, but there was a tendency for some sections of crops to “drown out” following rains. However, despite the vast pumping system, it was impossible to keep the lake bed adequately drained for any crops. So, in 1933–34, nature simply took over, and Lake Mattamuskeet returned somewhat to its former state—and there it is today. Of course, there are no reliable cost data because many individuals and companies or corporations were involved at times in the project. Some estimates indicate that as much as $30 million may have been sunk in this ill-conceived and fore-doomed project.

Stage II: 1910 to 1920

1. Curtis F. Marbut Enters the Soil Survey. According to the Report for the Bureau of Soils for 1909, Prof. Marbut became an assistant in soil survey that year. In 1910, there were major changes in the soil survey unit of the Bureau. Prof. Marbut was placed in charge, and four of the more experienced soil surveyors were appointed inspectors. (This title was changed to correlator years later.) Among the inspectors was Hugh H. Bennett, a native of Anson County, who had been a surveyor for about 6 years. With some sixty-odd men—federal and state—conducting soil surveys across the country, it was essential that their soil findings and map delineations be uniform from one state to another as well as within a state. Thus, areas of Norfolk sandy loam shown on the map of Edgecombe County should be reasonably identical to Norfolk sandy loan as mapped in Robeson County; or an area of Cecil sandy loam in Gaston County, N.C., should correlate closely with an area of Cecil sandy loam in Pike County, Georgia. Although Prof. Marbut (later Dr.) was a geologist by training and had taught geology on the university level, he soon began an intensive training to make himself an outstanding soil scientist. He was deeply interested in field work and the study of soils in their natural environment and spent much time away from his Washington office. Thus, although the top soil scientist in the country, he had a tendency to leave many administrative matters to others, especially his capable administrative assistant who practically ran the show.

2. Early Changes in Soil Classification and Map Work. Although the soil surveyors in North Carolina from the beginning (1900) had used geological formations and specific rock groups as the basis for soil classification, it was not until the survey of Cabarrus County (1910) that the report showed a diagram listing the classification of the soils groups according to origin. For example, Cecil soils from coarse-grained granite and gneiss; Alamance soils and Georgeville soils from fine-grained bluish slate. Dr. Marbut began to emphasize that soil characteristics rather than origin should be the basis for classification—texture, consistence, depth, color, stoniness, drainage, and in some regions salt or alkali content.

During this decade as the work progressed, or some time around 1910 to 1914, there were few USGS base maps available for any county soil surveys. Even if available, most were over 25 years old and far outdated due to many changes in roads and the fact that they indicated little of the detail required by the careful soil surveyor-scientist. Thus, it became necessary for the soils men to construct their own base maps. This was a very slow, tedious, and laborious procedure, but the men soon developed considerable skill with the plane table (a 15x15-inch board) equipped with a compass and mounted on a detachable tripod. Cloth-backed, heavy-duty drawing paper was used on the table, and a sight alidade served a double purpose as ruler and graduated scale. Transportation was by horse- or mule-drawn buggy. An odometer with a calibrated scale was mounted on the front axle so as to be visible to the driver and served for accurate road measurement. A metal pin fastened to one spoke of the wheel turned a star-shaped sprocket gear on the odometer in a similar fashion to the measuring arrangement on some bicycles today. A series of front and back sights on definite objects as the surveyors proceeded along the road gradually produced the base map. While the men moved along the route (road or other passable way for the vehicle), they made recordings of the distances between soil changes; also all essential features were indicated—such as streams, road intersections, dwellings, schools, churches. The sight alidade was graduated 50 spaces to the inch for the mile scale, and distances were pricked into the map paper with a very fine needle which was mounted in a heavy match stem, a "sucker stick," or even a thorn or other tough but small stick. Good eyesight and a steady hand were necessary for accuracy. When all the passable roads and trails had been traversed with the buggy, the completed field sheet resembled a sketch of poultry wire netting, with—usually—an area of 3 to 6 square miles of land within each 'net' that had to be traversed on foot, the surveyor carefully recording his paces and making fore and back sights on definite points or checking by triangular base sights. Surprisingly, the work was very accurate provided the surveyor was careful. It was not unusual that a 15- to 30-mile circuit around a plane table on the roads would close with an error of less than 300 feet. All of the survey field maps were adjusted by the Bureau of Soils map division with the aid of USGS bench marks, railway surveys, and other fixed data to which the surveyor had tied his maps. Thus, any errors in the field mapping were "ironed out" and the resultant map was accurate. However, it must be emphasized that the soil surveyors spent about half of their time and effort constructing the field base map, and about half time actually indicating the various soil separations. Surely, the value of a survey depended upon its map accuracy. Hence, the total effort to be correct or exact.

3. Tools Used in Soil Survey. During the 1900–1910 period in the State, the geologist's hammer evidently was deemed the most suitable tool since over half of all the early surveyors were geology-trained, and some were professional geologists. Gradually larger instruments, as pick, mattock, or spade came into use. In most cases, because many of the early surveys were in the Piedmont or Mountain regions, the road cuts, or banks, gullies, or other exposed "profiles" were examined simply by pecking loose a fresh area of soil. There is no definite record of the first use of the screw auger as a tool for an "easy and efficient" method of examining a soil and thus aiding in its classification. No doubt Prof. Whitney used an auger for his study of soils in the Coastal Plain of Maryland in the early 1890s while a member of that state's agricultural experiment station. Augers were used by soil survey field parties in the southwestern United States prior to 1902. Sometime after 1905, the screw type auger became the standard soil-examining tool by practically all soil surveyors in North Carolina. Even 70 years later, it is widely used. The common length at first was about 36 inches, although some men preferred a length of 40 or 42 inches, and this length seems about universal today. Over the years there have been many modifications of the auger or soil-probing tool. Some are adapted to use in very sandy soils, others for heavy clays, or for highly organic soils, with several gradations between these special types. Often small probes are used to extract a nearly undisturbed "miniature profile." Sharp rounded point spades, such as tiling spades, are often used for examining a larger slice of the soil. Of course, for a complete soil examination and profile description, a pit is usually dug to a depth of 4 or more feet with sufficient space to permit the scientist to enter and study the profile.

4. Quality of the Soil Surveys; Progress. Under the influence of Dr. Marbut, who had become a distinguished soil scientist of international note, and the supervision of his inspectors, the quality of soil surveys improved greatly during this decade (1910–1920). In addition, there were more men with experience (a few with 10 or 12 years) who could be placed in charge of the field parties and direct better workmanship. Also, graduates of Land Grant Colleges with training in agronomy entered the survey. Among the North Carolina leaders or teachers and "trainers" in this period were M. E. Sherwin, Professor of Soils at N.C. A&M College, and Professor C. B. Williams, Chief, Division of Agronomy, NCDA and N.C. Experiment Station. Both men were deeply interested and involved in the soil survey and in its value to the State's agriculture and land use. They also aided in supervising the field soil maps, and the additional soil series as recognized and indicated. Progress was relatively rapid, considering the many difficulties in preparing base maps in the field. During this full decade, soil survey maps of 34 counties were completed, which totaled approximately one-third the area of North Carolina. Of these, 14 were in the Piedmont region, 3 of which had partially usable USGS base maps; 11 in the Coastal Plain; 3 in the Mountain area, all with fair base maps; 5 in the Coastal Plain–Piedmont border counties; and 1 Piedmont-Mountain, also with a fair base map by USGS.

During Stage II, as county soil surveys were completed, the NCDA added two Test Farms. To determine possible use for agriculture of the "peat and muck lands"—because there was much agitation from "agricultural interests" to clear, drain, and place in crops vast tracts of these "organic soils"—the Blacklands Test Farm was established at Wenona in 1912. (However, almost continuous and uncontrollable fires forced the relocation of this farm to an area near Plymouth, in 1943, as the Tidewater Research Station. A portion of this farm contains considerable acreage of the “blacklands,” but the greater extent is in poorly to somewhat poorly drained mineral soils which are representative of the soils of much of the lower-lying Coastal Plain region.) Because of problems in tobacco production in the Old Belt Tobacco Area, a test farm was established in Granville County, near Oxford, on soils considered representative of the Belt. Now known as Oxford Tobacco Research Station, this valuable “test farm” has been in continuous operation since its establishment in 1912. Men in the N.C. soil survey selected these research farm areas out of a number of proposed sites.

5. Survey Assignments by Season; Personnel Notes. It was some time during the early part of this decade, probably in 1914, that a policy was established of moving soil survey parties across the State with approximately the summer and winter periods. The practice developed into definite assignment to a county survey in the Coastal Plain during the period approximately December-May, and to a county in the Piedmont or the Mountain region for May–December. Thus, field work could be conducted throughout most of the year, due to the milder climate of the eastern counties. However, during cold or snowy periods, little field work was possible. For these times, the surveyors would catch up on inking their field maps and otherwise complete these as far as possible, or they would gather data for the soil survey report—a real task in itself. There always was plenty to keep the men occupied. On one side, however, the cross-state assignments each year provoked hardships on families with children in school. Often a child would be in schools in three different counties in one calendar year—but all survived, and were perhaps the better trained for the shifting about.

During this stage of the survey, some of the men developed excellent finesse and turned out first-class maps in relatively short time. Their traverse work was very accurate. Whenever possible, one of these top individuals was placed in charge of a survey, and sometimes was assigned a new man for training. All in all there were some changes in personnel, and occasionally it seemed difficult to retain men in the survey. The job was physically difficult and no place for a man looking for a “soft snap” outdoors in the fresh air. There were some “characters,” of course, along with a few prima-donna–like individuals who never ceased to “fuss over” their maps and reports. Others did not care, and seldom lasted long.

Also in this decade, graduates of N.C. A&M College with degrees in agriculture and training in agronomy entered the soil survey. The first was S. F. Davidson in 1917. In 1918, W. A. Davis, the first individual with definite soil training in college, entered the survey. However, the first graduate of the college to enter soil survey was S. O. Perkins (Ind. Chem. degree) in 1912.

Probably the first attempt to use an automobile in North Carolina as a means of speeding up soil survey traverse with a plane table was around 1918. L. L. Brinkley, then of the State survey in Moore County, fastened his odometer-equipped buggy behind an auto. With Mrs. B. driving the car, he thought progress would be much faster. However, there was considerable difficulty in adjusting car speed to the nonpaved and sometimes very bumpy roads. The buggy, with Brinkley attempting to record measurements, soil changes, and other essential map features, often literally bounced and slithered all over the roads. The would-be time-saver was spilled out a few times, and the plane table flew out of the buggy frequently. Of course, these hazards resulted in the early abandonment of the experiment.

The first use of an airplane as an aid in soil survey mapping in the State was in Tyrrell County, 1920, by W. B. Cobb who had had some experience in World War I as a pilot and an observer. Since about 60% of Tyrrell County was covered by almost impenetrable wet woodlands, Cobb—assisted by W. A. Davis—used air observation to indicate points where he might enter such areas on foot and carry out reasonably definite traverse lines. He was also enabled to outline changes in forest and other vegetation to help correlate major soil boundaries and indicate drainage changes. He made sketches and took a few simple photographs, but there was no thought of total photography.

6. North Carolina Department of Agriculture (NCDA) Bulletins on Soils. In 1917, the department published bulletins of four adjacent counties in the Piedmont region. All had similar titles: Soil Survey Report No.__ on _________ County Soils, Agriculture, and Industries. These were prepared under the direction of Professor C. B. Williams, Head of the Department of Agronomy. Each was a follow-up of the previous county surveys: No. 1, Mecklenburg County, in 1910; Gaston County, 1909, as Bulletin No. 2; Lincoln County, 1914, as No. 3; and Cabarrus County, 1910, as No. 4. Evidently these reports represent the first efforts to utilize fully the basic soil survey. As the title of each implies, the objective was to integrate or tie-in the soil survey data with "carefully conducted soil-type experiments in Mecklenburg and adjoining counties." Soils are described as in the original soil survey reports, and the present (i.e., 1917) methods of tillage, crops and fertilizer practices indicated and described. Sections of each bulletin gave detailed information on the character of the soils, and "what experiments have shown to be the chief needs of the soils"; also, "how to supply plant food requirements, recommended fertilizer mixtures and quantities to apply on certain soils for particular crops; lime usage; and "crop rotations necessary for a permanent system of agriculture in the county." In various portions of each bulletin appear such statements as "deeper plowing in the fall and the use of winter cover crops will prevent washing on many of the slopes (especially Cecil soils) and largely eliminate the terracing now found necessary." Subsoiling is recommended for the "heavier clay soils."

However, to present information on soils and their management under a somewhat wider territory than individual counties or area surveys, the NCDA, beginning in 1911, published a series of three bulletins describing the soils, the agriculture, and the results of crop and fertilizer experiments in the three physiographic areas of the State.

The descriptions of the soils were taken from the several soil surveys completed up to the date the bulletins were published. Considerable data on mechanical and chemical analyses were given for most soils. Information on fertilizer use, liming, tillage, and yields came from the included test farms or from research on outlying privately owned farms.

The first bulletin: A Preliminary Report of the Mountain Soils, Vol. 32, No. 5, May 1, 1911, Whole No. 151, was prepared under direction of B. W. Kilgore, Director, Test Farms. This describes briefly the soils of the region based on soil surveys of two counties and parts of six counties. It gives the results of 11 years experiments with crops and fertilizers, and "deals largely with the chemical composition of the more important soils, and the results derived from the plant experiments."

The second bulletin: Report of the Piedmont Soils, Vol. 36, No. 2, Feb. 1915, Whole No. 206, 122 pages, was prepared under the direction of C. B. Williams, Chief, Division of Agronomy. The subtitle states: "with reference to their nature, plant food requirements, and adaptability to different crops." Descriptions are given for the soils in the various surveys prior to 1915. Complete analyses are given for the major or more extensive soils. The results of field experiments on specific soils with various crops are presented from the Iredell Test Farm, the Central Farm at Raleigh, and also from numerous outlying privately owned farms within the area.

The third bulletin: Report of the Coastal Plain Soils, Vol. 39, No. 5, May 1918, Whole No. 244, 175 pages, also was prepared under the direction of Prof. C. B. Williams. This lengthy report records "much of the work that has been done during the past 17 years in a systematic, detailed study of the leading types of soil found in the Coastal Plain region . . . with a view to ascertaining the nature of the soils of this portion of the State, their location, their extent and boundaries, the total amount of plant food constituents contained, their fertilizer needs for the most profitable production of crops, and their permanent improvement, and the crops to which they are best adapted." Major research work was conducted at the Upper Coastal Plains Test Farm (Rocky Mount) and the Blacklands Test Farm (Wenona), supplemented by work on many outlying farms, privately owned.

Several shorter bulletins by the NCDA prior to 1920 describe results with various crops on specific soils in many counties and present recommendations for management.

7. Hazards in Soil Survey Field Work. Here it may be appropriate to sandwich in a few comments incident to soil survey field work difficulties other than constructing maps or determining the types of soil—comments that will apply to the latter part of this decade and into the next. Sometimes the motive power—horse or mule—would become frightened and bolt rapidly, leaving plane table, augers, other tools, and probably a surveyor or two scattered along the roadside. There were frequent breaks in harness, sometimes a broken shaft, but rarely a wheel collapse. Occasionally the horse would sink to his middle in an innocent-appearing stream crossing, thereby causing the surveyor to unhitch and pull the buggy out himself. There were times when dogs, bulls, wild boar, or snakes objected to anyone moving along the trail or way. Some lone surveyors would become lost in swamp or forest for perhaps half a day, or become stuck or temporarily bogged down in muck or mire. Usually two surveyors worked together in potentially dangerous areas, thereby lessening the possibility of harm. The most disturbing incidents were when an irate farmer appeared with a pitchfork or a shot gun cradled in his arm and stated vehemently he "didn't want no gov'm't men messing on his land" and "get the blankety-blank outer here." Sometimes the objector would listen to explanations and become more calm; occasionally he would not. In general, nearly all land owners were cooperative since every effort was made before beginning a survey to advise the people of the county by newspaper articles —where there was a paper, but if not —, through the nearest newspaper available to county residents, through the county agricultural agent's office or through the school system and other news-spreading methods.

Stage III: 1920 to 1934

1. Improvement of Base Maps for Soil Surveys. During this period, practically all base maps were constructed by plane table surveys, and on an inch-to-the-mile scale. However, there were very few recent USGS units which were suitable for base maps, but only with several modifications. The usual period required to survey an average county (approximately 500 to 600 sq. mi.) by a party of two men was two field seasons (two winter periods for a Coastal Plain county; two summer periods for one in the Piedmont or Mountains).

L. L. Brinkley, previously mentioned, left the State soil survey in 1919 and later made very detailed maps of two counties, strictly as a business venture. The maps were adjusted and correlated by the map division of the soil survey unit (USDA) in Washington. One of the maps was of Nash County. It was practically perfect as a base map for the soil survey of the county, the only changes being the addition of new dwellings. By use of this map, the survey of soils was completed between Dec. 20, 1925, and June 1, 1926, thereby halving the usual period required for a county of 549 sq. mi.

2. Change in Transportation. The greatest time-saver in soil survey field work was introduced in North Carolina in 1920. W. B. Cobb and W. A. Davis, in Tyrrell County, used a Model T Ford as the mode of transportation. Road measurements were by means of special speedometer-odometer attached to the right side of the dash of the auto and connected by a flexible cable to a small gear box clamped to the right frame of the forward axle. A fiber sprocket on the gear box was turned by a notched metal ring attached to the wheel. A standard speedometer was used at first. A carefully calibrated and numbered scale to show 50 lines to the inch was pasted over the tenths dial of the odometer. Thus, the same scale was used as on the buggy odometer. However, great care was necessary to check the tire pressure (which then was recommended at 70 pounds by the tire manufacturer for the 30x3-inch tire). After first measuring accurately by chain a mile on a straight-away, level road, tire pressure adjustments were made by trial and error until the 'converted' odometer finally checked with the measured mile. Incidentally, the best tire tubes in the 1920s lost from 2 to 5 pounds pressure in less than one week, so the tire pressure of the measuring wheel had to be checked and adjusted every 3 or 4 days. About 1925, the Bureau of Soils furnished a specially built speedometer-odometer for use in soil survey traverse. This enabled much easier dial reading, but the problem of regulating tire pressure continued. Also, frequently the gearing or sprocket at the front wheel would foul with twigs, grass, or other material and cause breaks or long delays in untangling the mess. Occasionally the long cable itself would break. Thus, it was necessary to carry spare parts for repairs in the field, and almost qualify as a mechanic to do so.

3. North Carolina Agricultural Experiment Station Cooperation. In 1923, the N.C. Experiment Station began financial cooperation with the NCDA and the USDA in Soil Survey, and in 1925, began the employment of one or more soil surveyors. The cooperation of the Agricultural Experiment Station with the USDA (SCS) has continued to the present although currently there are no surveyors continuously in the field.

4. Better Trained Soil Surveyors. In the 1920s, most of the men employed for soil survey field work were graduates of agricultural colleges with training in soils and crops. A few men had doctorates in soils. The quality of the surveys improved greatly. Essentially, these trained men observed the soils more carefully and with greater objectivity. For example, in that portion of Burke County covered by the Hickory Area survey of 1902, five soil types were delineated; in the Burke survey of 1926 —the identical area—seven soil types are shown, but only two correspond to any shown on the 1902 map. More significantly, there is approximately ten times the detail on the later survey due, of course, to better understanding of soils and the trend away from geologist to soil specialist.

On January 1, 1920, when a recent graduate of N.C. State A&M College reported to the head of the Agronomy Department for assignment in soil survey, he was given two vials of litmus paper —one blue, the other pink — with specific methods for determining the relative degree of acidity of alkalinity of a soil. At that time, pH values for expressing the relative acidity or alkalinity of a soil were a few years in the future. (How we have progressed from field guesstimation to accurate laboratory calibration!)

5. Major Changes in Soil Classification. In the period 1926 to 1934, some soil surveyors began to indicate erosion and slope phases on the soil maps, but sometimes these phases were “correlated out” by the inspection staff in the field or in final consideration at the Washington office of soil survey.

Dr. Marbut retired from the USDA’s Soil Survey Division in the early 1930s He was succeeded by Dr. Charles E. Kellogg in 1934 as Chief, Soil Survey Division. Kellogg, a brilliant, competent, and forceful individual, soon began to make an impression on the entire soil survey program, national and state. He was responsible for many changes, including closer inspection and correlation of field work, speeding up the publication of reports, and somewhat better cooperation among the states conducting soil surveys within the Tennessee River valley region. Kellogg brought a few ambitious young men into his organization and placed them in key positions of much responsibility. Some of these changes caused considerable comment, especially in North Carolina, but apparently no serious situations in cooperation developed. On occasion Kellogg was a controversial figure, and there were periods of doubt as to the nature of the “cooperative survey.” To his everlasting credit, he stressed greater training for soil surveyors and encouraged them to study for advanced degrees. All in all, he certainly added zeal to the job.

Stage IV: 1934 to 1952

1. Aerial Photographs as Base Maps. With the advent of aerial photographs as base maps, there was a total revolution in soil survey procedure. No other factor has had a greater impact on any map work than the aerial photo. Although there was some use of “air pictures” in soil survey field work as early as 1928 (T. W. Bushnell in Indiana), these were of somewhat mediocre quality. It was mid-1934 before suitable air photographs were available in North Carolina. The long standard inch-to-the-mile scale for soil surveys exploded to scales as great as 500 feet to the inch. However, the mapping scale gradually settled down to a more practical system of 1320 feet to the inch. This scale, of course, gives the surveyor 16 times as much space as the old scale to indicate his findings. (Quite a contrast to Prof. Whitney's statement in 1901 that "a square of 10 acres represents an area 1/8 square inch on the map, and is to be taken as the unit of soil mapping.") Not only did the surveyor have far more space to indicate soil factors, he did not have to worry about constructing a base map. At least one-half the surveyor's time and much more of his energy had gone into preparation of the base map with plane table and other instruments. In addition, the surveyor with the aerial photo could leave the automobile and proceed to do all the work on foot—by far the more efficient means of getting about on practically all of the North Carolina landscapes he was called upon to survey soils and their related features.

It should be noted that during this stage most of the surveyors entering the work in North Carolina were college-trained soil specialists and soon were designated "soil scientists."

A further note: at the beginning of this Stage IV, two federal agencies were established which had almost as much impact on soil survey as did the aerial photo. These were the Tennessee Valley Authority (TVA) and the Soil Erosion Service which became the Soil Conservation Service in 1935 (SCS).

2. Cooperation with the Tennessee Valley Authority. This organization, soon after it began to operate, sought to improve land use for the protection of its several proposed hydroelectric projects. Control of soil erosion and the reduction of rapid run-off were considered essential. All areas—on a county-wide basis—draining into the Tennessee River were included in a major program. Thus, the 15 North Carolina counties which are drained wholly or in part by the tributaries of the river became a large area of an intensive land use project. As a sound basis upon which to build the program, the N.C. Agricultural Experiment Station and the TVA began cooperative soil surveys of the entire region. The station kept two or more experienced surveyors in the area who worked with USDA surveyors. The entire soil survey project was completed in 1947—beginning with Clay County in 1935 and ending with Avery. In these surveys, slope and erosion phases were indicated for the various soil types. The survey of Clay County was a joint project with the NCDA, N.C. Agricultural Experiment Station, and Bureau of Plant Industry of USDA. The surveys of Cherokee, Jackson, Madison, Transylvania, Swain, and Yancey counties were jointly with the above-named agencies plus TVA. The SCS became a cooperating agency with the Experiment Station, TVA and BPI (later Bureau of Chemistry and Soils) in the soil surveys of the other counties, namely: Avery, Graham, Buncombe, Haywood, Henderson, Macon, Mitchell, and Watauga. Base maps for all county soil surveys, except of Clay and Cherokee, were planimetric maps mostly compiled from air photos by TVA.

It should be noted here that beginning with the surveys in the TVA region, the Experiment Station no longer—with very few exceptions—transferred the surveyors from one county to another for summer and winter seasons.

3. Cooperation with the Soil Conservation Service. The Agricultural Experiment Station, chiefly through its soil survey staff, has cooperated with the SCS from its beginning late in 1933 (as the then Soil Erosion Service) in practically all the survey projects in the State. The eight original watershed project areas, all within the Piedmont or upper Coastal Plain–Piedmont regions, were selected with the assistance of a soil surveyor representing the Station. The first consideration for each selection was representative soils for the type of agriculture common within the county or counties, and where soil erosion was a definite problem. The same criteria applied to the choice of placement of the 23 Civilian Conservation Corps (CCC) camps concerned with improvement of land use as well as erosion control and preventive measures.

As the watershed projects were phased out gradually, the SCS began the establishment of Soil Conservation Districts over the State. The first such district in the United States was set up in Anson County in 1937, named Brown Creek. Prime mover in the project was the late Jimmy Cameron, the able county agricultural agent, who was assisted by a soil survey staff member jointly employed by Extension, SCS, and the Experiment Station. Several other soil conservation districts, each covering a complete watershed area, were established in the 1937–1945 period. In each instance the choice of the complete watershed area was based upon soils and land use representative of the region. As with Brown Creek, the respective agricultural agents usually were the principal sponsors of the districts. An Experiment Station soil surveyor also assisted in selecting watersheds representative of the soils and agriculture of the area. During the latter years of this Stage IV, soil conservation districts were set up on a county basis, rather than multiple counties or parts of two counties. Also during this period, the SCS county-by-county soil survey program was accelerated and the Experiment Station continued its cooperation, usually with the assignment of one or more surveyors to each county.

4. Research Stations — New or Relocated. During the period of Stage IV, the NCDA and the Experiment Station separately or jointly established nine new Research Stations. Six of these were relocated, five at a later date, due to encroaching urban development or other nonagricultural conditions. Each of these nine stations, as with the other earlier established research centers, was selected by a member of the sate soil survey staff because it closely represented the soils of the area upon which the prevailing crops grown. Thus, research on representative soils is being conducted on practically all crops (as tobacco, vegetables, peanuts, tree fruits) at locations where these crops are principally produced, for example, in Columbus, Sampson, Bertie, Henderson, and Buncombe counties, respectively.

5. Special Projects. A number of the experiment station soil survey staff made special purpose, very detailed soil, slope, erosion, and land use surveys for a few relatively small areas (none more than 3,000 acres) during the period 1936–1939. Among these was the Rabbit and Cat Creek project in Macon County. This survey was the basis for an intensive land use and home management program in which the Experiment Station, Agricultural Extension Service, the Tennessee Valley Authority, and the county cooperated. In Avery County, there was a similar intensive project for the Heaton Community. There the soil and land use survey was used as the basis for farm and home management planning. However, the Farmers Home Administration was the major agency conducting this program, along with cooperation from the Experiment Station, the Extension Service and Avery County.

By far the most intensive soil and land use program was that of Parker Branch in Buncombe County. This project was sponsored by the Hydraulic Data Division of the

TVA. The practices and study on this small (1060 acres), but complete, watershed were probably as intensive and exhaustive as any that have been based on the improvement of soil conditions to further water retention very appreciably. Cooperating agencies were the Experiment Station, the Extension Service, and the county. A representative of the State soil survey staff, along with TVA personnel, selected the area over several others—based largely on the surveyor's reconnaissance surveys of each proposed area. The primary factors in the selection were soils representative of the region and which had long been in crops. These were mostly corn, which went to feed horses at the numerous livery stables in Asheville, but also some tobacco and sorghum cane had been grown. As a consequence, the soils were severely eroded. At the beginning of the project—1952, the Station surveyor made a very comprehensive map of the watershed. In addition to soil type with slope and erosion phases, 11 land use classes (cultivated, pasture, forest) were indicated.

The resident project leader was a member of the Extension staff of the college and was in constant contact with the farmers or land operators. He aided in the establishment of practices that would improve the "hydrologic potential" of Parker Branch. Twice each year for ten years, or through 1962, one or more station soil surveyors visited the project to record very carefully soil and land cover conditions of each field unit (which were originally delineated based upon soil characteristics). These visits coincided with the period of major vegetative growth (mid-May to mid-June) and that of the least growth (early November to late December). The TVA Hydraulic Data Division calibrated all the seasonal changes—an elaborate and comprehensive process and result. The changes in land use over the ten-year period resulted in considerable lessening of runoff and soil loss—factors which were completely monitored by instruments were analyzed, correlated, and evaluated.

Here, also, may be noted another project which involved the soil surveyors. As some will recall, vividly and sadly, there were many professional engineers, and others in allied work, without any employment in the depression years of 1933–35. To give some of these professional useful work, they were assigned jobs with soil surveyors. In the western part of the State, E. F. Goldston directed a large party in preparing an inch-to-the-mile scale map of Avery County, presumably for a later soil survey. In the eastern portion, S. O. Perkins had charge of make-work parties in revising or completing base maps for soil surveys. However, as with much of the make-work programs of the depression, the net result or benefit to the soil survey projects of North Carolina was practically nil.

History of Soil Science at North Carolina State University[1]

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Foreword

Soil Science at North Carolina State University can trace its origins to an Act of the General Assembly in 1877, which established a North Carolina Agricultural Experiment Station. The history of Soil Science programs and the people involved from that time until the present has been chronicled and interpreted most effectively in this document. As you read it you will become very aware of the importance of soil science in meeting some of the real needs of the citizens of North Carolina, the nation and the world. Many outstanding people have shared in this mission. The enthusiasm and dedication of the current faculty to respond to new challenges in teaching, research and extension in soil science means that the tradition of excellence has continued. The department is most grateful to Dr. Ralph J. McCracken, former faculty member and Department Head, for volunteering his time to research and write this most interesting and informative history.

Robert H. Miller, 1989

Genesis (the Beginning), 1877–1907

The initiatives for the founding of North Carolina State University (originally named the North Carolina State College of Agriculture and Mechanic Arts) and the North Carolina Agricultural Experiment Station which came from members of the Watauga Club and other farm and political leaders of the state is well acknowledged. In addition, a group of advocates in educational and scientific leadership positions also played a significant part, and their role is often not fully recognized. This group was heavily involved in initiation and implementation of agricultural programs at N.C. State and especially in establishment of the roots of the soils programs here, and for that they deserve special recognition and thanks. This group includes Dr. Kemp Battle, President of the University of North Carolina in the 1870s; Dr. Washington Caruthers Kerr, State Geologist for North Carolina and a faculty member of UNC in the 1870s; Dr. Albert Ledoux, first agricultural

[1] This paper, written in 1989, has been slightly edited and appears here without its original table of contents and photographs.

chemist and who may be considered the first director of what was to become the N.C. Agricultural Experiment Station at NCSU; Dr. Charles William Dabney, Jr., the second Director of the Experiment Station and also an agricultural chemist and Dr. Milton Whitney, first Superintendent of the First Research farm (Battle 1966; Schaub 1955; Winters 1964, 1965).

The activities of these men provided the roots of the soil science program, a role not fully brought out in histories of the University, the School of Agriculture and Life Sciences and the Agricultural Experiment Station. President Battle became interested in the concept of a State Agricultural Experiment Station using the model of the one established in Connecticut in the early 1870s by Dr. W. O. Atwater. Dr. Atwater's objective for founding the pioneer Connecticut Agricultural Experiment Station was application of scientific knowledge in agriculture—a novel idea at that time—to support and supervise the newly emerging chemical fertilizer industry in Connecticut and to determine the nutrient needs of the soils on which the fertilized crops were to be grown.

Such activities were to follow up and exploit the recently completed research by chemists in Germany (especially that of Justus von Liebig), and England (especially Gilbert and Lawes), who had discovered that the growing of crops is "vastly aided by application of plant food to soils in form of chemical fertilizers"—a daring new idea at the time of its discovery in the 1840s. A Scottish professor of chemistry, James F. W. Johnston, who proposed that farmers learn these new experimental techniques from scientists and subsidize laboratory research on these new "special manures" (commercial fertilizers), also contributed to the concept of an agricultural experiment station (Knoblauch and others 1962).

Because of the strong interests in fertilizers and soils, North Carolina was one of the first seven states to establish a State Agricultural Experiment Station (Knoblauch and others 1962). In his position as State Geologist located on the campus of the University of North Carolina at Chapel Hill, W. C. Kerr was besieged with requests to analyze fertilizer materials as to their efficacy and quality and to make recommendations as to their use. He felt, much to his credit, that this kind of activity needed to be associated with an agricultural rather than a geological setting and therefore was one of the members of a team that led the efforts to establish the N.C. Department of Agriculture and what was to become the N.C. Agricultural Experiment Station. This fertilizer analysis program started on the campus at Chapel Hill where there were laboratory facilities, but Battle and Kerr were instrumental in moving this laboratory to Raleigh after the Experiment Station was successfully under way.

The thinking in Connecticut and of the leaders in North Carolina, especially President Battle, Kerr and Dabney, was that after the initial high priority work had been done and a program of control of quality of fertilizers and of recommending amounts to use was established, the researchers could then go on to other agricultural research needs in an expanded program. Thus these primordial programs of fertilizer and soil activities were not only the forerunners of the present soil science program but also could be considered the roots and the cause for establishment of the N.C. Agricultural Experiment Station (NCAES) now the North Carolina Agricultural Research Service (NCARS).

Genesis of what may be identified as soil-science–related activity within what is now NCSU and the NCARS is attributable to three actions:

1. Establishment of an Agricultural Experiment Station by an Act of the General Assembly in 1877 which stipulated that the Board of Trustees “shall employ an analyst skilled in agricultural chemistry” whose duties were to include analysis of fertilizers and to conduct experiments on the nutrition and growth of plants with a view of determining which fertilizers were best suited to the various crops in the state.
2. Appointment of Dr. Albert Ledoux as the first agricultural chemist in 1877 and nominally the first Director of the NCAES (though employed by the State Board of Agriculture).
3. Purchase of a 10-acre tract in what is now West Raleigh in 1885 for field experimentation with fertilizers and crops, which was augmented by a gift of 25 acres from the State Agricultural Society, the group that then sponsored and conducted the State Fair.

Ledoux, an excellent chemist, started a program of analysis of fertilizers as to quality (what came to be called fertilizer control) and their effectiveness in promoting crop growth. However, he resigned in 1880 after only three years in this position.

Dr. Charles William Dabney Jr. was appointed to replace Ledoux in 1880 and thus became the second director of the Agricultural Experiment Station (Winters 1965). Dabney continued and enlarged the work on efficacy of fertilizer materials and of the plant food requirements for crop growth on various soils, although strongly interested in plant nutrients, plant root functions and soil conservation.

Plant food requirements was the first priority item, as indicated in Dabney’s Agricultural Experiment Station Report for 1881, which included the statement that “the subject which most interests our people is that of fertilizing the soil.” Dabney studied and brought general attention to the “relative exhaustion of plant nutrients by cotton, wheat and tobacco.” He acquired this information by analysis of nutrient content of these plants and relating these data to the fertilizer requirements of the plants—a pioneering approach. He and his associates also reported on “how plants obtained ammonia,” value of deep plowing of soils and the relative costs of fertilizer materials. He urged the establishment of an experimental farm and was the prime mover in obtaining such a tract in 1885.

In 1886, Dabney appointed Milton Whitney as the first superintendent of the research farm in West Raleigh. On this tract, Whitney initiated research on physical properties of soils in relation to growth of plants, which was among the first, if not the first, such research in the USA. Also in 1886, Whitney began the first pot culture work in the USA for measuring the plant food requirements of crops, using 1-gallon candy jars as pots. About the same time, he investigated the amount of evapotranspiration of cotton and the effects of soil temperature and moisture on plant growth, which have been called “the first really important investigations of this subject in the USA” (Winters 1965).

He [Whitney] was to go on a few years later to wider responsibilities as Chief of the newly established Bureau of Soils in the USDA. In this position, he became world renowned for establishment of the first soil survey program in the USA and the first systematic classification of U.S. soils. He also became widely known for his highly controversial view that soil texture (content of clay, silt and sand) was the chief factor in soil productivity and not the soil’s nutrient status or fertility, which put him in sharp difference with the soil chemists and soil fertility specialists of that day.

He [Whitney] was also renowned for his ever present cigar and his allegations that he could determine the kind of soil in which a tobacco was grown by the aroma of the smoke from these cigars (Simonson 1986). Oral history indicates that not all of his work associates shared this cigar connoisseur’s enthusiasm.

The first soil fertility trials away from the Research Farm were conducted on the farms of six cooperating farmers in Orange and Chatham counties in 1886, due to the vision and efforts of Dabney. The first soil fertility research plots at outlying locations but controlled by the Station began on leased fields in Edgecombe and Robeson counties in 1899. These leased fields “primed the pump” for establishment of outlying research stations (then called test farms) which began shortly thereafter. Soil fertility plots, fertilizer trials and soil management trials and demonstrations were the soil science component of these early outlying research stations.

Thus by the turn of the century, the foundations were laid for a program in soil fertility and soil management and related soil science research. Because of this foundation C. B. Williams was able to comment in 1927 “there is probably no state that has a better knowledge of its soil and plant food deficiencies” (Williams 1927).

The pioneering soil survey program was also prominent in the early days of soil science activities at NCSU. The soil survey program in North Carolina began in 1900, a cooperative effort between N.C. State and the State Board of Agriculture (precursor of the State Department of Agriculture) (Lee 1984).

North Carolina became one of the first six states to begin a program of systematic classification and mapping of soils, with accompanying interpretations of use potentials. The first soil survey in North Carolina was the “Raleigh to New Bern Area” started in 1900. The purpose of the survey was to serve as a basis for systematic investigation of the fertilizer requirements of different crops (especially tobacco). Scale of mapping for this pioneer survey was one inch per mile compared with scales of 4 inches per mile and larger used today. Thirteen types of soils were recognized, and soil type names were established for soils prominent and extensive today but much more narrowly defined—such as Cecil and Norfolk. The area was selected because it paralleled railroad rights-of-way along which some geologic mapping had been done (the early soil surveys had a very strong geologic bias and basis) and because this was an important tobacco-producing area.

A second soil survey was begun in the Statesville area in the Piedmont in 1901. The report accompanying the soil maps of this area stated that farming practices had “caused washing and small gullies . . . with many fields having gullies with a depth of greater than 40 feet” (Lee 1984). This is one of the first published descriptions of concerns about soil erosion, which subsequently became a strong national concern and led to the establishment of the USDA Soil Conservation Service. Some recommendations for control of this erosion were made in the Statesville area soil survey report:—”gullied fields in a few years could be entirely reclaimed by judicious use of ditches and terraces and the filling in of the larger gullies by means of pine boughs and logs”—a forerunner of more technical and advanced erosion control recommendations to come later.

Early Soil Science Teaching Activities. The first formal recognition of soil science teaching at North Carolina State appears to be the 1890 Catalog, which shows that in the junior year agriculture majors were to receive instruction in agricultural chemistry, covering “atmosphere as plant feeder, the plant and the soil—its composition and origin, physical and chemical properties and its agency as reservoir plant feeder” (N.C. State College of Agriculture & Mechanical Arts 1890–1900).

By 1895–96, the catalog showed that in their senior year students also were to receive lecture topics in “care and use of manures, improvement of exhausted soils by rotation of crops and by growing renovation crops” (N.C. State College of Agriculture & Mechanical Arts 1890–1900).

For the 1897–98 academic year, a series of formal courses was listed for the first time, including a course in soil physics for seniors (mostly involving farm drainage and water handling practice) (N.C. State College of Agriculture & Mechanical Arts 1890–1900).

In the 1900–01 catalog, Agricultural Experiment Station Department and research personnel affiliated with the Experiment Station were listed for the first time, a beginning of the coordination of research-teaching-extension that has made the Land Grant College concept so effective (N.C. State College of Agriculture & Mechanical Arts 1890–1900).

Early Extension Activities for Transfer of Soils and Fertilizer Information. It is interesting to note that by 1888 demonstrations and tests of fertilizer use on various soils were conducted on 21 outlying farms in cooperation with these farmers. Demonstrations and on-farm tests included comparisons of rock phosphate, cottonseed meal and kainite (a potassium-bearing mineral) versus no fertilizer or stable manure only. Such extension activities continued in a growing but somewhat limited way until the passage of the Smith-Lever Act in 1914, which provided Federal funds for extension work and established a Cooperative Extension Service in each state.

The Soils Program Begins To Grow—The C. B. Williams Era, 1907–16

C. B. Williams was named agronomist and director of NCAES in 1907. William Etheridge was appointed Assistant Agronomist with responsibilities for teaching general soils courses in one or more of the one-year, two-year and short course programs.

This period was marked by the establishment of the first significant federal funding for agricultural research under the Adams Act. Two of the four agronomy-related station research projects funded by the Adams Act had soils themes as their main objectives. These were “Soil nitrification with reference to the bacterium concerned and its isolation” and “Relation of geology and chemistry of soils to productivity and fertilizer requirements” (Schaub 1955). Because of the expansion of programs beyond the original topics of fertilizers, soils and crops, several divisions were established within the Agriculture program in 1910—one of which was Agronomy, a precursor to the Soil Science and Crop Science Departments. Research programs in Agronomy and other divisions were supported by federal funds under the Adams Act and funds from taxes on fertilizer sales, as there were no direct appropriations of state funds for research support until years later.

In World War I, potash (potassium) became scarce and high priced, since this fertilizer material had previously been imported from Germany. Because of this need much of the research effort in this period was oriented toward solutions for the potash shortage. Research was conducted and recommendations made on use of tobacco stems and ashes as sources of potassium.

In 1913, a position designated as a soil chemist for research purposes appeared for the first time in the NCAES staff listings in the catalog section showing the Experiment Station staff (N.C. State College of Agriculture & Mechanical Arts 1912–16).

Also appearing in the 1913 catalog was the first listing of soil surveyors on the Agricultural Experiment Station roster (they had previously been affiliated with the N.C. Department of Agriculture). Listed as soil surveyors were L. L. Brinkley, R. C. Jurney and S. O. Perkins (N.C. State College of Agriculture & Mechanical Arts 1912–16).

Teaching, 1907–16. With the growth of the agronomy program the first listing of courses under an agronomy heading appeared in 1908. This listing included the first general soils course to be offered in the four-year baccalaureate program (N.C. State College of Agriculture & Mechanical Arts 1908–09). Melvin E. Sherwin was appointed to the first professorial position in soils in 1910 (N.C. State College of Agriculture & Mechanical Arts 1910–11). During this year, the first baccalaureate level course in fertilizers was offered. The listing of college courses for 1910–11 included General Soils, Fertilizers, Advanced Soils and Farm Drainage. During this period, one-year and two-year curricula were offered which included a general soils course and a soils and fertilizer course. (These one and two-year courses were discontinued shortly thereafter, but were resurrected in a different format with the establishment of the Agricultural Institute in the 1960s).

Extension, 1907–16. County extension work started in North Carolina in 1907. In 1909, the USDA and the college signed a “Memorandum of Understanding” for cooperative work. The Smith-Lever Act establishing cooperative extension was passed by the U.S. Congress and implemented in 1914. Though there were no designated soil extension specialists or agents in this period, soil fertility and fertilizer components were handled within the commodity extension programs.

Soil Science in World War I and the Post-War Period, 1916–23

Activities in all areas were curtailed somewhat in the 1919–24 period due to low crop prices, but there was still some growth and development.

In 1921, two new positions designated as Agronomists in Soils were added to the staff of the Agricultural Experiment Station. Also, 1921 marked the appointment of W. D. Lee as an assistant in soil survey. Mr. Lee was later head of the soil survey program for the NCAES and active in teaching and extension work in soil survey and classification at State College.

In 1923, for the first time, a member of the Agricultural Experiment Station staff was also listed as a member of N.C. A & M faculty in the annual catalog (N.C. State College of Agriculture & Mechanical Arts 1921–22, 1922–23). C. B. Williams was the individual so listed. This was a further step in the integration of research, teaching and extension functions.

Teaching, 1916–23. A course in geology was introduced in the Agronomy group of courses in 1921 and was taught by R. B. Etheridge. This is another reflection of the close association of geology and soil survey in that period. The first offering of a course specifically in soil survey was in 1921, and was taught by Etheridge and Sherwin (N.C. State College of Agriculture & Mechanical Arts 1921–22, 1922–23).

Soil Science in the Twenties and Depression Years, 1924–34

Reorganization of the agricultural component of the North Carolina A & M College took place in 1923 and 1924. The Agricultural Experiment Station and Extension Service became full and regular entities of the College, under control of the college trustees (the N.C. Board of Agriculture had previously been in charge of the Experiment Station). The overall program was designated as the School of Agriculture with a Dean as chief executive officer.

The Director of Extension and of the Experiment Station reported to the Dean. B. W. Kilgore was named the first Dean of the school (Schaub 1955). The Division of Agronomy became the Department of Agronomy with a person appointed by the school administration as head. The Department brought together research, teaching and extension components in both crops and soils.

C. B. Williams was named as the first Head of the Agronomy Department in 1925. He had additional responsibility as Vice Director of the Experiment Station, of which the

Director was R. Y. Winters. This was an adjustment of the previous arrangement in which Mr. Williams had served as director along with his responsibilities in Agronomy.

At the time of this reorganization, the State Board of Agriculture was supporting agricultural research at the level of $60,000 per year and extension activities with $20,000 per year (derived from fertilizer tax receipts). The Federal research funding at this time was $30,000 per year. The Purnell Act of 1925 provided additional Federal funding in the amount of $20,000 per year. This was increased $10,000 per year for the next four years as a provision of the Act.

State funding of agricultural research by direct appropriation was not achieved until 1939. The Great Depression commenced in 1929 with consequent reductions in support. These cuts precluded further growth of programs until the worst of the depression was over in 1934.

Research, 1924–34. During and despite the depression and associated funding problems, the first research on minor element deficiencies and toxicities was started in 1929. There were almost immediate results with the discovery of the value of small amounts of boron for greatly increased growth of alfalfa. This finding was due to the research of L. G. Willis, a soil chemist who was employed in 1925. Mr. Willis first worked in a laboratory in Patterson Hall and later (about 1935) established a laboratory in the research station at Castle Hayne near Wilmington so he could be closer to the areas where micronutrient deficiencies were significant problems.

In summing up 50 years of agronomic research in North Carolina in 1927, C. B. Williams listed 48 “outstanding” results in the areas of soil, soil fertility and fertilizers and six in the area of natural plant food resources in the state (Williams 1927). These results included

- the best analyses and quantities of fertilizers to use for different crops grown on various soil types have been determined by field experiments;
- the fertilization of crops and the fertilizer trade have been placed on a more rational and scientific basis;
- best systems of crop rotations for different soils and farming systems have been worked out;
- North Carolina has become a pioneer state in the establishment of efficient fertilizer control, established that soil fertility investigations for different crops must be carried out on a specified soil types in the field;
- worked out the most effective times and methods of applying fertilizer materials;
- soil survey reports and maps of about three fourths of the counties of the state have been prepared;
- use of commercial fertilizers has increased thirty times since experimental work began;
- established that the use of lime is essential;
- found that the mineral components of the soil furnish a fairly good index for its fertilizer requirements;
- practically all soils of the state were found to respond to phosphate fertilization;
- showed the relations between the physical properties of soils and crop growth;

- found that chemical analyses of soils alone are an unsafe basis for making fertilizer recommendations;
- fertilizers are used to best advantage only when their application is determined strictly by results of experiments on North Carolina soils;
- determined that organic matter is an important need;
- taking the soils of the state as a whole, examined phosphate and marl beds of North Carolina and shown them to be of benefit; and
- conducted one of the earliest studies on the application of the hydrogen electrode for determination of soil acidity and that the use of lime decreases this acidity.

Williams also described agricultural development in North Carolina up to 1927 as a result of these research findings. A summary of these developments follows:

> "Publication of the results of fertilizer experiments has stimulated usage of fertilizers such that North Carolina had become one of the largest markets for fertilizer in the U.S., soil survey data have been useful in agricultural development projects, soil types naturally deficient in plant nutrients have been brought into profitable cultivation, better rotation of crops is being practiced, farmers are more nearly approaching the optimum amounts and quantities of fertilizers for largest yields, wider use of lime, better methods of soil preparation being used, the grade of fertilizers used by farmers has been greatly improved without materially increasing price per ton, and reduction of erosion of farm lands has been brought about."

In this report, Williams also described problems currently being researched, stating that "research of a more practical nature and fundamental research" was being conducted, with fundamental research projects having been chosen with a view toward practical use of the results which has "gone far toward eliminating the antagonism of farmers of the state toward pure scientific investigations."

It is interesting to compare these statements with the present situation and views. Facts and practices that we now take for granted were regarded as strikingly new, several of his statements and conclusions have not worked out and have had to be revised, there is less concern about the immediate and practical applications of basic research, and many of the problems and research needs described by Williams are still with us to some degree.

Teaching, 1924–34. A significant appointment to the teaching faculty was made in 1925. William Battle Cobb was appointed to teach courses in the areas of geology, soil geology, soil survey and other soils courses. His inspiring and motivational teaching had a major positive impact on students until his premature death in 1933.

Another significant appointment (1931) was that of Dr. J. F. Lutz who was hired to teach soils, soil conservation, and soil physics and to conduct research in soil physics. Thus began a career of 42 years of dedicated service to N.C. State and for agriculture in North Carolina.

In 1924, Randall Etheridge, who had joined the faculty earlier, replaced M. E. Sherwin in the soils teaching program. This appointment occurred because of Mr. Sherwin's sudden and unexpected death.

The College academic catalog for 1926–27 listed graduate courses in soils for the first time. Soils courses offered in the Agronomy Department in 1926–27 are listed in Table 1.

Extension work in the soils and fertilizers area continued to be conducted by commodity crop personnel.

Table 1. Soils courses offered by the N.C. State College Agronomy Department in 1926–27.

Curriculum	Course	Instructor
"Term" (1- and 2-year & short courses)	Soil management	Cobb
	Soil types and mapping	Cobb
	Fertilizers	Cobb
Lower level undergraduate	Soil geology	Cobb
	Soil management	Cobb
Advanced undergraduate and graduate level	North Carolina soil types	Cobb
	Fertilizers	Cobb
	Soils of North Carolina	Cobb
	Fertilizers	Cobb
	Soil surveys	Cobb
	Field course in soils	Cobb
Graduate courses:	Pedology	Cobb
	Soil technology	Cobb & Willis
	Advanced soils	Cobb & Willis
	Soils research	Cobb & Willis

The Soils Program Starts to Blossom, 1935–40

Several factors were responsible for a burst of growth and increased breadth of coverage starting in 1935. With the passing of the worst of the depression years, several new Federal programs began and ongoing ones were expanded which provided additional support for soils work. Also, in 1939, the first direct state appropriation for support of agricultural research became a reality.

C. B. Williams took advantage of these opportunities to recruit the best people he could find for additional faculty positions, though lacking full support funds for all of them (Woodhouse 1979). Several faculty members were added and new programs were started in this period. The faculty of this period was composed of outstanding people who dedicated their entire careers to furthering the soils program in the interests of North Carolina agriculture. Faculty member appointments and their areas of specialty included

- J. F. Lutz (1931) — teaching, soil physics and soil conservation;
- W. H. Rankin (1931) — soil fertility and management for small grains;

- W. W. Woodhouse (1936) — soil fertility and management of pastures and forages (initially supported by funds from the Tennessee Valley Authority);
- Emerson Collins (1936) — soil fertility research for peanuts and cotton initially followed later by extension responsibilities; and
- R. L. Lovvorn (1936) — soil fertility research and management of peanuts and forages initially moving later to pasture management and weed science.

Research, 1935–40. Though the program had begun to grow after the depression years, there was still very little money for support of research projects in this period. As indicated earlier, C. B. Williams' policy was to recruit the best people he could and to see what they could do with the small amount of funds available (Woodhouse 1979).

Expansion of research activity in this period included new research on soil fertility and fertilization of pastures and forages, cotton, peanuts and soybeans. New research activity also began in the areas of soil physics and conservation.

Soil Survey, 1935–40. A major development in the soil survey program in this period was the introduction of air photos as a base for the field mapping. As indicated by W. D. Lee, "No other factor had a greater impact on any map work than the aerial photo" (Lee 1984). North Carolina was one of the states to pioneer in this technology because of William B. Cobb's experience with this technique in the Air Corps in World War I. No longer did the soil surveyors need to make their own base maps as they proceeded with their work; interpretations of soil patterns could be made from the "air pictures" as they were called.

Other developments for the North Carolina soil survey took place in this period—the start of TVA funding of soil mapping on a cooperative basis (TVA, NCAES, and USDA) in the fifteen westernmost counties of North Carolina and the initiation of soil surveys by the newly founded USDA Soil Conservation Service for purposes of soil conservation Planning. These developments accelerated the soil survey program and also resulted in much less involvement of the NCAES soils program in operational field soil surveys.

Teaching, 1935–40. Following the untimely death of W. B. Cobb in 1934, C. B. Clevenger was appointed to the soils teaching program and also served as Head of the Division of Soils in the Department of Agronomy. He and J. F. Lutz carried the main burden of the soils teaching program until the departure of Mr. Clevenger in 1942.

A listing of soils courses offered by the end of this period (1942) illustrates the progress that had been made in a few years, both in number and breadth of soils courses offered and in number and training of the faculty involved (N.C. State College of Agriculture & Mechanical Arts 1940–41) (Table 2).

Extension, 1935–40. During these pre-World War II years, the extension programs were almost exclusively focused on the county agent level with only a few state level crop commodity specialists. These specialists were directly responsible to the Director of Extension, rather than to the subject matter Departments as is now the case (Jones 1986).

Table 2. Soils courses offered by the N.C. State College Agronomy Department in 1940–41.

Curriculum	Course	Instructor
Undergraduate	General soils	Baver and Clevenger
	Soil fertility	Lutz
	Fertilizers	Collins
	Soil management	Lutz
	Soils of North Carolina	Lutz
Advanced graduate and undergraduate	Soil development	Lutz
	Soil fertility evaluation methods	Piland
	Advanced soil fertility	Baver and Lutz
	Special problems	staff
Graduate	Advanced fertilizers	Collins
	Physics & colloidal chemistry of soils	Baver and Lutz
	Soil physics	Baver and Lutz
	Soil seminar	staff
	Soil research	staff

Move to National Prominence — A World Class Soils Program Begins, 1940–60

A series of fortunate circumstances and situations triggered the events that eventually led to the development of a full-scale and internationally prominent soils program. These events started in 1940 and came to near fruition by the late 1950s.

C. B. Williams retired as head of the Agronomy Department in 1940 after a long and illustrious career of service to North Carolina agriculture. Dr. R. Y. Winters had resigned in 1938 as director of NCAES, and no permanent replacement had been made by 1940. In 1940, Dr. Frank P. Graham, president of the University of North Carolina System, took strong personal interest in filling the two vacant positions (head of the Agronomy Department and NCAES director) so that North Carolina could have the best agricultural program possible. He regarded these two positions as key to that aim. He is reported as stating that he was "looking for a means of really putting the School of Agriculture into a position of leadership and service to the nation." During his recruitment effort to fill these positions, he was reported to have become concerned because people with whom he consulted around the country would give him two lists, one composed of the top people in the field and another list of lesser lights thought suitable for the North Carolina State College positions. He is described as stating, "Quality is all important and if a person is not good enough for the best institution in the USA, he is not good enough for North

Carolina" (Lutz 1979). He was successful in persuading two outstanding soil scientists from Ohio State University, Dr. Robert Salter and Dr. Leonard Baver, to come to N.C. State in October 1940 as director of the NCAES and head of the Agronomy Department, respectively. Although no official records were found for substantiation, common understanding on the N.C. State campus was that President Graham had made oral commitments to Drs. Salter and Baver that strong efforts would be made to increase state funding support and that a Ph.D. program would be established at N.C. State (Lutz 1979).

Soon after Salter and Baver arrived on campus, new department heads were brought in for other departments in the School of Agriculture and new programs were opened. It now is apparent that the soils program and the rest of the agricultural components of N.C. State were on their way to excellence. The soils program had the additional advantage that it had been built on the excellent foundation which had been laid by C. B. Williams and others noted previously.

Dr. Salter left N.C. State for a position in Washington, D.C., a little over a year later, and Dr. Baver was named director of NCAES. Dr. Ralph Cummings—a North Carolina native, N.C. State graduate, and soil scientist by profession—was brought from Cornell University to become head of the Agronomy Department in 1942 at the age of 29.

Many of the major developments in staffing and programs planned and desired by the new administrative team had to await the close of World War II. But several new programs were started in the early 1940s before the full impact of World War II was felt. These included the establishment of the soils extension program, a state-funded tobacco soil-fertility–fertilization program, a pasture and forage research program, and a research program on nitrogen fertilization of corn in combination with optimum production practices.

Research, 1940–45. During the first part of this period the first state appropriation for tobacco research was made and development of a strong state-supported tobacco research program followed, closely coordinated with the previously existing Federal program. Tobacco research had previously been conducted with Federal funds and with personnel located at the Federal Research Station in Oxford, N.C. The first state-supported tobacco research program in the agronomy area was led by J. F. Lutz. With the close of World War II and the consequent increase in funding and addition of new personnel, the tobacco research program was greatly expanded. The leaders of the soil fertility research program for tobacco were Dr. W. G. Woltz and Dr. C. B. McCants, in close conjunction with extension specialists Roy Sennett and S. N. Hawks.

Another soils and crops program started in the early part of this period was pasture and forage fertility management. This program was accelerated in 1940 as a result of the first direct appropriation of state funds for agricultural research (Woodhouse 1979). Dr. W. W. Woodhouse was in charge of the soils aspects of this program, in which role he continued until his retirement in 1975. In the first years of the program, Dr. R. L. Lovvorn was in charge of the crop science component. The team of Woodhouse, Lovvorn and associated extension specialists was chiefly responsible for the introduction of tall-fescue–

ladino pasture mixtures. This program begun in the late 1930s but reached fruition in the 1940s. The development of a pasture and forage program played a big role in the growth and commercialization of the beef and dairy industries in the state, and in other parts of the South. This group was also responsible for the introduction of fescue as a lawn grass, now a common practice in the Middle Atlantic region.

Dr. B. A. Krantz joined the Agronomy faculty in 1943 to conduct research on soil fertility and mineral nutrition of row crops. This program soon focused on high rates of nitrogen application on corn in combination with optimum production practices.

A significant change in 1942 was the transfer of Emerson Collins from soil fertility research to that of extension specialist for soil fertility and fertilizers, the first soils extension specialist at N.C. State.

The soils faculty of the Agronomy Department in 1942, prior to the disruptions of World War II and the following period of great expansion included the following:

- Soil Chemistry: Leland Burkhart, Adolf Mehlich, J. R. Piland and J. F. Reed
- Soil Fertility: R.W. Cummings in charge; W. H. Rankin – small grains and corn; W. W. Woodhouse – forage crops; F. J. Gibson (TVA funded); W. L. Nelson – cotton; W. E. Colwell and N. C. Brady – peanuts and soybeans; J. F. Lutz, E. G. Moss (USDA) and T. L. Copley (USDA) – tobacco
- Soil Physics: J. F. Lutz, R. W. Cummings and W. L. Nelson
- Soil Survey: W. D. Lee in charge, E. F. Goldston and William Gettys (TVA funded)
- Teaching: J. F. Lutz in charge, with others from the research area on a part-time basis
- Extension: E. R. Collins in charge of soil fertility and fertilizers; W. D. Lee part-time in soil interpretations and land use; E. H. Meacham (SCS) in soil conservation.

In World War II, research and graduate training programs were generally interrupted. Major emphasis during this period was production research and technology for quick payoff in food production with some accompanying de-emphasis of basic research (Cummings 1979). However, the soils program was primed to move forward vigorously after the close of World War II. The foundation laid by C. B. Williams, additional funding and staffing, and the drive to excel instilled by the Baver-Cummings administrative team would soon bring the soils program at NCSU to national prominence.

The Post-War Takeoff. Many of the reasons for this takeoff period for soil science at N.C. State can be found in statements made by R. W. Cummings about his philosophy and policies during his term of service as Agronomy Head and Director of the Agricultural Experiment Station:

> "We had during the period that I was Head of Agronomy and Director of the Experiment Station, principally during the period that I was head of Agronomy . . . concern for and success in identifying people with good minds and real promise and who were reasonably free of preconceived notions. . . . we stressed rigor, quality, dedication, energy and real

competence in making the choices (in staffing). We gave a lot of emphasis to giving the people the tools with which to work, a great deal of freedom and at the same time some encouragement."

"As Research Director, I kept attempting to put a little bit more balance in the direction of basic research, realizing that one would exhaust the store of basic knowledge, and one needed to have a continuum from the problems that needed solution at the operational level with the same degree of rigor all the way through to where one is understanding not just what is happening but why . . . . An institution doesn't build its reputation without broadbased good talent" (Cummings 1979).

These approaches, attitudes and policies are generally reflective of those of other agricultural administrators during the grand period of growth of soil science and other agricultural and life science fields at N.C. State in the 1940s and 1950s—including Deans I. O. Schaub, H. Hilton, D. W. Colvard and Brooks James and Director of Research R. L. Lovvorn.

The size of faculty and support staff in soils doubled from 1942 to 1950. Students jammed classrooms; many of these students were returning veterans. Additional funds became available from increased direct state appropriations, from renewed and new Federal programs providing "hard money" formula funds, and from grant funds from various Federal agencies. With these financial resources available the soils program entered the takeoff phase.

Several first and other major developments took place during this period. The first Ph.D.'s with a soils major were awarded to N. S. Hall and N. C. Brady in 1947. However, these degrees were actually awarded through UNC–Chapel Hill because it was the only campus within the UNC system authorized to award a doctorate at that time.

As programs and numbers of soils faculty members increased, the size and quality of the research program grew, and this restriction was soon removed. The first Ph.D. with a soils major actually awarded through N.C. State was in 1949 to D.D. Mason, who later became the long-time Head of the Department of Statistics at N.C. State. Founded by Gertrude Cox, this Department became world renowned in its own right and had much to contribute to the success of soils research programs both then and now.

The first use of radioisotopes for research in North Carolina, and among the first uses anywhere for agricultural research, was initiated in the soils program in 1947 by N. S. Hall. Radioisotopes of phosphorus were used to measure the uptake of phosphorus in the plant and its subsequent translocation within the plant. Radioisotopes became a powerful tool in soil fertility and plant nutrition research during this era.

In 1950, research was initiated by McAuliffe and others to use stable isotopes and mass spectrometry in investigation of soil-plant investigations. This research was among the first use of such technology to study agriculturally related problems in the United States. These techniques enabled very precise measurement of many chemical elements in soils, plants and air—thus allowing study of their fate and distribution in the plant-soil systems. It proved especially useful for studies of nitrogen and of nitrogen's role in soil-plant systems. The original equipment was built on site by McAuliffe, and since replaced by "high tech" commercial equipment in the laboratory of Dr. R. Volk, a current faculty member, who has continued and effectively expanded this research in plant chemistry and soil-plant relations.

Faculty additions during this period included W.G. Woltz who joined the faculty in early 1946 specifically to expand the soil fertility and fertilizer research program for tobacco. In 1949, Clayton McAuliffe (noted earlier) and N.T. Coleman joined the faculty to expand the soil chemistry program; N. S. Hall joined the soil chemistry program after completing his Ph.D. at N.C. State and a period of service at the Oak Ridge National Laboratory. E. T. York Jr. was hired to lead the teaching program in Agronomy and to be the leader of the peanut soil fertility research program. S. L. Tisdale became a member of the Agronomy faculty in early 1949 for research on soil tobacco fertility with teaching responsibilities. S. R. McCaleb joined the faculty in 1949 to start a research program in soil genesis and classification (joint with USDA).

Research, 1945 60. Many of the significant breakthroughs that took place in this period involved close integration of soils and crop research and extension efforts. The first major one was in the corn program (Cummings 1987). By 1944, Paul Harvey of the crops group in Agronomy (originally detailed to North Carolina by USDA for cooperative corn breeding programs) had developed several promising single cross corn hybrids.

In 1943, B. A. Krantz had joined the soils group for research on soil fertility. Using the hybrids developed by Harvey and his colleagues, Krantz in 1944 laid out 11 experimental sites in the coastal plain and piedmont, chosen to represent a variety of soils and climatic conditions. Variable rates of nitrogen applications and spacings were used in carefully replicated experiments on farmer fields. Nitrogen rates were applied over a much wider range and at higher rates than the then conventional practices. The objective was to determine the range of response of corn plants to high nitrogen rates together with sets of optimum production practices.

The resulting responses to high rates of nitrogen and the spacing and population experiments were so successful and spectacular that Extension soil fertility specialist Emerson Collins, Experiment Station Director Baver, Extension Director Schaub and Agronomy Head Cummings, made a special tour of the plots. As a result the Agronomy Department was asked to prepare specifications for corn demonstrations the next season and the Extension Director asked the County Extension Director in each of the 100 counties to conduct at least four corn-nitrogen demonstrations.

W. V. Chandler was detailed to the soils program in 1949 by the USDA to cooperate in completing and writing up the results of this successful program. By use of nitrogen applications up to 150 pounds per acre per year, Krantz and Chandler were able to boost corn yields to more than 100 bushels per acre in their research plots. These results, surprising at the time because several agricultural leaders and farmers had stated that it was not possible to produce 100 bushels of corn per acre in North Carolina, greatly changed the perspective and prospects for corn in the southeastern USA.

In a few years, average corn yields in North Carolina increased from 20–25 bushels to 80 bushels per acre and higher. Corn is now the fifth ranking farm commodity in North Carolina, producing cash receipts of $245 million in 1980 (Krantz and Chandler 1954). This great increase in corn production was also a shot in the arm for the emerging hog and beef industry in North Carolina. A crop that was previously considered useful only for “mule feed” had become one of the leading grain crops in the state. As a veteran research station superintendent put it, “Our people in the coastal plain shifted from growing corn accidentally to growing it on purpose.”

This joint research-extension, soils-crops, state-Federal success with corn is cited here because it paved the way for similar developments in tobacco, peanuts, pastures and forages, small grains and soybeans. The approach and philosophy has been in a significant factor in the development and effectiveness of the Soil Science Department and its sister Department of Crop Science.

Advances in the peanut soil-fertility–mineral-nutrition and crop management area in this period included the identification of different nutrient requirements and methods and times of fertilizer application for the peg (seed pod) of the peanut versus the purely vegetative parts of the plant. This important finding was based on research by W. E. Colwell, N. C. Brady, Fielding Reed and colleagues. This research was further expanded and implemented in practice later by Preston Reid and Fred Cox, who also researched the micronutrient and macronutrient requirements of the peanut.

This period also saw a tremendous expansion in the soils aspects of tobacco research, drawing on the new large infusions of state-appropriated funds. The work by C. B. McCants, W. G. Woltz and associates on soil fertility and mineral nutrition of tobacco included establishment of need for additional magnesium on sandy soils, the plant’s requirements for both ammonia and nitrate sources of nitrogen, establishment of optimum soil levels of phosphorus and potassium, and determination of the amount of nitrogen needed for replacement of that leached out of the root zone by rains, as well as the correlation between mineral nutrition and leaf quality.

For small grains, the introduction of shorter and stiffer-stemmed varieties (especially wheat) by crop breeders G. K. Middleton and Charles Murphy opened the way for fruitful research by Houston Rankin on response to higher nitrogen levels and consequent higher yields. These findings had a strong positive effect on wheat production in North Carolina somewhat similar to that of the corn program previously discussed.

The soybean program also experienced a takeoff during this period based on the foundations of soil fertility and mineral nutrition work combined with optimum sets of production practices developed earlier by Werner Nelson and Jack Rigney, using varieties with germplasm developed for this region by crop scientists, E. E. Hartwig, Herbert Johnson, and Charles Brim (USDA). In the late 1950s and 1960s, this work was picked up and expanded by E. J. Kamprath who worked on the lime requirements to overcome toxic aluminum levels and the fertility needs and by Fred Cox, working on the micronutrient needs and deficiencies. As a result of this combined breeding, soil fertility, and soil management program, soybean production in North Carolina has grown to the point where it was in fourth place among North Carolina crops in cash receipts in 1980 with production exceeded only by Illinois, Iowa and Missouri (Miller 1983).

Another significant development in this period that helped push the Soil Science Department to the forefront in the soil-fertility–mineral-nutrition area was the development of soil testing technology and techniques of soil fertility evaluation research that measured response to nutrients both in the greenhouse and in field plots. This work was done in close cooperation with the N.C. Department of Agriculture, which has the responsibility for performing the soil tests on farmer soil samples.

During this period, and until recently, the position of director of the Soil Testing Division of the NCDA held a joint appointment on the faculty of NCSU, first with the Agronomy Department and later with the Soil Science Department when it was established as a separate Department. Soil testing directors W. L. Nelson, J. W. Fitts, S. L. Tisdale, E. J. Kamprath (and later P. H. Reid in the 1964–70 period) built on the foundation of research on soil fertility and fertilizers that was the initial objective for the founding of the NCAES and the agronomy programs at NCSU. They developed the program, which has become the largest publicly supported soil testing operation in the U.S.

The NCDA Soil Testing Division directors, with their NCSU colleagues and support from the NCDA, conducted field plot and greenhouse research for calibration of the tests for available nutrients and for predicting the yield and growth response serving as the basis for fertilizers and lime recommendations. These recommendations were developed with the input of the appropriate extension specialists.

Dr. Adolf Mehlich also contributed significantly through his soil chemistry research during this period. He conceived and pioneered the now world-renowned, double-acid extraction for measuring soil nutrient levels which could then be calibrated with field and greenhouse tests for more precise fertilizer recommendations. This soil test is used in many of the acid soil regions of the world. Mehlich also developed methodology for measurement of soil acidity as a basis for lime recommendations. This method has been supplemented with procedures for measuring exchangeable aluminum levels as a basis for determining lime needs—the basic concepts and methodology for which were also developed in the Soil Science Department.

The concept of exchangeable aluminum as the major source of the acidity in mineral soils was developed by N. T. Coleman and his colleagues and graduate students in the Soil Science Department during this period. Contributions to the development and acceptance of this concept were also made by Dr. Hans Jenny of the University of California. The subsequent extension and application of this concept through a better understanding of the effects of exchangeable aluminum on plant roots and nutrient uptake was made by W. A. Jackson and colleagues in the Soil Science Department during the latter part of this time period.

The application of these concepts to improve liming practices to overcome the exchangeable aluminum problems in acid mineral soils was developed by E. J. Kamprath and associates, also in the Soil Science Department. More will be said about this contribution in a later section. Coleman and colleagues initially experienced considerable difficulty in their work with exchangeable aluminum in convincing others that the classic concept of exchangeable hydrogen as the sole source of soil acidity must be modified. However, after several years of research, publishing of several papers and the support of Dr. Jenny and some European soil chemists, the concept has become internationally accepted. The basic concept and its extension to plant nutrition and development of methods for neutralizing the aluminum thus stands as one of the major historical contributions of the Soil Science Department.

An important research program initiated in this period was the series of basic studies of nitrogen nutrition of plants conducted by Dr. R. J. Volk. This program utilized ^{15}N and mass spectrometer technology to study the basic concepts of nitrogen uptake and metabolism in plants. The tobacco plant was the primary experimental plant in this early work.

A parallel research program to the nitrogen nutrition work of Volk in this period was the research by Dr. W. V. Bartholomew on the nitrogen cycle components of soils, organic matter, the atmosphere and crop plants. These studies used techniques of biochemistry and microbiology to determine the rate of mineralization of nitrogen from organic materials and the role of microorganisms in these processes. Results were very helpful in making nitrogen application recommendations for crop plants and in determining the effects and benefits of green manure crops.

A research program in soil clay mineralogy initiated by S. B. Weed during this period has made important, interesting and lasting contributions to our understanding of the chemical and physical nature of the soil systems of the state. His work involved the use of X-ray diffraction and related techniques for determining the species, composition, and behavior of the small and rather poorly crystalline clay-sized minerals composing the active fraction of North Carolina soils. The work of Weed and colleagues has shown that a significant component of the surface layers of most North Carolina soils is a newly recognized mineral called “hydroxy interlayered vermiculite” which imparts properties to the soils important in plant growth. The work of Weed complemented the work of C. I. Rich of Virginia, who first reported this important finding. Dr. Weed substantiated the widespread occurrence of these clay minerals and delineated more fully their origin and significance in soil reactions.

Other major research developments and new research directions in this period were the joint research efforts by W. A. Jackson and R. J. Volk on mineral nutrition of plants, soil-plant relations and plant chemistry; coastal studies, especially dune stabilization and marsh reclamation, by W. W. Woodhouse; soil fertility of vegetable crops and sweet potatoes by R. E. McCollum; soil fertility and soil management for commercial cut flower, bulb and blueberry production in southeastern North Carolina by Carlos Bickford; and soil fertility and soil management of vegetable crops in the Mountains by James Shelton. The latter two faculty were housed at research stations in proximity to their work and represent only the second and third off-campus location of researchers at NCSU—the first was L. C. Willis who was located at the Castle Hayne Station near Wilmington for micronutrient research in the 1930s and 1940s after several years of on-campus research. Shelton’s appointment was the first instance of a split appointment between research and extension in a soils faculty position, a procedure which was to become more commonplace later.

Also during this period, a program of research on soil geomorphology and landscape development in the Coastal Plain was initiated cooperatively with the USDA Soil Conservation Service and funded in part by National Science Foundation grants to the Department. R. B. Daniels (USDA) and Ralph McCracken were the project leaders. Components of these studies were the subject of several graduate student theses. This work contributed a much fuller understanding of the origins and properties of Coastal Plain soils and of the important differences among them associated with their landscape positions and origins. This work revolutionized the classification and mapping of Coastal Plain soils and provided a much sounder basis for the soil fertility and management research and extension programs. This work was expanded and extended to the rest of the southeastern Coastal Plain by R. B. Daniels and E. E. Gamble (USDA) with additional significant findings.

A 15-year project of watershed hydrology and small watershed management and conservation in the mountains, supported chiefly by TVA funds, and in close cooperation with that organization also occurred in this period. This field work was conducted on two small watersheds of a few acres each on the mountain research station near Waynesville. Representing the Department in this activity were J. F. Lutz and W. W. Woodhouse with Matt Gilbert and later Charles England as the on-site project managers. The work involved measurement of surface and base flow discharge from the two highly instrumented watersheds under various types of crop and pasture grass cover and tillage practices. The watersheds also were used to measure the movement of various pesticides in the surface and base flow discharges. The research provided significant and useful information on subsoil lateral flow of water and runoff under various cover types and on the potentials for pesticides contamination. The major part of the hydrologic analyses was done by TVA staff at their Muscle Shoals, Alabama, location.

An analytical service laboratory was developed during this period by J. R. Piland, using the most up-to-date technology then available. This facility provided a very useful service of analyses of plant samples for researchers in soils, crops and other Departments of the then School of Agriculture. As described more fully in a later section, the laboratory was placed under the direction of Dr. J. W. Gilliam upon the retirement of Mr. Piland in 1968 and further modernized and automated. It is now under the direction of Dr. Wayne Robarge.

A mark of the growing status and maturity of the Department's research program was the designation of N. T. Coleman as a Reynolds Distinguished Professor in 1960 for outstanding basic research in soil-plant relationships, nutrient uptake and soil chemistry, the first such recognition to come to the Department.

Administrative and Facilities Changes, 1945–60. Williams Hall was completed and occupied in 1952. This construction enabled the soils group to be brought together in one building, giving them adequate facilities in which to work and to be together for greater coordination and mutual support. Previously, soils faculty had been located in several buildings on campus.

W. E. Colwell was designated as Head of the Agronomy Department in 1948 when Dr. Cummings was named Director of the N.C. Agricultural Experiment Station. In 1953, W. E. Colwell was appointed Associate Director of the NCAES for tobacco research and E. T. York, Jr., was appointed to succeed him as Head of Agronomy. After two years, Dr. York resigned to join the Potash Institute. At this time a decision was made to split the Agronomy Department into a Soils Department and a Field Crops Department. The reason given was that the Agronomy Department had grown so large that it had become administratively unwieldy and the programs had become so diverse that it was difficult for one person to administer both crops and soils interests.

The first head of the newly established Soils Department was J. W. Fitts, who previously held a joint appointment as director of the soil testing division of the N.C. Department of Agriculture and professor of soil fertility at N.C. State. The increasing emphasis on research, especially basic research, was recognized by the change of the name of the department to Department of Soil Science in 1960.

Teaching, Post-War to 1960. At the time of the establishment of the Soils Department in 1956, H. C. Folks was designated as the person in charge of the soils teaching program, in addition to his responsibility for research in soil genesis and classification. In 1961, Dr. Folks left to become Assistant Director of Instruction in the School of Agriculture and Life Sciences and in charge of the newly formed Agricultural Institute two-year program.

S. E. Younts of the Potash Institute was appointed to be in charge of soils teaching. Several new courses were established during this period and a great deal of attention was given to advising and counseling undergraduate students on a one-to-one basis. This period was marked by increased numbers of students in the departmental course offerings and an increase in graduate students, including several foreign students.

New courses established in this period included Soils and Plant Growth at the undergraduate level and Soil Mineralogy, Forest Soils, Soil Genesis and Classification, Soil Chemistry Methods and Soil Management at the graduate level.

During the latter part of this period, the graduate training program came into maturity, with a full range of courses and opportunities to major in the recognized subdisciplines of soil science. With the addition of courses mentioned in the previous paragraph, receipt of grant and "hard money" funds to support assistantships and the arrival of outstanding domestic and foreign graduate students, the graduate program moved to national prominence.

Extension, 1945–60. New extension positions in soil management and soil fertility (on full time basis) were established in the late 1950s. W. C. White was the first to occupy the position of Extension Soil Fertility Specialist on a full-time basis; Clifford Martin was the first Extension Soil Management Specialist. The extension program was then operated jointly with Crop Science as an Agronomy Extension program, with Emerson Collins serving as specialist-in-charge.

In the latter part of this period, a trend developed towards involvement of extension specialists in applied research, especially evaluation of experimental fertilizer and pesticide materials and new soil management techniques. Plots were located both on outlying research stations and in farmers' fields. Their plot work used replication and other statistical techniques and some of the results were published in professional journals as well as popular publications. In several cases, faculty had joint extension-research appointments. This trend was accompanied by a parallel trend of faculty researchers undertaking more laboratory oriented basic, fundamental research.

Soil Survey, 1945–60. In the latter part of this period, county officials became much more interested in use of soil surveys for tax assessment, land evaluation and land use planning purposes and therefore became willing to supply funds in support of soil survey in their counties. These funds seemed best used to employ soil surveyors through a state agency, as the size and orientation of the programs would go beyond the capability and the missions of the Experiment Station and Extension Service. Also a tight ceiling on federal employment levels restricted Soil Conservation Service hiring of soil survey personnel. The Soil Science Department withdrew from operational soil mapping in this period, and a unit was formed within the State Department of Natural Resources and Community

Development (NRCD) for soil surveys, largely using county funds. However, the Soil Science Department has continued its strong support of the soil survey program through research, assistance with the planning, review and correlation of the county soil surveys and contributing significantly to the development of a new comprehensive soil classification system now used nationally and internationally.

The Soil Science Department Begins Involvement in International Activities, 1955–63

This period saw the beginning of the participation of soil science personnel in programs of technical assistance and training in and for less developed countries, mostly funded by the United States Agency for International Development (USAID). These were university-wide, school-wide, intra departmental and consortium types of programs. In 1954, NCSU entered into an agreement with USAID and Peru for a program of agricultural assistance and development known as the N.C. State Mission to Peru. The first Chief of Mission was R. W. Cummings.

Since 1955, at least one member of the Soil Science Department has been continuously located in Peru. At times, two to three Soil Science faculty members were on long term (two or more years) duty in that country, in addition to several short term assignments. A few soil scientists were also retained on a visiting professorship basis, either for direct participation in the Peru program or to backstop a faculty member on long-term service in Peru. Soil Science faculty participating in long term assignments in Peru in this time period were Robert McCollum in soil fertility, Frank Doggett in soil management and conservation, Preston Reid in soil fertility, and James Spain in soil management.

This North Carolina mission to Peru closed in 1980 but was reopened on a more limited basis in 1985 as the University-wide Research, Extension and Education Program (REE). Since 1988, the program has continued as the Agricultural Technology and Transfer program (ATT).

Due to the long-term emphasis and expertise in soil fertility, fertilizers and soil fertility evaluation in the Soil Science Department, the USAID in 1960 requested J. W. Fitts, then Head of Soil Science, to manage a multi-year, multi-country technical assistance and training program in soil fertility evaluation, including soil testing, in several Latin American countries. This program was first known as the International Soil Testing Project but later became designated as the International Soil Fertility Evaluation and Improvement Program.

The program called for several soil fertility evaluation specialists to work in a country or group of countries, helping to install or accelerate a soil testing and fertilizer advisory program. These specialists were supported by a small backstopping staff in the Soil Science Department in Raleigh. Initially involved in these within-host-country positions were Carlos Bickford, R. B. Cate, A. H. Hunter, Sam Portch, J. L. Walker and D. L.

Waugh. Drs. Gordon Miner and John Nicholaides were also involved but later joined the Soil Science faculty in Raleigh.

The International Soil Fertility Evaluation and Improvement Program was closed in 1975 after successfully installing soil testing and soil fertility programs in several Latin American countries. Positive accomplishments included increased fertilizer use and improved crop yields, improved soil testing methodologies and specialized equipment for soil testing which are still used in many countries.

The Broadening and Maturing of Soil Science at NCSU, 1960–89

This period can be described as one of broadening, deepening and maturing of all components, of attacking new problems and opportunities including nontraditional ones. Significant growth in numbers of faculty, staff and graduate students occurred. The 1960s, 1970s and 1980s have seen initiation of research, teaching and extension efforts in environmental quality, waste disposal, erosion control and evaluation of soil productivity, soil tillage research, the use of soil science information for urban-suburban areas and the soil science aspects of alternative and sustainable agricultural systems as well as significant expansion of research on mineral nutrition of plants and nutrient uptake in relation to photosynthesis and other basic research in plant chemistry.

International activities have become more fully integrated into departmental programs working in programs which have complementary benefits for the domestic programs and for faculty professional development. New programs on improving productivity of tropical soils in selected countries (soils similar to those in North Carolina), and improving the capability of the faculty to do work with the less developed countries were started. Pedro Sanchez joined the department in 1968 to coordinate these efforts and to focus on research and teaching of tropical soils—bringing with him wide experience and enthusiastic leadership which continues to date.

A Soil Science extension group was established in 1975, split off from the Agronomy Extension group. J. V. Baird was named specialist-in-charge and served in that capacity until 1988. J. P. Zublena replaced J. V. Baird as specialist-in-charge in 1988.

Administrative changes during this period were: J. W. Fitts resigned as head in 1964 to spend full time on the International Soil Testing Project and was replaced by R. J. McCracken. In 1970, McCracken was appointed Assistant Director of Research in the School of Agriculture and Life Sciences (Assistant Director of the Agricultural Experiment Station) and J. V. Baird was named acting head. C. B. McCants was appointed as head in 1971 and he served in this capacity until 1981. When he became director of the management entity for the Soil Management Collaborative Research Support Program, a Title XII, AID funded program. R. H. Miller, from Ohio State University was named department head in 1982, serving until 1989.

Major programs in Soil Science in 1989 are: soil chemistry, soil physics, soil fertility, soil genesis and classification, soil microbiology, soil management, urban soil science, soil mineralogy, soil-plant relations, waste management, forest soils (joint with the College of Forest Resources), coastal management studies, soil analyses, and tropical soils.

Since 1970, the department has grown from 27 to 30 tenure track faculty plus 7 other full time faculty members, from 28 to 44 supporting staff members and from 29 to 54 graduate students. When N.C. State University celebrated its 100th anniversary in 1987, the Soil Science Department ranked as the largest soil science department in the U.S.

In July of 1987, the department moved into its portion of the new Williams Hall addition, with its much-needed additional floor space. This addition has given considerable relief to the previous overcrowding in Williams Hall, allowing technicians and graduate students to come out of the closets, storerooms and "bullpens" for more efficient and effective working conditions.

Research, 1960–89. Research activities of this period reflect new directions and a broadening which were expressions of the philosophy and concerns of the Department Heads and senior faculty in meeting perceived new needs and changing conditions. New directions for this period include new initiatives in

- on-site and offsite waste disposal,
- the investigation of environmental impacts of agricultural practices on environmental quality including ground and surface water (B. Carlisle, A. Amoozegar, D. K. Cassel, J. W. Gilliam, S. W. Buol),
- coastal stabilization and wetland marsh establishment studies (S. W. Broome; E. Seneca, Botany),
- evaluation and development of alternative agricultural systems (L. D. King),
- studies of soil productivity with respect to new concepts and concerns about soil erosion and its control (J. W. Gilliam, R. B. Daniels, D. K. Cassel),
- determination of factors important in soil productivity (R. B. Daniels, S. W. Buol),
- recognition of the growing importance of forestry and forest soil ecology in the state (A. G. Wollum, C. B. Davey),
- basic research on mineral nutrition, nitrogen use efficiency and uptake by crop plants (W. A. Jackson, R. J. Volk) and
- establishment of a tropical soils program and its integration with other departmental programs (P. A. Sanchez, J. Nicholaides, T. J. Smyth).

Titles of research projects established in the last 10 years are indicators of the broadened scope of the departmental research programs: Use of industrial and municipal wastes for soil improvement and crop production, potential of paper mill wastes for soil improvement and crop production, optimization of on-site wastewater disposal systems depending on ground absorption, environmental determinants of crop growth and soil productivity, nitrate and photorespiratory metabolism in C3 and C4 plants at subambient atmospheric oxygen levels, fragile environment utilization in tropical rainforests and evaluation of alternative farming systems (Miller 1983).

In this period, many of the research advances of the previous period have been consolidated, expanded and extended with useful results. An important development with high impact has been the application of the research findings on exchangeable aluminum as the main source of acidity in mineral soil systems. The application is the development of techniques for alleviation of this source of soil acidity, including methods for predicting the amount of lime to apply to overcome the main problem and for eliminating the side effects and including deficiencies of calcium and micronutrient deficiency and toxicity problems. This knowledge and technology has been applied in North Carolina, in other states with similar problems and also in the humid tropics where exchangeable aluminum has been a major barrier to increased food production. E. J. Kamprath has been the main project leader in aluminum research and Pedro Sanchez has played a key role in introducing these new concepts into tropical regions.

Early in the 1960s a forest soils research and teaching program was established in the department, jointly with the Department of Forestry in the then School, now College of Forest Resources. C. B. Davey joined the Department in 1962 with a joint appointment to lead this program which has been successful in providing the research support for forest fertilization programs as well as in helping define the quality of sites for tree plantings. When Dr. Davey was appointed Head of the Department of Forestry in 1970, A. G. Wollum was appointed as a new faculty member with responsibilities in forest soils and soil microbiology.

In this period, S. W. Buol has led a very active program in research in needed modifications and adjustments in the relatively new (1975) Soil Taxonomy promulgated by the U.S. Cooperative Soil Survey. Buol has led International Committees for redefining the Oxisol soil order and for recognition of a previously unrecognized morphologic feature, the kandic horizon, a subsoil zone of high weathering and very low cation exchange capacity important in the southeast and in other warm humid and tropical regions of the world. His studies are leading to major improvements in the international soil classification system, as well as bringing about significant changes in soil mapping and classification in the USA. S. W. Buol and P. A. Sanchez have developed a new practical soil classification and interpretation system which is coming into use in many parts of the world as well as the U.S. called the Fertility Capability Classification (FCC). The FCC predicts the capability of a soil to respond to fertilization and management practices for food and fiber production.

The research program of the department has been enhanced by access to the phytotron facility adjoining Gardner Hall and operated by the College of Agriculture and Life Sciences in cooperation and coordination with Duke University. This facility enables the study of plants under varying environmental and soil fertility regimes. One member of the Soil Science Department, C. D. Raper, Jr., makes extensive use of the facility in his work on plant-microenvironmental interactions. The facility was financed by federal grants and strong support from the tobacco industry.

An important research support facility, the Analytical Service Laboratory was further developed, automated and equipped with new instrumentation in this period. Leadership was provided by J. W. Gilliam, Maurice Watson (now at Ohio State University), and W. P. Robarge. This laboratory continues to provide a wide range of chemical analyses of plant materials for researchers in Soil Science and other departments of the Colleges of Agriculture and Life Sciences and Forest Resources.

Teaching, 1960–89. Two significant curriculum additions were made during this period.

- A Conservation Curriculum was added at the 4-year undergraduate level in 1970, in cooperation with the Department of Forestry. This curriculum was a response to student need for more training and background knowledge of our natural resources for improved conservation and management.
- Secondly, a Soil Management Curriculum, including a set of three new courses, was added to the Agricultural Institute (two year) program in 1968. The courses added were Principles of Soil Science, Fertilizers and Soil Fertility, and Soil Management and Conservation. Although the curriculum is no longer offered, the Department continues to teach all but Soil Management and Conservation.

Several new courses have been added at undergraduate and graduate levels to help students meet current problems and opportunities:

♦ Undergraduate level (4-year program):	Water Management Soil Resources and Land Use Alternative Agricultural Systems
♦ Undergraduate and Graduate Level:	Soil-Crop Management Systems
♦ Graduate level:	Soil and Plant Analysis Advanced Forest Soils Tropical Soils: Characteristics and Management

The past three decades have seen further growth and development of a very strong and active undergraduate Agronomy Club, cosponsored with the Crop Science Department. However, the most outstanding indication of accomplishments in the teaching program has been the success of soil science graduates. For example, seven soil science graduate students have been named to positions as Department Heads, Directors of Experiment Stations and Deans.

Leadership in the academic affairs program has changed during this period. In 1961, H. C. Folks was appointed Assistant Director of Resident Instruction in the School of Agriculture and Life Sciences and S. E. Younts was appointed to replace him. Dr. Younts resigned in 1964 to join the Potash Institute in Atlanta (he later became Vice-President of the University of Georgia). M. G. Cook was appointed teaching coordinator in 1965 and served until 1985 when he asked to be reassigned to the extension faculty in Soil Science. Joe Kleiss is the current teaching coordinator.

Extension, 1960–89. The number of extension personnel in Soil Science has increased five-fold since the early 1960s—from one to approximately five full time equivalents.

Increased staffing and program activities include land use planning using soil interpretations, on-site waste disposal, soil tillage and management, soil fertility and management in the Blacklands (organic soils of northeastern North Carolina) and vegetable, fruit crop, and ornamental production in the mountains. The extension program is operated in close coordination with the commodity specialists in the Crop Science and Horticultural Science Departments and with the Soil Testing Division of NCDA.

International Programs, 1960–89. As previously indicated, the International Soil Testing Project closed in 1975 after successfully introducing soil testing and fertilizer advisory programs in a number of Latin American countries.

In 1972, the Soil Science Department received funding from USAID for research on tropical soils primarily in Peru and Brazil. This program has focused mainly on characterizing and understanding soil acidity in tropical soils and techniques for correcting it, overcoming phosphorus deficiencies in the red soils of the tropical savannas, and soil fertility-soil management programs for sustainable agriculture on soils cleared from humid tropical forests. The objective was to obtain basic information to serve as a foundation for technical assistance, technology transfer and training programs in less developed countries most in need of increasing their productive capacity and conserving their natural resources. The tropical soils research program is still active and continues to evolve to a more resource conservation emphasis. The strong similarity of soils in the humid tropical regions to those in North Carolina has been of great importance for maintaining the strength and focus of the tropical soils program within the department.

The Soil Science Department was a member of the 4-University Consortium on Soils of the Tropics awarded a grant for development of faculty knowledge and capabilities for participating in technical assistance, technology transfer and training programs in tropical soils of less developed countries. This program came to be known as the 211 (d) program, in reference to the section of the Foreign Assistance Act which authorizes and encourages such activities. This program enabled department-wide familiarization with tropical soils and with principles and techniques for low cost, low input sustainable agriculture, plus a better understanding of the nature, properties and productivity of the soil resources of the world, especially in the tropics. This grant terminated in November 1975.

The renewal of the University-wide Research, Extension and Education program in Peru in 1982 has meant additional International involvement for the Soil Science Department. In 1987, three members of the Soil Science Department were in the REE program—as Chief of Party, Research Advisor and Extension Advisor.

In 1981, the Soil Science Department of NCSU with three other U.S. universities, was asked by the Agency for International Development (AID) to develop a tropical soils research program under Title XII called the Soil Management Collaborative Research Support Program or Soil Management CRSP. This program was designed to research methods for increasing productivity and production of tropical soils in a number of Latin American, African and Far East less developed countries in differing agro-ecological zones. The other three universities are Cornell University, University of Hawaii and Texas A&M University. The program is known by the acronym TROPSOIL (for Tropical Soils Program). The Soil Science Department has conducted field studies in cooperation with the host country agricultural research organizations in the humid tropical jungle area of the

Upper Amazon Basin in Peru near Yurimaguas and Manaus, Brazil, and in the humid rainforests of Sumatra, Indonesia. Land clearing, soil fertility and liming needs and soil and management practices for efficient, low cost sustainable agricultural production were the objectives of the initial research. Pedro Sanchez and John Nicholaides were the on-campus coordinators of the program for the Soil Science Department until Dr. Nicholaides left in 1985 to head the International programs in agriculture at the University of Illinois. Dr. Sanchez continues as coordinator and Dr. T. J. Smyth, faculty project leader at Manaus, Brazil (1982–87) was returned to campus to replace Dr. Nicholaides.

Long standing involvement in international programs by the department has resulted in better research, teaching and extension programs in soil science at NCSU. Many of the soils in the less developed countries in which Soil Science Department people have worked are similar to those in North Carolina, except for being a little more acid, infertile and weathered, in some instances. Working with soils which are a little more extreme in these respects has helped in understanding North Carolina soils and how they can be improved. Many pieces of information and technologies developed or learned in the International programs have been adapted to North Carolina conditions for the benefit of North Carolina agriculture. Particularly important are techniques in low cost, low input sustainable agriculture and alternative agricultural practices.

Summary—A Look Back and A Look Ahead

The purpose of a historical study of an organization is more than merely to satisfy idle curiosity about the past—it is to recognize and honor those who contributed to the founding, past successes and setting of the course for the organization. It is also to learn from the past so that opportunities and challenges of the future may be successfully met.

The success story of Soil Science at N.C. State can be attributed to the vision and foresight of the earlier administrators and educators in the School (now College) of Agriculture and Life Sciences and by the University administration; the dedication, loyalty and wisdom of the departmental faculty and staff; the continuing solid support from the state's citizens; and the Positive and forward-looking actions of the state's agricultural, educational and political leadership. The recent addition to Williams Hall is brick-and-mortar evidence of that support. This support has come from the policy of involving the people in the planning of programs, keeping them well informed and, most importantly, keeping the programs current and relevant to the needs of the state. Another strong success factor has been the continuing good cooperation with and support of the N.C. Department of Agriculture and the USDA's Soil Conservation Service and Agricultural Research Service.

The Soil Science Department has been able to avoid the pattern we sometimes observed elsewhere—in which there has from time-to-time been an outstanding department for a period of years, followed by periods in which the program reverts to a lower status of recognition and achievement. This has been avoided in the Soil Science Department by maintaining a mix of experienced and active "old hands" and "young comers" by continuing efforts on part of the faculty and administration to keep the research and teaching programs up-to-date, and by an effective and aggressive extension program which has provided feedback on the research and educational needs of the state and carried research results to all parts of the state.

The program has been able to maintain a well-balanced mix of basic and applied research. No other Department in the country can claim the distinction of having one of its top professors receive a national award for applied research excellence as well as an Honorary Doctorate (E. J. Kamprath, 1986) in the same time period other professors (including W. A. Jackson and R. J. Volk) in the Department were receiving national and international recognition for very basic, on-the-frontier research.

The challenges and problems which lie ahead for the department seem even more demanding than those of the past. Based on past performance, continued sound leadership, excellent personnel and continuing public support, we can be assured the department will meet these challenges as successfully as it has those in the past.

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Appendix I. Chronology and Landmarks

1877	Albert Ledoux becomes first state chemist (predecessor to position of director of NCAES) with responsibility for analysis of fertilizers, determination of which fertilizers best suited for North Carolina soils and to conduct experiments on nutrition and growth of plants, in Chapel Hill.
1880–87	Charles William Dabney — director of NCAES: pioneering studies of exhaustion of plant nutrients by cotton, wheat, and tobacco; analyzed plants for nutrient content and related these to fertilizer needs, studied and evaluated nitrogen and phosphate fertilizer sources, predicted that North Carolina phosphate beds would be a great resource in the future, urged establishment of experimental farm, moved program to Raleigh.
1885	acquisition of first experimental farm, in West Raleigh
1886	first outlying soil fertility trials in farmers fields
1886–87	Milton Whitney—superintendent of experimental farm: began first greenhouse pot cultures to determine plant food requirements of crops, started lst research on physical properties of soils in relation to plant growth
1898	first offering of a course specifically identified with soils: Soil Physics for seniors (main drainage technology)
1900	Start of first soil survey in North Carolina: Raleigh to New Bern area, one of first in U.S.
1901	Statesville area soil survey report describes serious erosion and suggests control and conservation measures—one of first statements of concern for erosion and suggesting remedial measures
1907	C. B. Williams become director of NCAES; Adams Act (Federal) increases funding allowing establishment of first federally funded soil research projects; “study of soil nitrification with reference to the bacterium concerned” (first mention of soil microbiology research in North Carolina) and another on “relation of geology and chemistry of soils to productivity and fertilizer requirements”
1910	M. E. Sherwin named as first professor of soils
1914	Soil sections established in Division of Agronomy: soil fertility, soil chemistry, soil survey

1917	C. B. Williams named as first dean of agriculture
1924	School of Agriculture established
1929	Research initiated on minor element deficiencies and toxicities in North Carolina; immediate results with discovery of value of boron for alfalfa growth; relocated to Wilmington area in 1940s as first instance of location of research personnel away from Raleigh
1935	At time of name change to N.C. State College, all departmental curricula, including Agronomy, revised for better preparation of students, soils curriculum revised to give more scientific basis for soil management and soil fertility
1937	First direct appropriation of state funds for agricultural research (funded by fertilizer tax receipts through NCDA and by federal funds prior to this time)
1940	C. B. Williams retires after long illustrious career; G. K. Middleton named acting head
1940	Robert M. Salter (soil scientist by profession) appointed director of NCAES and L. D. Baver appointed as head of agronomy department (also soil scientist by profession): marked start of move of soil science and crop science to world class programs
1940	Ph.D. program approved for agronomy (with soils and crops majors)
1941	L. D. Baver appointed director of NCAES upon resignation of Salter
1942	First designation of "extension specialist" in soils—Emerson Collins designated as soil fertility and fertilizer specialist in addition to duties as specialist-in-charge of agronomy extension
1942	R. W. Cummings (soil scientist by profession) appointed head of agronomy department
1947	N. S. Hall and N. C. Brady receive first Ph.D. in agronomy with soils major (awarded through UNC–Chapel Hill)
1947	First research in North Carolina on use of radioisotopes, in soil fertility and soil chemistry programs; among first research efforts in U.S. using radioisotopes in agricultural research
1948	W. E. Colwell appointed head of agronomy department upon designation of Cummings as director of NCAES

1950	Equipment designed and first research initiated using stable isotopes and mass spectrometry, among 1st such research in USA
1952	W. E. Colwell (soil scientist by profession) appointed head of agronomy department upon designation of Cummings as director of NCAES
1953	Completion of Williams Hall
1953	E. T. York becomes head of agronomy department, Colwell to associate director of NCAES for tobacco research
1956	Soils department established with J. W. Fitts as first head
1960	N. T. Coleman named first Reynolds professor in soil science department for outstanding basic research in soil-plant interactions, plant nutrient uptake and soil chemistry
1962	Names change to soil science department
1962	Soil science department initiates International Soil Testing and Soil Fertility Evaluation Program (with AID funding support)
1963	J. W. Fitts moves to full-time position with International Soil Testing Program; Ralph J. McCracken appointed as head of soil science department effective 1/64
1963	Initiation of research program for coastal dune stabilization and vegetation stabilization through fertilization and vegetation management—first nonfarm related soils research
1968	Soil management curriculum added to Agricultural Institute with three new courses for training in applied soil science and technology
1968	Conservation curriculum added as interdisciplinary program with soil science department participating—response to increased concern about natural resources
1970	Environmental quality (water quality) research undertaken marks broadening of soil science research program to include environmental quality
1971	C. B. McCants becomes third head of soil science department as McCracken named assistant director of NCAES 7/70; J. V. Baird as acting head to 1/71

1971	Department undertakes Tropical Soils Research Program led by Pedro Sanchez to improve soil productivity in less developed countries
1972	W. A. Jackson named as second William Neal Reynolds professor in soil science for international recognition of research in soil science, plant nutrition and photosynthetic efficiency
1972	Waste disposal research commences with new full-time position; extension programs in nonfarm soil interpretations and in waste management initiated
1981	Start of Tropical Soils (Tropsoils) technical assistance program with less developed countries in cooperation with other U.S. universities through AID funding
1981	E. J. Kamprath named third William Neal Reynolds professor in soil science
1982	R. H. Miller becomes fourth head as C. B. McCants transfers to full-time director of the management entity, soil management CRSP
1983	W. A. Jackson selected as the first alumni distinguished graduate professor at N.C. State in recognition of outstanding graduate instruction and scholarly research
1984	New program in alternative, sustainable agriculture initiated
1986	E. J. Kamprath receives Soil Science Society of America applied research award
1986	Soil science personnel move into new addition to Williams Hall
1987	E. J. Kamprath receives honorary doctorate from the University of Nebraska
1989	R. H. Miller resigns as department head. E. J. Kamprath becomes acting head

Appendix 2. Soil Science Department faculty, including soil scientists affiliated with former Agronomy Department

Period of Service	Name	Field of Activity or Position Held
1877–80	A. R. Ledoux	fertilizer analysis & soil fertility; state chemist
1880–87	C. W. Dabney	fertilizers, plant nutrient needs, director NCAES
1886–90	M. S. Whitney	soil-plant relations; supt. research farm
1887–97	H. B. Battle	fertilizer analysis; director NCAES
1897–99	W. A. Withers	agricultural chemistry; director NCAES
1900–07	B. W. Kilgore	lecturer on soils & fertilizers; director NCAES
1902–06	C. K. McClelland	general soils; asst. professor of agriculture
1903–04	B. F. Walton	soil-plant field experiments
1907–40	C. B. Williams	agronomy, director & vice-director NCAES; head agronomy dept.
1908–09	C. M. Conner	professor of agriculture, taught lst soils course
1908–10	C. L. Newman	professor of agriculture, general soils
1909–10	W. M. Lunn	instructor in soils
1909–24	M. E. Sherwin	soils teaching—lst designated professional position in soils
1913–15	J. K. Plummer	soil chemist—first designated soil chemist
1913–20	L. L. Brinkley	soil survey
1913–20	R. C. Jurney	soil survey
1913–20	S. O. Perkins	soil survey

1913–20	W. F. Pate	"agronomist in soils"
1913–14	F. N. McDowell	"agronomist in soils"
1914–15	H. L. Joslyn	instructor in soils
1914–15	E. C. Blair	agronomist in soils
1921–25	R. W. Green	agronomist in soils
1921–25	S. K. Jackson	agronomist in soils
1921–55	W. D. Lee	soil survey leader; extension
1921–25	S. F. Davidson	soil survey
1921–25	W. A. Davis	soil survey
1921–25	R. B. Etheridge	instructor in soils
1924–25	W. F. Pate	soils teaching
1925–34	W. B. Cobb	teaching, soil survey, geology
1925–45	L. G. Willis	soil chemist, micronutrients
1925–33	H. B. Mann	soil fertility, fertilizers
1926–30	S. R. Bacon	soil survey
1928–30	F. Davis	soils teaching
1929–75	E. F. Goldston	soil survey
1929–68	J. R. Piland	soil analysis
1931–75	J. F. Lutz	soil physics, soil conservation
1931–75	W. H. Rankin	soil fertility — small grain
1934–42	C. B. Clevenger	general soils teaching

1936–65	E. R. Collins	extension soil fertility and agronomy specialist-in-charge
1936–38	R. L. Lovvorn	soil fertility & mgmt.— pastures; later director NCAES
1936–75	W. W. Woodhouse	soil fertility — pastures & forage
1938–70	A. Mehlich	soil chemistry
1940–42	L. D. Baver	soil physics, head agronomy dept.; later director NCAES & dean of agriculture
1941–45	G. A. Herring	soil chemistry — analyst
1945–46	L. Burkhart	soil chemistry, soil fertility
1946–50	J. F. Reed	soil chemistry
1941–54	W. L. Nelson	soil fertility, soil testing
1942–56	R. W. Cummings	soil fertility, head agronomy dept., director NCAES
1943–49	B. A. Krantz	soil fertility — corn
1945–75	J. F. Doggett	extension — soil conservation
1945–52	W. L Lott	soil fertility & chemistry — fruit
1946–56	W. E. Colwell	soil fertility & soil mgmt., head Agronomy Dept.
1946–56	N. S . Hall	soil chemistry — radioisotopes
1948–60	M. Gilbert	soil management — wastesheds
1949–52	W. V. Chandler	soil fertility — corn (USDA)
1949–60	N. T. Coleman	soil chemistry
1949–55	H. E. Evans	soil-plant relations

1949–55	C. D. McAuliffe	soil chemistry — stable isotopes
1949–56	S. B. McCaleb	genesis & classification; mineralogy
1949–57	S. L. Tisdale	soil chemistry, soil testing
1949–55	E. T. York, Jr.	soil fertility, in charge teaching; head agronomy dept.
1951–55	T. J. Mann	tobacco-mgmt. & fertility
1951–55	E. V. Miller	soil management
1952–55	A. C. McClung	soil fertility — small fruits
1952–60	C. H. M. Van Bavel	soil physics (USDA)
1954–55	M. E. Harward	soil fertility, chemistry
1954–76	J. W. Fitts	soil testing; head soil science dept.
1954–present	R. J. Volk	soil-plant relations
1955–present	W. A. Jackson	soil-plant relations
1955–68	P. H. Reid	soil fertility, soil testing
1955–present	E. J. Kamprath	soil fertility, soil testing
1956–64	H. C. Folks	in charge teaching, soil genesis; later, asst. director of instruction SALS
1956–76	W. V. Bartholomew	soil microbiology
1956–89	C. B. McCants	soil fertility-tobacco; head soil science dept.; director TROPSOILS
1956–73	R. J. McCracken	soil genesis; head soil science dept.; assoc. director NCAES
1956–present	S. B. Weed	soil chemistry, clay mineralogy

1957–70	B. Baird	soil mgmt. & soil fertility
1958–60	J. M. Brown	extension soil management
1958–76	A. H. Hunter	soil fertility, soil testing
1958–62	E. O. Skogley	soil chemistry, teaching
1958–70	D. Craig Williams	soil chemistry
1959–64	W. C. White	extension soil fertility
1959–89	R. E. McCollum	soil fertility
1959–present	J. E. Shelton	soil fertility
1961–66	C. B. England	soil management — watersheds
1961–65	R. J. Miller	soil chemistry
1961–64	S. E. Younts	in charge teaching, soil fertility evaluation
1962–present	F. R. Cox	soil fertility
1962–present	G. A. Cummings	soil fertility
1962–66	R. A. Leonard	soil chemistry
1962–89	C. K. Martin	soil management
1962–65	J. M. Spain	soil management
1963–present	C. B. Davey	forest soils, joint appt. - forestry & soil science
1963–present	J. B. Weber	herbicides — soil chemistry; joint appt. crop science & soil science
1964–present	J. V. Baird	extension soil fertility; specialist-in-charge
1964–66	J. S. Barnes	soil fertility
1964–66	R. E. Hanes	coastal studies

1964–71	D. L. Terry	tobacco soil fertility
1964–74	J. L. Walker	soil fertility evaluation
1964–66	J. R. Woodruff	soil fertility
1965–72	R. B. Cate	soil fertility evaluation
1965–present	M. G. Cook	in charge soils teaching; extension soil management
1965–present	J. W. Gilliam	soil chemistry, soil analysis
1965–75	C. D. Sopher	soil management
1965–74	D. L. Waugh	soil fertility evaluation
1966–present	S. W. Buol	soil genesis & classification
1966–75	G. L. Jones	agronomy extension specialist-in-charge
1966–76	M. Watson	soil analysis
1968–76	L. E. Aull	extension soil interpretations
1968–71	C. Mulchi	tobacco soil fertility
1968–89	J. Phillips	soil interpretations on site systems, asst. director, cooperative extension, NCSU
1968–present	P. A. Sanchez	tropical soils
1969–present	C. D. Raper	plant-environmental relationships
1969–71	T. R. Tonkinson	soil-plant relations
1970–present	J. P. Lilly	soil fertility
1970–present	E. D. Seneca	coastal studies, joint appt. botany & soil science; head botany
1970–present	R. W. Skaggs	soil water, joint appt. bio. agr. eng. & soil science

1970–77	E. E. Gamble	soil geomorphology (USDA)
1972–84	B. Carlisle	waste disposal — soils
1972–present	A. G. Wollum	soil microbiology
1973–present	S. W. Broome	coastal studies
1973–present	G. S. Miner	tobacco fertility
1974–present	D. K. Cassel	soil physics, waste mgmt.
1974–85	J. Nicholaides	tropical soils
1975–present	L. D. King	waste mgmt., alternative agriculture
1975–present	H. J. Kleiss	soil genesis & classification: teaching coordinator, soil science
1975–present	G. C. Naderman	soil management extension
1976–present	D. A. Bandy	tropical soils research & chief of party (REE)
1977–present	D. W. Israel	soil-plant relations, joint USDA
1978–81	G. F. Peedin	tobacco soil fertility & mgmt.
1978–present	W. P. Robarge	soil & plant analyses, acid deposition impacts.
1979–84	C. G. Cogger	on-site waste management
1981–84	F. W. Simmons	soil management
1981–present	M. J. Vepraskas	soil physical properties
1982–present	H. L. Allen	forest soils; joint appt. forestry & soil science
1982–87	J. R. Benites	tropical soils
1982–present	R. B. Daniels	soil genesis & geomorphology (also 1958–74 soil geomorphology USDA)

1982–present	G. D. Hoyt	soil management
1982–present	R. H. Miller	head soil science dept.
1982–present	T. J. Smyth	tropical soils
1983–88	H. P. Denton	soil management
1983–present	M. T. Hoover	extension waste management
1984–88	D. T. delCastillo	soil management (Peru)
1984–87	P. McDaniel	lecturer: teaching, soil genesis
1985–present	J. C. Alegre	soil physics, tropical soils (Peru)
1985–present	A. Amoozagar	waste management
1985–87	W. B. Couto	tropical soil genesis & classification
1985–present	M. D. Openshaw	soil management, tropics
1988–present	C. A. Palm	tropical ecology, agriforestry
1987–present	L. T. Szott	soil ecology, agriforestry
1988–present	J. P. Zublena	soil fertility, extension specialist-in-charge

Organic Soils

J. P. Lilly
Extension Soil Science Specialist (retired), North Carolina State University

Introduction

Eastern North Carolina has as many as 1.5 million acres of peat and muck soils. There are many more acres of land with enough organic matter in the topsoil to influence the use of the soils. These soils occur almost exclusively in the tidewater and lower coastal plain regions. The flat topography, impermeable subsurface layers (aquatards), large distances between streams, and high rainfall combine to create conditions under which organic matter can accumulate.

Organic soils (histosols) do not exist at the latitude of North Carolina without poor drainage. They are, by definition, wetlands in their natural state and are known as swamps, pocosins, bays, marshes, and bogs. Some even go by the old English designation of "desert."

It is estimated that there were over 2.2 million acres of pocosins in the state in 1962. Many of these soils have been modified for agricultural, forestry, or other uses. There is a long history of attempts to "reclaim" such land, but activity has declined substantially in recent years due to wetland regulations.

History

The first European settlers entered northeastern North Carolina by land from tidewater Virginia. They viewed the wetlands as wastelands and a hindrance to land development. At the time, all agriculture was slash and burn, with its constant demand for fresh land. The Europeans did not have the equipment and technology to convert the swamps to agricultural uses or to effectively utilize the forest resources of the wetlands.

By the early 1700s, the Great Dismal Swamp of North Carolina and Virginia was being utilized for timber, mainly cypress and juniper. Much of the timber was converted to shingles where the trees were felled. Shingles were then carried out of the swamp by hand, mule cart, or barge.

Also by the early 1700s, there was a shortage of agricultural land in the region. Even though there was interest in clearing swamp land, little was accomplished. In 1763, just before the American Revolution, George Washington and his associates acquired 40,000 acres in the Dismal but were never successful in developing swamp land for agricultural use. However, they did dig a canal at Lake Drummond to facilitate logging, and this canal (called the Washington Ditch) is generally considered to be the oldest canal still in use in the United States.

Less formidable, more easily drained wetlands were being developed even earlier around Lake Mattamuskeet. Soon after 1700, the English government allowed settlers into the south Albemarle and Pamlico regions. The Hyde County area was settled during this time and named in 1711. Hyde was designated a county in 1738 and is the oldest surviving county in North Carolina.

By 1711, records show that all desirable land along navigable streams had been claimed, and there was pressure to find new land. The settlers naturally utilized the well-drained land first but, undoubtedly, began to make use of more poorly drained very early.

The Revolutionary War changed land ownership and use patterns considerably. The English government had controlled land ownership through land grants and other means. After the Revolution, all unclaimed lands became state property, and the state was interested in developing as much of it as possible.

Essentially the only industry and the only outlet for investment in America was land. Citizens of the new nation of the United States were not allowed to invest in English-controlled countries or territories. Land was wealth, and land investment and speculation were very popular.

Veterans of the Revolutionary War were given land by the newly formed government. The western lands of Tennessee, Kentucky and Ohio were attractive but isolated from markets and subject to hostile Indian attack. Some investors decided to turn their attention to the only remaining undeveloped land in the east—the swamp lands. Rice was being cultivated in the coastal zone from Virginia south and was an attractive crop. However, swamps were believed to produce malaria, and swamp drainage was believed to improve the public health.

Several ambitious projects were started in the larger swamp lands at about the same time immediately after the Revolutionary War. One was the digging of the Dismal Swamp Canal. The other was the Collins Plantation project in what was later to become Washington County.

The Dismal Swamp Canal was intended to open water transportation between the port at Norfolk and the inland waters of northeastern North Carolina. North Carolina had a treacherous coast with poor and shallow inlets to the ocean. Nor really good ports existed.

Digging of the canal began at each end in 1793. The canal was essentially completed in 1805, but there were no locks. Locks were added by 1812, providing 19 feet of lift for passage through the middle of the swamp. The Great Dismal, like many coastal swamps in the Tidewater area, is an elevated pocosin-type swamp that is higher in the center than on the edges.

The canal was a limited success for water transport, but it had the unexpected effect of draining swamp land to the east of the canal. The spoil bank and the canal itself intercepted the eastward flow of water and diverted it, making the land relatively easily drained. This land was very rapidly utilized for agriculture. With additional drainage over the years, it is estimated that only one third or less of the original swamp remains today.

The other major development in organic soils was at Lake Phelps, at times called Lake Scuppernong. The lake was not known to exist by Europeans until 1755, even though Indians had utilized it for over 4,000 years. In 1784, a group of businessmen from Edenton, led by Josiah Collins, received permission to drain the lake from the North Carolina General Assembly. Lake drainage was a common practice for developing agricultural lands in other parts of the world, including the Netherlands and England.

The Collins group acquired rights to nearly 170,000 acres of land lying from the Alligator River west to the area around Lake Phelps. The lake was not drained, however, because a survey revealed that the lake was higher than the Scuppernong River and could supply water power, irrigation, and water transport. Slaves were procured from Africa, a canal was dug from the lake to the Scuppernong River, and land was cleared north of the lake for farming. So far as is known, this project was the first in North Carolina to use deep organic soils on a large scale.

Records indicate that the cleared land was forested in cypress and had over three feet of organic surface with numerous buried cypress logs. Land clearing was very laborious. Trees were girdled and left to die and then to fall on their own. They were then cut into lumber on the plantation. Lumber sales were a significant part of the plantation's income.

Over time, Collins became the sole owner of this plantation, called Somerset Place. Rice was the first crop grown, but problems with malaria led to a shift to corn and wheat. Other land developers soon followed, notably the Pettigrew family on an adjacent plantation called Bonarvia.

The apparent success of these developments attracted widespread attention from the agriculturists of the time. One of the best known and most active was Edmund Ruffin of Virginia. Ruffin farmed near Richmond but had some experience with organic soils along the James River. He was very interested in sustainable production.

Edmund Ruffin was the first person to argue that the black soils of the South were peat lands similar to those of Europe. At the time, European scientists rejected the notion that organic soils could exist as far south as Virginia and North Carolina. Their experience was mainly with peat bogs, which owed their existence primarily to cool climate. Ruffin republished European articles on peat soils in his agricultural journal, the *Farmer's Register*.

Ruffin was an astute observer and saw that black soils subsided when drained. When he visited Somerset Place in 1839, he found an estimated 5,000 acres of land being farmed by five or six proprietors. When Ruffin revisited the area in 1857, he found evidence that at least three feet of organic surface had been lost since the field ditches were dug. Ruffin published his findings in his book of 1861 and argued at length for the reality of subsidence.

Ruffin also described land abandonment in Hyde County due to loss of land elevation near the Pamlico Sound. Land development in wetland soils had been ongoing for many years in Hyde County. By 1839, Ruffin estimated that there were 32,000 acres of land in cultivation around the lake. In 1861, Ruffin described this land as " . . . the most extensive and important of all the drained and cultivated swamp lands on the Atlantic coast, and also the oldest of such improvements." He included soil profile descriptions and soil chemical analyses in his book.

During the time period preceding the Civil War, the state of North Carolina tried vigorously, but unsuccessfully, to develop other swamp lands. The Board of Internal Improvement promoted swamp drainage from 1819 until 1826. In 1825, the state Literary Fund was established to support public education. All remaining state-owned swamp lands were turned over to the Board to be used to raise money for public education.

The state began surveying the swamp lands in 1827. Activity greatly increased in 1836 after the state received a windfall payment as their share of the monies realized from the sale of western lands. The state received over $1,400,000, paid off the state debt of $400,000, set aside $100,000 for current expenses, and richly endowed the Literary Fund. At the time, these were huge amounts of money.

The Literary Board set aside $200,000 for swamp land drainage. Between 1838 and 1842, it had canals dug at Pungo Lake, Alligator Lake, and Lake Mattamuskeet. Over the next 10 years, the Board tried to sell land but sold very little and at very low prices.

Later, in 1855, a canal was dug into Open Ground Swamp in an attempt to open that land to development. Ruffin visited Open Ground in 1856 and proclaimed it totally worthless for agriculture. The Civil Was ended this era of land development and bankrupted both the state and the plantation economies of the larger farming operations.

Rich and Not-So-Rich Soils

The problem of land development during the first half of the 1800s was that all black soils are not created equal. In fact, this problem was still manifested even into the 1970s and 80s. Compounding the problem was the lack of understanding of soil fertility and chemistry.

Some soils were very productive, but others were not, and the reasons why were not clear. In the early 1800s, Ruffin and others wrote at length about the richness of the swamp soils and their continuing fertility. This was a time when agriculture was still based on slash and burn, and commercial fertilizers and limes were not understood, nor were they available.

Soils around Lake Mattamuskeet were described as productive for as long as 70 years, which was unheard of on upland soils of the time. The main reason for the continuing productivity was most likely the release of nutrients from the decay of the organic soil itself, especially phosphorus.

The main cropping pattern was continuous corn intercropped with peas. Hogs were fattened on the peas and waste corn. The corn received nitrogen from the peas and phosphorus from decay of organic matter. Many nutrients, notably potassium, were recycled in this manner. In addition, hog manure provided some nutrients. This system was apparently sustainable for the relatively low-yielding corn of the time.

Another very important factor contributing to the fertility of these soils was the higher-than-expected base saturation of the some of the underlying mineral soils of Hyde County. These parent materials are quite young and less highly weathered than more upland soils. This circumstance could have contributed to the long-term sustainability in the absence of lime use.

The cropping system at Somerset Place was different, with a corn-wheat-fallow rotation. In addition, Ruffin had recommended lime use, and some lime was being applied at Somerset Place. Ruffin is credited with realizing the need for lime on the acid soils of the south, and he published a book on the subject.

The agricultural successes in some places and failure in others prompted the State of North Carolina to hire Edmund Ruffin as a consultant in the 1850s and to commission a book, which he titled *Sketches of Lower North Carolina and Similar Adjacent Lands*. This book describes agriculture in several areas of the state, including Edgecombe County, the area north of Albemarle Sound, Lake Phelps, and Lake Mattamuskeet. The book makes recommendations for agricultural improvement in each area. The book also contains sections on forestry and on the barrier islands.

Ruffin's book was published in 1861 by the Institute for the Deaf and Dumb in Raleigh and was immediately forgotten due to the trauma of the Civil War. Ruffin himself was never able to accept defeat in the war and committed suicide at its conclusion. This aspect of his life has tended to overshadow his monumental contributions to agriculture of the time.

Ruffin's book includes some of the first, if not the first, soil profile descriptions of wetland soils in North Carolina as well as soil analyses. His greatest contribution was his unusually clear interpretation of what he observed in the field. However, he was a product of his time, and the introductory chapter of his book attempts to explain southeastern geology in light of the great flood of the Bible.

After the Civil War

If the war had not occurred, the science of soils would likely have advanced more quickly. Soil processes were still a mystery and would remain so for generations to come. Trial and error had shown that all swamp lands were not equally productive, but the reasons were not understood.

In 1867, W. C. Kerr, state geologist wrote that “The inevitable conclusion . . . is that the swamp lands are simply vast beds of peat, the only portions of them having any agricultural value consisting of a few belts and ridges.” Distinction was made between “hard swamp” (shallow organic) and “deep swamp” (deep organic), and there was general agreement that so-called “juniper lands” were worthless.

There were some successes. General Blount of Beaufort County, who owned 50,000 acres, was described in 1860 as being a “ . . . successful pioneer in subjugating the swamps.” As late as 1896, though, the State Board of Agriculture wrote, “The character of Hyde County soil has never been understood. The cause of its fertility has never been explained . . .” The board also wrote, “Lands in Hyde County, cultivated for a period of one hundred years continuously in corn, without the application of manure, show no apparent loss of fertility.”

The main activity in swamp lands after the Civil Was was logging. Northern entrepreneurs, many of whom came south with the Union Army, began to log the swamps. At the time, most of the state’s forested swamp land was still in virgin growth but heavily modified by fire.

The Great Dismal Swamp was the most highly modified swamp land. Drainage by the Dismal Swamp Canal and devastating fires had repeatedly denuded the swamp and burned off a considerable amount of the organic surface. The Dismal as it is today is not the same swamp as existed in the late 1700s.

Fires were common throughout the east after the arrival of the Europeans. Indians had used fire to clear land and open up the forest for game, and settlers continued the practice to control pests and to improve grazing. Fire had devastated the long leaf pine lands used for naval store production, and fires continued to modify the vegetation of the great swamps and to remove organic surface. The records of the Pettigrew family indicate that great swamp fires were a common occurrence. Early records indicate that the drainage projects of the 1830s, 40s, and 50s resulted in more rapid loss of organic surface.

The forests of the north were, for the moment, depleted and lumber was needed for everything from building construction to roof shingles, tubs, pails, barrels, water tanks, and so on. By the end of the 19th century, the majority of the state’s swamp lands had been logged, and timber companies were moving on or going out of the logging business. There was no reforestation, and there was a continuing demand for agricultural land.

Few fertilizers and little lime were used in the state, and the black soils still held out the promise of productivity. Cut-over swamp land began to be promoted for development. European settlers were wooed with promised of land. Many came to places such as Terra Cecia and New Hanover and Pender counties.

New Era

Large amounts of former timber company land had been acquired by the railroads in order to obtain their railroad rights-of-way. In the western United States, railroad companies had been given land as an incentive to build railroads, and there was a history of land promotion and sales. In North Carolina, the Norfolk and Southern acquired the lands of the Roper Lumber Company and began to promote land sales actively.

The Norfolk and Southern was aware that many questions were unanswered concerning successful agriculture on these lands and, in 1912, donated land for the establishment of the Blackland Test Farm at Wenona in Washington County. This occurrence followed the passage of the state Drainage Act in 1909. For the first time, landowners could cooperatively drain lands in a logical manner on an area-wide basis. By 1911, some 53 drainage districts had been established or were being established covering over 700,000 acres of land.

One of the first drainage projects was at Terra Cecia in Beaufort County. The Wilkinson brothers had logged the land and then developed it for agriculture. By 1928, it was estimated that over 500,000 acres of land had been drained in the coastal plain by drainage districts.

The Blackland Test Farm may have been the first research station in the United States devoted to organic soils research. Research was conducted with cattle, horses, and various crops. Attempts were made to drain the land with tile drains. Fire was a constant problem for the entire time the farm existed. Unfortunately, crop yields were consistently low, and little progress was made in that area.

The main agricultural problems appeared to be in the areas of insect control (billbugs on corn), liming, plant nutrition, and root zone development. There were no effective chemical controls for billbugs, which could totally wipe out a corn crop. Liming was not well understood; rates were usually too low; and the quality of the lime was poor. Because of subsidence, root zones had to be deepened over time. In addition, the organic soils were so acid, woody, and wet below the tilled top few inches that roots did not grow downward, and crops were often injured by drought. However, one of the greatest limiting factors, and a point of embarrassment for soil scientists, was the failure to recognize copper as an essential nutrient.

The need for copper on organic soils was discovered in Florida in the mid 1920s through "shotgun" nutrient experiments in the Everglades. The researchers there knew that organic soils had problems, so experiments were designed in which essentially every chemical available was applied to the land. The response to copper stood out, and by 1927, a number of growers in the Everglades were applying copper even though the essentiality of copper was not established scientifically until 1931.

For whatever reason, tests with copper in North Carolina were not impressive, probably because yields were low due to other problems. In 1936, Willis and Piland were recommending against the general use of copper. There was a theory of "toxic iron" in vogue among some soils researchers, and Willis and Piland concluded that any beneficial effect of copper was simply a catalytic effect in reducing soluble iron in the soil. As a result, successful use of organic soils was delayed for many years.

Because of the many problems, the state gave up on organic soils in the early 1940s and moved the operations of the Blackland Test Farm to the present location of the Tidewater Research Station in 1943. There were no organic soils at that location, and the name changed to reflect the change in emphasis of the station. Over the years, there were some people who noticed better crop growth under copper transmission lines, but the issue of copper deficiency was not addressed intently until the 1960s. The work of Roger Hanes, Robert Patterson, Eugene Younts, and Carl Schauble finally established copper as an essential part of organic soil agriculture.

The use of copper was a major step forward, but people were realizing that organic soils differed from mineral soils in many other ways. There were issues of drainage, other nutrients, insect control, weed control, subsidence, and liming. In general, the deeper organic soils contained large amounts of undecayed wood that made clearing and development very difficult.

The chemistry of organic soils differs from that of the mineral soils in the state. For example, organic soils are low in aluminum and can support crop growth at much lower pH values than mineral soils can. Also, the same aluminum factor changes soil test phosphorus interpretation. These are only two of the differences now recognized.

The realization of the unique needs of organic soils, along with a boom in land development in the east, led the legislature to establish a position in organic soils research and extension and to place the position at the Tidewater Research Station in the 1960s. The first blackland soil specialist was J. R. Woodruff. After he left to accept a position at Clemson University, Steve Barnes was hired in 1964. When Steve left to work with First Colony Farms in 1974, I — J. Paul Lilly — was transferred to Plymouth from Castle Hayne to fill the position. By the time I retired in 1995, the emphasis had changed considerably from land development and crop production to environmental and sustainable concerns. Carl Crozier is now located at the Vernon James Research and Extension Center with responsibilities in organic soils.

Since the 1960s, new extraction techniques and soil test interpretations have proven that organic soils cannot be treated as mineral soils. In general, recommendations for lime and nutrients are more reliable than in previous years. There are still areas where more precision is needed, and research continues.

First Colony Farms

By far the largest and most ambitious development of organic soils was by First Colony Farms, beginning in 1973–74. Malcolm McLean acquired some 376,000 acres of mostly swamp land in Washington, Tyrrell, Hyde, and Dare counties with plans for developing it into agricultural lands, pastures, forest lands, and wildlife areas. Much land was developed, but large-scale agriculture proved to be both expensive and difficult. The farm was converted to a tenant system within a few years.

Plans to develop some lands were frustrated by evolving wetland regulations. For example, ambitious plans for Dare and Tyrrell counties were eventually abandoned after extensive work on an environmental impact statement. In another case, attempts to strip some of the undesirable surface organic soil and use it for fuel encountered the same opposition.

Ultimately, First Colony Farms sold and traded most of the land. One tract in Dare County was acquired for bombing ranges. Another large tract in Dare and Tyrrell counties was acquired by Prudential Insurance and eventually formed the basis for the Alligator River National Wildlife Refuge. Some land was sold, and a remnant of about 100,000 acres formed the basis for Pocosin Lakes National Wildlife Refuge.

Peat Mining

In the late 1970s, First Colony Farms conducted experimental peat mining south of Lake Phelps in the vicinity of Allen Road in Washington County. The energy crisis of the 1970s, as well as tightening environmental regulations on sulfur emissions, had resulted in renewed interest in using organic soils to fuel power plants. The state commissioned Dr. Roy Ingram to conduct a survey of minable peat. His report was issued in 1987.

First Colony Farms abandoned their peat mining attempts, but other projects were proposed in Hyde and Pamlico counties and perhaps in other places. At present, the only peat mining in progress is to obtain peat for use in soil mixes. The “peat” of North Carolina is less desirable for horticultural purposes than peat moss from the north, but it is nearby and abundant.

One reason for the interest in mining peat is that fact that organic soils of North Carolina are, for the most part, underlain by mineral soils that are often better for agricultural production than the overlying organic. Woody colloidal muck soils are very difficult to develop and have long-term limitations for crop production. In addition, no land in North Carolina has been abandoned due solely to loss of organic surface in contrast to south Florida where the organics are underlain by rock and abandonment is a real concern. In the past, land developers even encouraged the removal of the overlying organic soil by fire in order to uncover the more easily managed mineral soil.

Classification

Until the 1960s, soil surveys generally gave very little information about organic soil areas. They were usually designated as “swamp” or “peat” and that was thought to be sufficient. However, the great increase in land development starting in the 1960s led to a need for more detailed information. Work by J. W. Dolman, S. W. Buol, and others established basic characteristics of organic soils.

The researchers of the time recognized that one important characteristic of many organic soils of North Carolina was the presence of colloidal muck. Colloidal muck soils are difficult to drain and develop because they are sticky, plastic, impervious to water movement, and very acid. They must undergo a “ripening” process before they are suitable for agriculture. When drained they undergo irreversible drying and may develop poor water-holding characteristics. Deep colloidal muck soils are very difficult to farm successfully.

By the 1970s, a system of organic soil mapping based on organic thickness, nature of the organic material, and characteristics of the underlying mineral soil was evolving. Washington County was mapped in the late 1970s and was the first county mapped with this degree of detail. Even so, soil maps are still less precise than on most mineral soils. There are many inclusions, and the variability of the underlying mineral soils makes mapping more difficult. Also, soil surveys of organic soils are confounded by the fact that the surface thickness is subject to change. Long-term subsidence or more rapid loss by fire can change the soil series name when depth of the organic layer is used as a mapping criterion.

Present and Future

Evolving wetland regulations have essentially ended clearing of organic soils for agriculture. In addition, state and federal governments have acquired large areas of these soils for wildlife refuges, bombing ranges, and other purposes. Other areas are managed for forestry. Many developed areas of organic soils are in environmentally sensitive areas and are under fire for environmental reasons.

Agriculture will likely continue in areas already developed but will not expand. The cleared organic soils will inevitably subside and become lower in organic matter. Over the years, a very large portion of the original organic surface of the eastern swamp soils has been lost due to fires and drainage. The deep organic soil of the Collins Plantation north of Lake Phelps no longer exists. I would estimate that as much as one half of all the original organic mass of the state has been lost. Farmed — and some forested — areas will continue to lose organic surface because of drainage. Some areas, most notably Pocosin Lakes National Wildlife Refuge, are being managed in an attempt to stop or reverse the loss.

The organic soils of North Carolina have a long and colorful history. In comparison with most mineral soils, they are still not well known. They have stimulated many dreams and have frustrated many potential users. In many ways, they have been North Carolina's frontier for the last two centuries, but they have defied easy conquest. Even after a century of soils study, they remain in many ways a mystery.

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An Anthology of Soil Science in North Carolina[1]

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I. Introduction

The course of ***soil science*** in North Carolina was shaped by the nature of the soils in North Carolina.

A. History of soils in North Carolina can be traced to the quartz, feldspar and mica-rich rocks that formed on the supercontinent (Rodinia) one billion years ago.

B. Few mafic and ultramafic rocks formed, and few carbonates were present.

C. North Carolina is almost devoid of sedimentary limestones rich in calcium (Ca) and phosphorus (P).

D. When the collision with Africa ended, about 270 million years ago, the Appalachian mountains were as lofty as any modern mountain chain. Since then they have been eroding and providing the sediment for the Triassic Basins and the Coastal Plain.

E. Soils in North Carolina formed from nutrient-poor rock, much of which was further impoverished during transport, are nutrient-poor soils.

F. Vegetation, however, concentrated what few essential elements that were present into the surface of the soil.

II. What the first European settlers found

A. In 1822, Professor Mitchell described the soils of North Carolina and the first attempts at farming as follows: “The soil of this State is pronounced, by those who have travelled extensively on both Continents, to be of a middling quality. It is of that kind which seems most to demand the employment of science and skill in its cultivation, and to promise that they shall not be employed in vain. Our grounds are neither so fertile that they will produce spontaneously what is necessary to the sustenance and comfort of our citizens, nor so sterile that we have reason to

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1 This article is a reprint of the original paper with slightly modified headings and some added figures: Buol SW. 1999. An anthology of soil science in North Carolina. In: Allen JL, editor. Proceedings of the 42nd annual meeting of the Soil Science Society of North Carolina; 1999 Jan 19–20; Raleigh (NC). Raleigh (NC): SSSNC. p 3–6.

abandon them in despair. When our ancestors landed on these shores, they had for ages been covered with a continued forest, the trees of which, as they decayed and fell, had deposited on the earth a rich bed of vegetable matters, which was ready to furnish the most abundant nourishment to any seed that might be committed to the ground. The first settlers, therefore had nothing to do but to select the most promising spots, clear away the timber, and loosen the soil, so that the vegetables to be grown could strike their roots into it. As the fertility which they had at first found was, in the course of a few years, exhausted, it became necessary, either to provide a means of renewing it, or disforest another tract and bring it under cultivation. As it was found that the latter could be done at the least expense of time and labor, it was perfectly natural that the exhausted land should be thrown out, and fresh ground brought under tillage."

B. By 1822, Professor Mitchell described the state of land use in North Carolina as follows: "This process has been going on till most of the tracts whose situation and soil were most favorable to agriculture, have been converted into old fields and in our search after fresh ground to open, we are driven to such inferior ridgeland as our ancestors would have passed by as not worth cultivating. It is useless to complain of the course which our planters have pursued—they have pursued their own interest—and pursued it in the main with discretion and judgement. It were perfectly absurd to expect them to attempt to improve their lands by the application of manures so long as the could obtain, at less expense, the use of that great store of vegetable matter with which nature had for many centuries been covering our country. It is not to be expected that a man will raise a hundred barrels of corn in a way which we may point out to him as the best, at an expense of three hundred dollars, when his past experience informs him that he can produce it in his own way for two hundred."

C. Professor Mitchell then predicts the future and the need for ***soil science*** as follows: "But, in process of time, as this system goes on, the planter will look down from the barren ridges he is tilling, upon the grounds from which his fathers reaped their rich harvest, but which are now desolate and abandoned, and enquire whether he cannot restore to them their ancient fertility, at a less expense than he can cultivate those lands of an inferior quality, with which he is now engaged. Till he is driven by necessity to make this enquiry, we can hardly hope that agriculture will be studied as a science. The planter will not give us a patient hearing when we talk to him about manures."

D. Paul Lilly notes that North Carolina had the greatest acreage of cropland during and just after the Civil War (1865).

III. Post Civil War

And so it was that with peace and reconstruction after the Civil War that the Hatch Act provided federal funding for the study of agriculture. State monies were also channeled to scientific study of soil. As was true in all southern states, the first priority for Hatch money was for research to improve soil fertility.

A. Commercial fertilizers were known and made available to farmers, but fertilizer products had no quality control and results were not uniform.

B. A cry from the farmers went up to the North Carolina State legislature "Do something about FERTILIZER FRAUD! In North Carolina, as in most other southern states, this demand was answered by employing agricultural chemists to test and evaluate the fertilizer products on the market. The following chain events took place in North Carolina:

1877	Dr. Albert Ledoux is appointed the first Agricultural Chemist, located in Chapel Hill (Fertilizer Analysis).
1880	Dr. Charles W. Dabney, Jr., replaces Dr. Ledoux. Program is moved to Raleigh.
1885	Dabney establishes first experimental farm for fertilizer trials in West Raleigh (now North Carolina State University campus).
1886	Milton Whitney becomes first superintendent of West Raleigh research farm. Whitney began the first pot cultures in candy jars.

C. It is written that when Dr. Dabney made one of his reports revealing that some "fertilizers" were nothing but powdered coal and equally worthless products, the business interests of some of the legislators were implicated and his testimony was challenged by several impassioned testimonials praising the fertilizer value of such products. One legislator was reported to have declared that no thinking man would trust a so-called Doctor in a white coat who spent his time, at taxpayer expense, shuffling around in a foul-smelling laboratory. He then declared that only the crop plants knew good fertilizer from poor fertilizer. Dr. Dabney, being quick of mind, responded that the good man had a point and the legislature should make land available for field testing of fertilizer. Thus the West Raleigh Farm, later to become the NCSU campus, was established.

D. Numerous reports of fertilizer analyses were published during this era. Most reports totaled the chemical value of the P, and sometimes the N and K, contained in various fertilizer products, calculated the dollar value of these elements and revealed where and from whom the fertilizer was purchased and the price charged for the fertilizer. The reports were published in monthly North Carolina Department of Agriculture publications and publications available to the farmers of state. (It is interesting to observe that some of the publications carried a plea to the farmer to "read well and pass on to your neighbor.")

E. One of earliest Experiment Station Bulletins dealt with samples from several phosphate mines on the coastal plain of North Carolina that were being worked for rock phosphate fertilizer. These were the forerunners of our present phosphate mining in eastern North Carolina. So great was the need for P in the acid, igneous-rock-derived soils of the state that mineral sources, such as the mineral Wavealite, were known to be quarried for fertilizer during the Revolutionary War (1776) near Charleston, South Carolina.

IV. Soil identification and mapping

A. Some soils grew better crops than other soils. This has always been obvious to farmers tilling the land. However, no systematic way had been devised to translate this knowledge in a quantitative fashion to scientists and thus establish a defined entity of soil upon which to conduct scientific research. The quality of crops grown on different kinds of soils differed. In North Carolina, the quality of tobacco was of greatest economic concern. Could scientists identify and locate the best soils for producing the finest tobacco?

1894	Milton Whitney leaves North Carolina to become director of the Division of Agricultural Soils in the U.S. Weather Bureau, USDA.
1895	The Division of Agricultural Soils becomes an independent unit.
1897	The Division of Agricultural Soils is designated the Division of Soils.
1900	The first soil survey *Raleigh to New Bern Area* is published by W. C. Smith, USDA Bureau of Soils, in cooperation with the North Carolina Agricultural Experiment Station and the North Carolina Department of Agriculture. (North Carolina was one of the first six states to start a soil survey.)
1901	Division of Soils is designated the Bureau of Soils, with Milton Whitney as Chief.

B. In *Raleigh to New Bern Area*, 13 types of soils were identified and, in addition, three land types—sandhills, muck, and meadow—were mapped.

C. As a result of this survey, the Upper Coastal Plain Test Farm (now a research station) was established at Rocky Mount in 1902.

V. Soil conservation and improvement

A. By 1900, the land was in bad shape and this was obvious to a more mobile public. The General Education Board, funded by Rockefeller to improve education in the South, determined "They could render no substantial educational service to the South until the farmers of the South could provide themselves with larger incomes. It was necessary to improve Southern agriculture." Could science change the course of land degradation? They funded farm demonstration work with the supervision of USDA and with Dr. Knapp in charge.

B. In North Carolina several people took up the challenge.

1903	Hugh Hammond Bennett graduates from Chapel Hill. Bennett maps soils in Tennessee, North Carolina, and Virginia.
1907	C. B. Williams is named Director of the North Carolina Agricultural Experiment Station.
1907	County extension work starts in North Carolina.
1914	The Smith-Lever Act establishes cooperative extension work between USDA and North Carolina State College.
1920	First aerial photos by W. B. Cobb and W. A. Davis are used in the soil survey of Tyrrell County.
1921	W. D. Lee is appointed as assistant in soil survey.

C. Soil survey was well established as a tool to organize the complex patterns of soil into units that could receive scientific attention. World War I experience with the airplane demonstrated a view of the land that could speed and increase the ground accuracy of soil identification.

D. The Dust Bowl era of the 1930s brought the problems of the land to the people via their pocketbook and literally dirt on their window sills.

E. Soil chemistry and crop science were coming to understand that total elemental analysis of soil did not predict how crops would respond. New methods of analyzing soil to determine plant-available forms of essential elements had to be developed. Although this breakthrough was taking place in many parts of the world, North Carolina attracted some individuals who were leaders in this effort.

1931	J. F. Lutz joins North Carolina State College as soil physicist and conservationist.
1931	W. H. Rankin joins North Carolina State College for small grain soil fertility research.
1931	Hugh Hammond Bennett becomes head of the Soil Erosion Service, later named Soil Conservation Service and eventually reinvented as the Natural Resources Conservation Service.
1936	E. R. Collins joins North Carolina State College as extension soil fertility specialist-in-charge.
1936	W. W. Woodhouse joins North Carolina State College for pasture and forage soil fertility research.
1938	Adolf Mehlich joins North Carolina State College as a soil chemist.
1941	W. L. Nelson joins North Carolina State College for soil fertility and soil testing research.
1941	R. W. Cummings joins North Carolina State College as Agronomy Head, Director North Carolina Agricultural Experiment Station and soil fertility researcher (later to lead in the establishment of International Research Centers around the world).

1945	J. F. Doggett joins North Carolina State College as extension soil conservationist.
1945	W. G. Woltz joins North Carolina State College for tobacco soil fertility research.
1949	N. T. Coleman joins North Carolina State College as a soil chemist.

F. Many individuals who contributed to soil science in North Carolina have not been identified in this list, and for this I apologize. And, I will not attempt to continue the chronology of individuals beyond 1950 in order not to risk embarrassment by oversights. It would be a fertile area for you to contribute to the Soil Science Society of North Carolina effort during this next year. Get out your pencil or keyboard.

VI. Effect of science on soil stewardship

What has happened on the land as direct, indirect, or coincidental results of the interjection of ***science*** into stewardship of the soil in North Carolina and throughout the nation and world? A complete treatise could fill volumes, and the following are but a few results where I believe ***soil science*** can be credited as a major contributor:

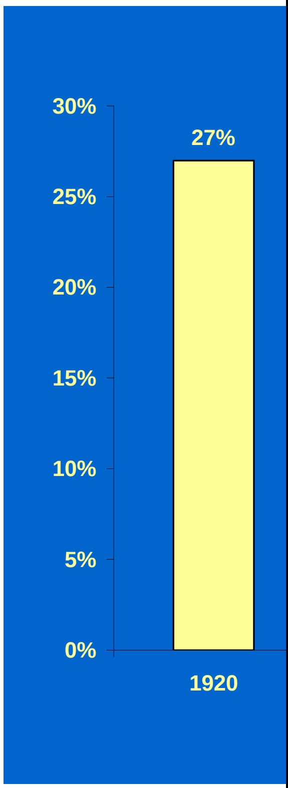
- Decrease in food cost as a percentage of family income in the USA (Figure 1)
- Acreage of US land used to produce domestic food over this century (Figure 2)
- Improvement of yields Iowa and North Carolina comparison for corn 1920–1980 (Figure 3)
- Conservation of the land.

VII. Importance of land to civilization

We are not done yet. We will never be done. Life on earth may have originated in the sea but it is the land—LAND WITH SOIL, not rock land—that supports civilization as we know it. To improve civilization, we need to improve our knowledge of that which supports civilization. Although often unseen as we hide in our soil pits and “foul-smelling” laboratories, we need occasionally to celebrate and take pride in our profession. This next year is one such occasion. Contribute to the celebration. Tell your version of ***soil science*** to the Rotary Club, the local newspaper, your local schools and churches. Like apple pie and motherhood, soil is appreciated and cherished by all people. Instinctively all people know that life depends upon soil. Most people do not understand soil. They need not understand to appreciate and revere. There is no better subject to champion than soil.

Percent of Income Spent on Food

Figure 1. Percent of U.S. income spent on food.



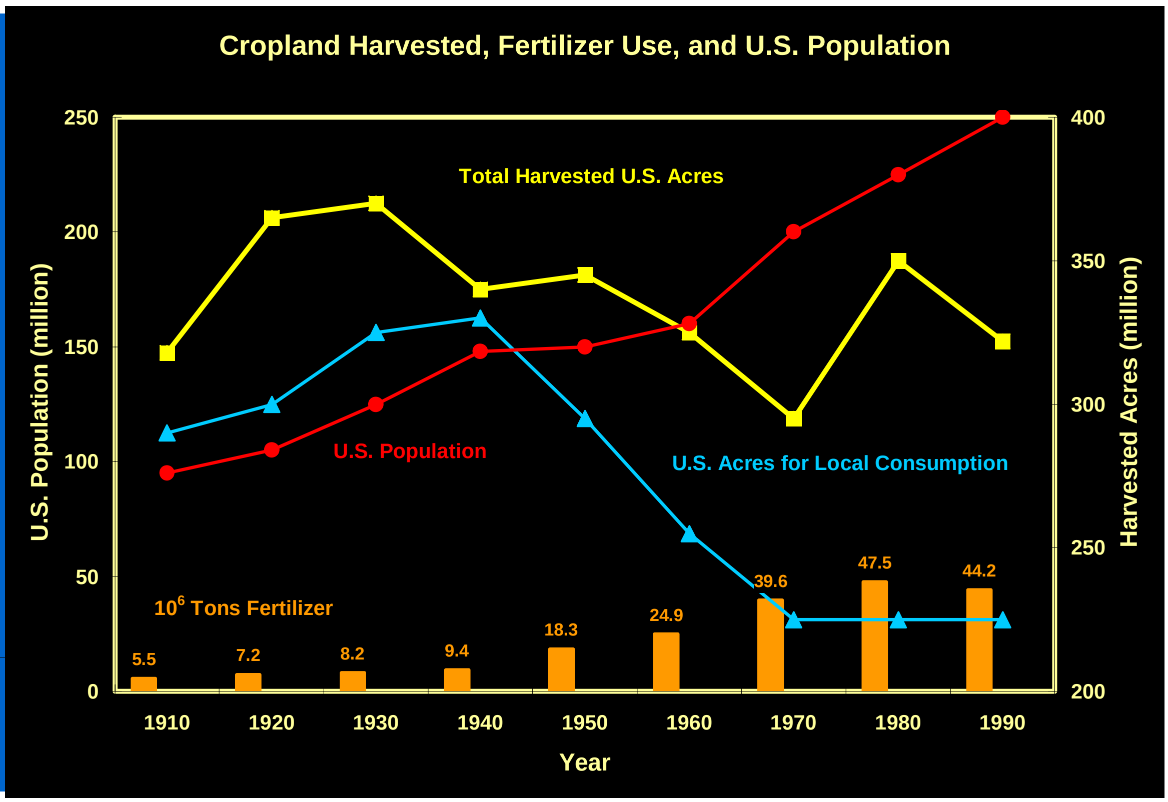


Figure 2. Total U.S. cropland harvested, U.S. cropland harvested for local consumption, fertilizer use, and U.S. population.

	Norfolk Soils (N.C.)		Tama Soils (Iowa)	
Year	1925	1983	1919	1979
Corn Yield (bu/A)	32	110	42	130
Fertilizer Rate (lbs/A)				
N	32–47	120–158	0	150–180
P	3–5	18	0	30–48
K	5–10	67	0	67–99

Figure 3. Historical comparison of average farmer fertilization rates on a naturally fertile and a naturally infertile soil in the United States (original data from soil survey reports and agricultural extension records).

Ten Milestones in Conservation Tillage: History and Role in the North Carolina Conservation Program[1]

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Introduction

No-till has evolved in North Carolina over the last 40 years to become the most important conservation practice for cropland. Beginning with those trial and error days in the early sixties and a few brave farmers, visionary conservationists, and researchers and a few innovative chemical and farm implement companies, no-till gradually became a dependable option for the farmer, first for treating erodible cropland and later for soil improvement and moisture conservation on any cropland. The development of no-till often took one step forward and two steps backward, but with better equipment, herbicides, and the need to reduce the farmer's time for planting a crop, no-till has become an accepted method for planting most crops in North Carolina. Although no-till is being practiced for tobacco and vegetable crops, conventional clean tillage is still the norm for these crops.

The change in the attitude of farmers has played a key role in making no-till the most widely used conservation practice in North Carolina. When your father, grandfather, and great grandfather believed that deep plowing and cultivation was essential to grow a crop, it was difficult for a farmer to change to a system with no tillage. Farmers now consider trash farming, as sometimes no-till is called at the country store, a compliment and not an indication of lazy farming.

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1 This article is a reprint of the original paper with some color figures added: Brock BG, Canterberry JH, Naderman GC. 2000. Ten milestones in conservation tillage: history and role in the North Carolina conservation program. In: Sutherland JL, editor. Proceedings of the 43rd annual meeting of the Soil Science Society of North Carolina; 2000 Jan 18–19; Raleigh (NC). Raleigh (NC): SSSNC. p 13–18.

What is No-Till

No-till is one of several versions of conservation tillage that minimizes the soil disturbance during seedbed preparation and while growing a crop. In the early days, it was sometimes called sod planting. There are several types of conservation tillage, including ridge-till, mulch-till, strip-till, no-till, and any other planting method in which the soil surface has at least 30 percent ground cover after planting. In this paper, strip-till and vertical tillage that does not disturb more than one-third of row width is considered no-till. Planting or drilling is accomplished using disc openers, coulters, row cleaners, in-row chisels, or roto-tillers.

No-till planting provides very effective erosion control and moisture conservation. With this form of conservation tillage, the planting equipment places the crop seeds directly into the soil through the residue of a previous crop without any tillage (plowing or disking). This leaves most of the soil surface undisturbed by tillage and protected by the existing crop residue, which reduces runoff, thus preventing erosion and conserving water for crop uses.

The Importance of No-Till in Cropland Management

For the first time, crops can be produced while making soil improvements. Conservationists plan for soil losses not to exceed a tolerance level, or “T” level. Even at this rate, there is some question as to whether a given soil can produce at its potential because of runoff, soil loss, and loss of vital organic matter. Thanks to no-till technology, high yields can be produced while erosion and water runoff are virtually eliminated. With these conditions maintained over time, organic matter and cation exchange capacity (CEC) improvements are possible.

Farmer experience and research results have shown a doubling of soil loss reduction and CEC improvements. For example, Wood and Worsham found soil loss in the coastal plain with no-till tobacco to be reduced by 95 to 98 percent as compared to conventional tillage. In the piedmont, Steve Gibson, Cleveland County Extension Agent, found that CEC and organic matter nearly doubled after 10 years of continuous no-till with corn and soybeans. Sometimes it takes a little longer for benefits of no-till to accrue. In the mountains, where moisture is generally more dependable, Dr. Greg Hoyt noted increased tomato yields during the fourth year of continuous strip-till as compared to the standard black plastic system.

Wildlife Benefits

No-till has proven to have benefits for most wildlife but especially for bobwhite quail. A N.C. State University (NCSU) study found that bobwhite quail chicks found their daily insect needs in only 4 hours in no-till. With conventional tillage there were not enough hours in the day to meet the needs of quail chicks.

Other Benefits

Farmers often find unexpected benefits with long-term conservation tillage. For example, a U.S. Dept. of Agriculture Agricultural Research Service (USDA-ARS) study in Georgia found higher populations of beneficial insects in conservation-tilled fields, resulting in higher predation of bollworm eggs (75 percent compared to 25 percent).

Costly Conservation Practices Not Needed with No-Till

With adequate ground cover, no-till can allow more intensive use of steeper fields. Costly terraces and grassed waterways can be eliminated or minimized. Irregular slopes statewide make true contouring virtually impossible. With a good job of no-till, row direction makes little difference in soil loss.

The efforts of many interests have contributed to no-till technology. Equipment manufacturers, chemical companies, seed companies, researchers, crop and soil consultants, and others have made significant impacts. However, a great deal of credit goes to the forward thinking farmers for their persistence in the refinement of basic concepts relative to this revolution in farming.

Long-Term No-Till

The ultimate in no-till is long-term no-till, which is planting all crops continuously in at least 80 percent plant residue from preceding crops. Long-term no-till not only reduces soil erosion and improves water quality but also improves soil quality. This is the only conservation practice that can be used for continuous row crops, while soil improvement takes place at the same time. The soil improvement is the result of increased organic matter and microbial activity. Through long-term no-till, residue built up on the soil surface reduces the impact of raindrops, increases infiltration, and thus reduces runoff. A big advantage of long-term no-till is the need for fewer structural practices, such as contour farming, terraces, and, in some cases, grassed waterways.

Research shows that long-term no-till also reduces the amount of nutrients and pesticides reaching surface and ground water due to the increase in organic matter content. After three years, yields from continuous no-till are normally better those from conventional tillage on most soils in North Carolina. Troublesome weeds, such as bermudagrass, trumpet creeper, horsenettle, and some briars, may need special control treatment after several years of continuous no-till. Bermudagrass should preferably be eradicated before using no-till. With no-till, farmers have the opportunity to farm larger acreage due to less time and labor inputs.

The three authors of this paper have all been privileged to participate in the development of this important technology. We feel that these ten developments were significant milestones along the way. The following paragraphs provide a brief discussion of each.

Figure 1. In 1962, Haywood County farmer John Kirkpatrick used this homemade unit to prepare a narrow, tilled zone which was later followed with a regular planter. Erosion control on a steep slope was a major goal.

Figure 2. Mr. Kirkpatrick in January 2000. His ideas 40 years ago led to a major farming revolution.

Milestone 1—The Idea

A Kentucky farmer, Harry Young, is generally credited with the first no-till planting (in 1962) in the U.S. In our research into this, we discovered that a Haywood County dairy farmer, John Kirkpatrick, is documented as also having planted no-till corn in 1962 (Figure. 1). It was "sod planted" into an old fescue sod. We also discovered that Mr. Kirkpatrick had earlier produced a good crop of corn by broadcasting the seed and disking it into a fescue sod. He was not, however, able to get his silage chopper to make a good harvest because the corn was not in rows. As of this writing, Mr. Kirkpatrick is still in good health, an octogenarian, living in Haywood County (Figure 2).

Milestone 2—An Effective "Burn Down"

The earliest plantings were made into a sod. At corn planting time, the sod was quite vigorous and competitive. Therefore, it needed to be controlled to an extent sufficient for corn growth and development. All that was available was a pre-emerge herbicide, atrazine. It did a reasonable, but not always dependable, "burn down."

About 1967, Chevron Chemical Company released Paraquat as an effective "burn-down" product. This product, along with pre-emerge herbicides, made no-till corn more dependable. Another important spin-off was the use of Paraquat to eliminate weedy plants in wheat fields. Along with the use of suitable residual herbicides, no-till double-cropped soybean production came to be. Things were looking up!

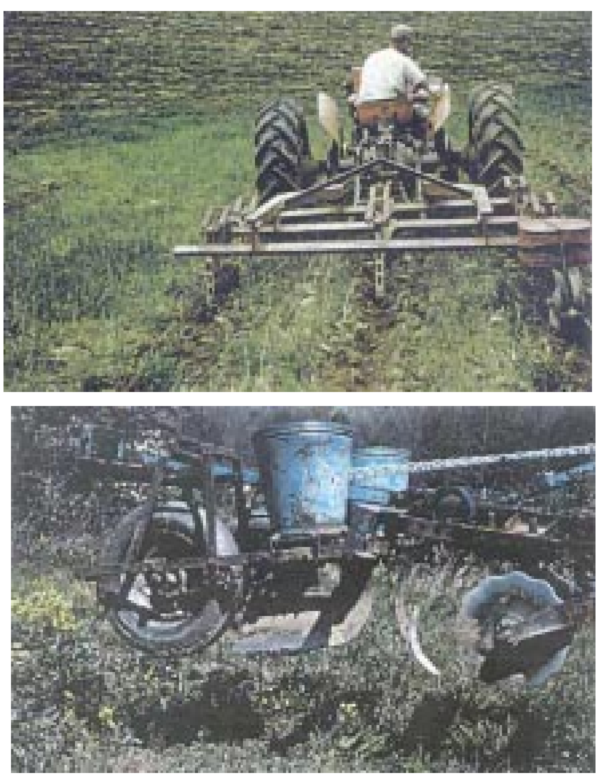

Figure 3. Early innovations and several farmers' adaptations of planting equipment for use under no-till conditions.

Figure 4. More examples of planter adaptations for no-till culture in the 1950s and 1960s.

Milestone 3—Better Equipment

The first plantings were made with homemade planters. Most common were coulters, followed by a narrow chisel of some type, then the standard planters (Figures 3, 4). These rigs were simply not heavy-duty enough to plant in very heavy residue nor dry soil conditions. Stands were generally not sufficient.

Encouraged by the promising results the farmers were seeing, plant manufacturers and the agricultural engineers at NCSU developed planters that were capable of getting improved crop stands. Especially effective were planters developed by Allis-Chalmers, Cole, and Ferguson; grain drills by Tye; and planters engineered by J. C. Ferguson and Eustace Beasley of NCSU.

Milestone 4—Demonstrations and Research

To their credit, the Soil Conservation Service (SCS) —now Natural Resources Conservation Service), NCSU, and various industry personnel saw the merit of what early farmer efforts produced and began to work with the early leaders in making research trials and on-farm demonstrations. Though there are surely others, the following people come to mind:

SCS

- Dan Windley, Beaufort County
- J. E. Pollock & C. C. Abernathy, State Agronomists
- Paul Britt, Moore County
- Howard Williams, Haywood County
- Bobby Brock, Lee County
- Sam Yound, Alleghany County

NCSU

- J. A. Phillips, Soil Science
- E. O. Beasley, Agricultural Engineering
- H. D. Bowen, Agricultural Engineering
- Steve Barnes, Soil Science/Research Station
- Wallace Baker, Agronomy/Research Station
- John Clapp, Extension Soybean Specialist
- R. L. Lovvorn, R. J. McCracken, P. H. Harvey, G. D. Jones, F. J. Hassler, W. D. Toussainant, Department Heads
- G. C. Klingman, Weed Science
- J. C. Ferguson, Agricultural Engineering
- J. M. Spain, Soil Science
- C. K. Martin, Soil Science
- C. D. Sopher, Soil Science
- W. M. Lewis, Weed Science
- A. D. Worsham, Weed Science
- Dick Perrin, Agricultural Economics

Private Sector

- John York, Chevron Chemical
- John Bell, Bell Implement Company of Goldsboro
- Thomasson Implement Company of Yadkin County.

The numerous forward-thinking farmers in all regions of the state who cooperated with on-farm demonstrations were very instrumental in getting this technology adopted. Without their assistance, it would have been a slow development indeed.

Milestone 5—Better Weed Control

Both pre-emerge and post-emerge herbicide improvements continued. A broader selection gave the no-till farmer most of the same options as the conventional farmers. Non-selective post-emergence herbicides made it possible to control troublesome perennials, thus allowing the use of continuous no-till. Soil quality improvements of unprecedented proportions were not possible with elevated organic matter levels in the upper inch or two of the soil profile.

Many farmers began to use "wait and see" management to tailor a post-emerge spray program to the weed crop rather than continue a broad-based pre-emerge program. Among the numerous chemical companies, BASF was notable in the early promotion of such an approach.

The development of crops which are tolerant to post-emerge herbicides allowed still another advance in refinement of weed control technology. Troublesome broadleaf weeds, especially in cotton, can now be controlled with broadcast sprays. The Monsanto Chemical Company was especially active in developing this improvement.

Milestone 6—The 1985 Farm Bill

Called the Food Security Act of 1985, this farm bill requires that erosion reductions be made on the Nation's most erodible lands. It is left up to the farmer and his personal preferences to select the methods of erosion reductions to employ. Conservation tillage is the method of choice for the vast majority of grain farmers and a few peanut producers. It is safe to say that this Federal legislation proved to be a major incentive for adoption of conservation tillage. Fortunately, the technology was advanced sufficiently to make this economical and technically sound choice.

Numerous trial plantings of no-till tobacco and vegetables were made as an attempt to meet Farm Bill requirements with these crops. Some successes were made; however, dependable results have been slow to emerge, and as a result, wide use with these high-value crops has been sporadic. However, there is promise enough for optimism that these crops will also one day be commonly produced with conservation tillage.

Milestone 7—The Asheville, Statesville, and Greenville Meetings

In late summer of 1992 and early 1993, two of the more significant no-till conferences were held in Asheville and Statesville. In each instance major presentations were made by successful farmers and by notable research scientists. Static equipment displays showed state-of-art planters.

John Bradley of Milan, Tennessee, was a major attraction as a readily recognizable research figure in a successful no-till production. Phillip Davis, a farmer, discussed his successes as a consistent top producer in grain farming.

A highlight of the Statesville meeting was an inspiring presentation by a farmer from Chile, Carlos Crovetto. His contagious enthusiasm helped to encourage many farmers to use continuous no-till.

A year later, a similar session was held in Greenville. It too was well attended even though it had to be rescheduled due to icy weather.

In each of these informational meetings, there were excellent cooperation and hard work by the N.C. Dept. of Agriculture, USDA, NCSU, and private industries. These events were no doubt of considerable importance in helping our farmers to better understand and appreciate the potential of conservation tillage.

Milestone 8—Still Better Equipment

After a relative lull in equipment advances, a fresh round of improvements came rapidly in the late 1980s (Figure 5). A major weakness was overcome by the introduction of dependable, highly effective grain drills by several companies. Small grains could now be drilled into heavy residue, thus closing the circle for continuous no-till. Numerous other lines of equipment included

- straw choppers and spreaders for combines that uniformly dispense residues for easy double-crop planting,
- row cleaners that brush aside heavy residue concentration for better planter performance,
- in-row rippers for row planters that make it possible to minimize the effects of root-restricting pans,
- numerous rippers that can give a shattering effect to pans with minimal disturbance to the ground cover,
- spray equipment that makes it easy to cover the target pest with post-emerge applications, and
- coulter designs that are available for any possible soil condition.

Milestone 9—Media Coverage

Without question, farmers learn tremendously from other farmers—those both local and distant. Innovators have often paved the way for widespread use of better farming methods. This has been true with the adoption of conservation tillage. News of what others are doing stimulates ingenuity and often leads to a better way.

Newspapers, magazines, radio, and television have all contributed by bringing success stories to the attention of farmers throughout the state. These stories give encouragement to try and provide ideas that are often improved by others. From the small weekly newspaper to the large regional newspaper, success stories have been covered. Radio and television have hosted numerous programs featuring an encouraging word for this technology. Farm magazines have consistently given coverage of success stories over a wide area for many years. Extensive coverage has been provided by *Carolina Farmer*, *Progressive Farmer*, and *Southeast Farm Press*. *Southeast Farm Press* has also been the sponsor of several no-till conferences.

Milestone 10—Monetary Incentives

There is a long and successful history of publicly funded incentives to encourage adoption of conservation measures. Numerous financial advantages have been offered to those farmers who are willing to try this new technology. Among these are

- incentive payments from the Agriculture Conservation Program (ACP);
- tax credits from North Carolina;
- equipment rebates from the State of North Carolina and private industry,
- the Agriculture Cost-Share Program, as administered by local soil and water conservation districts (SWCDs);
- low-cost equipment rentals by local SWCDs, the Cattlemen's Association, county Extension offices, equipment dealers, and others;
- incentive payments from the Environmental Quality Incentives Program (EQIP);
- pesticide rebates from chemical companies.

Summary

The development and adoption of conservation tillage assuredly must be listed among the significant revolutions in the history of farming. It is true that there remain a number of refinements to be made. So, we will always look for a better way. Conservation tillage is truly that better way (Figure 6).

We have made every reasonable effort to give due credit to the many contributions to the development and refinement of this technology. Any shortfalls are regretted.

Figure 5. In the summer of 2000, there were major changes in production techniques on the Washington County farm of Charles Allen, pictured with a 42-foot-wide no-till planter.

Figure 6. Obvious effects of about 25 years of long-term no-till culture on a Cecil soil.

History of Soil Testing in North Carolina

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The history of soil testing as provided by the N.C. Department of Agriculture and Consumer Services divides roughly into two parts. Prior to 1973, the Soil Testing Division (as it was then called) operated with an important, but relatively limited, mandate: to test soils and make fertilizer and lime recommendations. After 1973, the Agronomic Division (as it has subsequently been known) began to fulfill a broader mission. At present, the division provides not only soil testing, but also nematode assay, plant tissue analysis, waste analysis, solution analysis, and a statewide field services advisory program.

The Soil Testing Division: 1939–1972

The Soil Testing Division was established in 1938 to analyze soils and make site- and crop-specific fertilizer and lime recommendations. Work began in July 1939 when I. E. Miles was named the division's first director. After converting some downtown Raleigh office space into a makeshift laboratory, Miles and his staff of six full-time and seven part-time employees began soil testing in early 1940. The staff also began a concerted effort to educate state residents about the new service. Particular attention was devoted to cooperating with fertilizer dealers, educators and other agricultural agencies.

Throughout the early years, the division worked closely with farmers and agricultural leaders to verify the efficacy of its fertilizer and lime recommendations. Analytical procedures were updated repeatedly so that recommendations would be tailored to new farm management practices and crop varieties. Modern farmers owe a large debt to the division's early employees, whose careful evaluations and painstaking refinements helped build the foundation of practical knowledge upon which N.C. agriculture continues to flourish.

The service grew rapidly. With promotional assistance from the N.C. Extension Service and the Soil Conservation Service, the division analyzed 65,000 samples in 1940; 22,000 in 1944; 42,000 in 1947; and 85,000 in 1949. By the early 1950s, state farmers were using more fertilizer, and using it more efficiently, than any other farmers in the nation. Such efficiency can be attributed, in large part, to the leadership efforts of directors Werner L. Nelson (1948) and Dr. J. W. Fitts (1950).

Although farmers were the primary benefactors of soil testing, the state agricultural experiment station, highway department and even federal agencies relied on the division for technically precise information about soil chemistry. Scientists interested in establishing soil testing programs in other states and nations came from as far away as South America, India and China to spend weeks, or even months, in North Carolina studying the program and looking for ways to adapt it to their own regions.

Educational effort was devoted to demonstrating the value of soil testing without creating unrealistic expectations about the kinds of problems it could solve. Initial enthusiasm over the new tool caused some growers to view it as a panacea, forgetting that planting dates, crop variety, weeds, insects, diseases, nematodes, soil physical conditions and a host of other variables all affect yields as well. Division representatives emphasized that optimum production requires that each of these variables be carefully managed.

Equal attention was devoted to teaching farmers the proper means of taking a representative soil sample—a variable which, to this day, remains the weakest link in the testing process. As Director Fitts stated, “A soil testing laboratory does not test a farmer’s land, only the sample submitted.” Getting farmers to submit samples that accurately reflect field conditions is one of the enduring challenges faced by any soil testing program.

By the early 1950s, soil testing was an established part of the state’s most efficient agricultural enterprises. Nonetheless, administrators felt that a 400% increase in sampling would be required if the state was to maximize its productive potential. To help meet this expanded workload, the division moved to the new Agricultural Building Annex in 1955. Under the leadership of director S. L. Tisdale, the division also established a research position responsible for developing more accurate chemical tests and a more precise means of translating test findings into field results.

Throughout the 1950s, the division maintained close ties with N.C. State University. By the mid-1950s, the division was performing more than 6,000 soil tests per year for university researchers. In collaboration with the university’s visual aids department, the division also prepared an educational soil testing film for use by extension agents and vocational teachers.

In the early 1960s, farmers were spending 10–20% of their gross incomes on fertilizer and lime. As director Eugene J. Kamprath explained, farmers needed reliable information about where and when to apply those amendments if they were to the maximize the return on their investments. This was precisely the role the division was empowered to fulfill.

During Kamprath’s tenure, the division began compiling county-by-county summaries of soil test results, liming rates and recommended fertilizer grades for all major crops.

These summaries helped local agricultural workers identify the principal fertility constraints to plant growth. They also helped fertilizer dealers and policy makers respond to long-term, region-specific needs.

Under director Preston R. Reid, the division took advantage of laboratory equipment innovations, such as the atomic absorption spectrophotometer, to improve both the accuracy and the range of its services. Also about this time, the division found itself responding to the needs of a much broader range of users. In 1966, more than 3,300 urban homeowners submitted soil samples in an effort to improve their lawns and gardens. In responding to their needs, the division not only helped to beautify the state, it also helped to curb a serious, but often overlooked, environmental hazard: overly zealous fertilization of small plots by large urban populations.

The division's laboratories continued to serve as an important training ground. From 1964 to 1966, for example, agronomists from more than 27 countries in Europe, Asia, Africa and Latin America attended training sessions at the facility. In addition, tours and training classes for state residents were conducted throughout the year. The division also worked closely with other state laboratories to promote nationwide uniformity of soil testing methods and recommendations.

In 1969, director Donald W. Eaddy identified a number of gaps in the agronomic services available to state farmers. To close those gaps and improve land use efficiency, Eaddy proposed that the Soil Testing Division be expanded into a more comprehensive Agronomic Division. The new division would add to its established duties

- soil analyses for micronutrients and toxic elements,
- plant tissue analyses,
- a pilot program on waste and solution services and
- nematode assays.

In 1971, the North Carolina legislature approved Eaddy's proposal, along with his request for a new building capable of supporting the division's expanded role. These changes were to take effect in 1973.

The Agronomic Division: 1973–present

As the range of division services broadened, NCDA officials recognized the need for regionally based agronomists who could help growers implement management recommendations in a cost-effective and environmentally sound manner. These agronomists would also help maintain two-way communication between growers and the division's central offices, thus ensuring that the various laboratories remained responsive to field level problems. By the time the division moved into its new Ballentine Building in 1974, the first regional agronomist was already in the field, and by the end of the decade, three additional positions had been added.

Among the more important events of the 1970s was the decision to hire, as a consultant, the world-renowned soil chemist Dr. Adolf Mehlich. During his 13 years with the division, Mehlich developed the soil testing procedure Mehlich-3, which provides information on all essential soil nutrients. Working in the division's new Cooperative Greenhouse Facility, Mehlich also developed an improved method for measuring humic-matter levels, thus allowing growers to determine lime requirements and herbicide needs more accurately. For its broad impact on improving land management practices in both developed and developing countries, Mehlich's research stands as a source of pride to all those associated with the Agronomic Division.

Throughout this period, the division was also refining its nematode assay and plant/waste/solution sections so that they could provide users with the most scientifically up-to-date information possible. The utility of these services, as measured by rising workloads, called for steady increases in staff size. Additional lab technicians and regional agronomists were hired.

As public concern about environmental issues increased, the division was called upon to play a larger role in three areas:

- protecting long-term productive capacity of the agricultural resource base,
- safeguarding water from contamination by nutrients and pesticides and
- protecting food from contamination by nitrates, heavy metals and other chemicals.

As a result, the division's workload increased by 76 percent from 1980 to 1994.

Not only was the division asked to evaluate more samples, but also the number of determinations per sample was rising dramatically (i.e., the division was deriving more and more information from each sample). The workload in the plant/waste/solution section, for example, increased by 158 percent from 1982 to 1992. Such increases severely taxed the division's laboratory resources and personnel.

By the close of the 1980s, state policy makers recognized that, in order to fulfill its expanded agricultural and environmental responsibilities, the division would require a larger facility with state-of-the-art equipment. In 1990, funds for a new agronomic building were approved. At that time, the soil testing section purchased instruments with the capability of evaluating 19 elements simultaneously, including heavy metals that may pose an environmental threat.

Before moving into the new building in May 1994, the division expanded its staff to include additional agronomists and technicians, along with a computer analyst and a communications specialist. By 1995, all data generated in the new laboratories were being collected and transferred electronically.

In 1996, the division became the first agronomic testing facility to put its reports online via the Internet. Growers who send in samples are able to check their lab results as soon as analysis is complete—without waiting for a report to arrive in the mail.

In 1997, all agronomic laboratories developed expert computer systems to generate interpretations and recommendations for routine samples based on sample analyses. As a result, section specialists could give more attention to interpreting analyses and writing individualized recommendations for the more troubling problem samples.

By 1998, a new section—field services—was created within the division to manage a newly reorganized and expanded team of regional agronomists. That same year, the soil testing and waste analysis laboratories received DENR-DWQ certification for providing testing for animal waste permit compliance purposes. A new recommended policy statement for heavy metal loading rates was developed in conjunction with the Soil Science Department at N.C. State University.

In March 1999, Dr. Richard C. Reich assumed directorship of the division and initiated laboratory equipment upgrades. The plant/waste/solution section acquired a new Perkin Elmer 3300DV ICP (inductively coupled plasmaspectrometer) for more efficient analysis of essential elements and selected heavy metals. In September, the division installed a 900-gallon bulk argon tank to facilitate uninterrupted laboratory operation of all ICP units.

During 2001, the division added online data entry capabilities to its Web site so users could fill out and submit information sheets for all types of agronomic samples via the Internet. In addition, the nematode assay section adopted a new microsystem for identifying races of soybean cyst nematode. Due to increasingly stringent environmental regulations and more intensive sampling in connection with precision agriculture, the division's soil sample load continues to increase (Figure 1).

Figure 1. NCDA&CS Agronomic Division: Number of Soil Samples Analyzed from 1965-2000.