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Morphological, Greenhouse, and Chemical Studies of the Black Belt Soils of Alabama

By
GEORGE D. SCARSETH

AGRICULTURAL EXPERIMENT STATION
OF THE
ALABAMA POLYTECHNIC INSTITUTE

M. J. FUNCHESS, Director
AUBURN, ALABAMA

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By
GEORGE D. SCARSETH
Assistant Professor of Soil Chemistry

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Morphological, Greenhouse, and Chemical Studies of the Black Belt Soils of Alabama

THE BLACK BELT SOILS of Alabama have long been recognized as being radically different from those in the other provinces of the State. They probably have presented more unsolved problems of soil fertility than any other soil group in Alabama. Beyond the information contained in the soil survey reports of several counties in the Belt, little has been published concerning these soils.

On account of this limited information, a special investigation was started in 1928 to study the Black Belt soils in the field as to their morphology and geological relationship, in the greenhouse to determine their response to fertilizers, and in the laboratory to determine their physico-chemical properties. It is the purpose of this publication to report the results obtained in these investigations.

MORPHOLOGICAL STUDIES

Geographical Location

In shape the Black Belt soil province of Alabama resembles the lower half of a crescent. It enters the State on the middle western border and extends southeastward across the State to approximately 30 miles of the State line as shown in Figure 1. The area is about 150 miles north of the Gulf of Mexico. The geological map of Alabama (32) shows an area that is known as the Selma chalk formation. The boundary of this formation outlines, with some exceptions, the boundary of the Black Belt area. The area in Alabama is approximately 170 miles long and has an average width of about 20 miles. The several counties containing Black Belt soil types are listed in Table 1.

Factors Influencing the Development of the Soils

Historical.—It would be needless to introduce facts pertaining to history were this a virgin area, but in this area the effect on the soil by the activities of man has been of very marked importance and therefore should not be omitted from considera-ation.

Settlement on the edges of the Black Belt area was started about 1817 but "planters avoided the black prairie before 1830 because they had not learned to master the sticky soils" (21) In 1827 the French colony at Demopolis reported to their European creditors that their vines and olives failed "because of the newness of the soil" (1). In 1820 about 69 per cent of the popula-

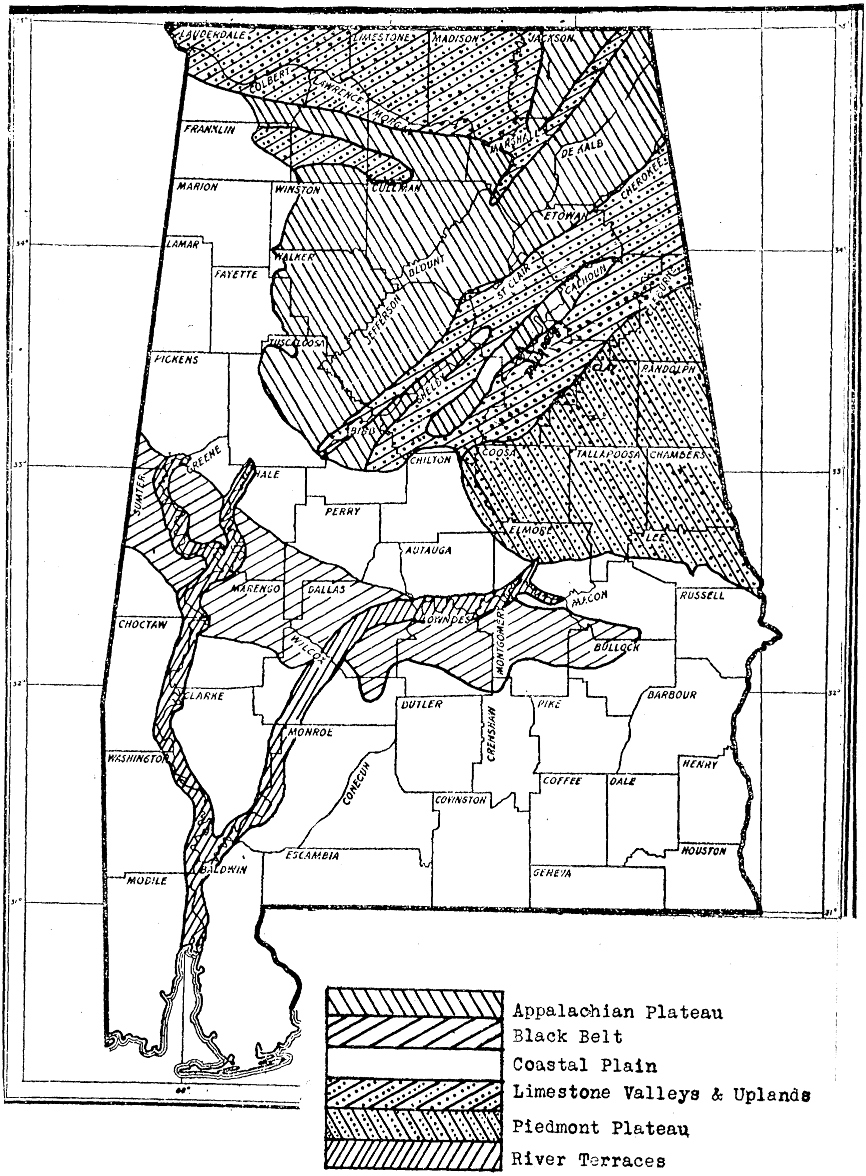

FIGURE 1.—The Soil Provinces of Alabama.

TABLE 1.—Alabama Counties Containing Black Belt Soils

County	Estimated acreage in Black Belt area	Per cent
Dallas	460,000	19.8
Lowndes	445,000	19.4
Sumter	346,000	14.8
Marengo	276,000	11.8
Montgomery	184,500	7.9
Greene	174,000	7.5
Perry	138,500	5.9
Hale	127,000	5.5
Bullock	57,500	2.5
Wilcox	46,000	2.0
Macon	34,500	1.5
Pickens	32,000	1.4
Total	2,331,000	100.0

tion was white, whereas by 1870 about 80 per cent of the population was colored; since that time the ratio of white to colored has varied very little.

By 1860 large plantations which had been operated with slave labor were developed. Cotton has been the principal crop, however, much corn has been grown for stock feed. The frequent cultivation of these crops enabled erosion to carry away much soil, thereby rapidly decreasing the fertility. Introduction of commercial fertilizers has helped to slow up the decline of production but at the same time has increased the cost, thus demanding a more intensive and systematic method of farming. The arrival of the cotton boll weevil about 1914 seriously crippled cotton farming and caused many farmers to move out of the Belt. The farm population decreased 26 per cent from 1910 to 1925 (12).

It is evident that farming activities in the Black Belt for nearly 100 years have altered the soils to a considerable extent because of practices which favor erosion. This area in its virgin state was known as the Black Prairie, or Canebrakes, and was covered with a dense growth of grass. An early observer stated, "The color of the soil is prevailingly black" (21). A soil survey made in 1902 of Perry county (10) shows that practically all of its area contained in the Black Belt was Houston clay, a black prairie soil, but today the majority of the soils in this same area is Sumter clay. Much Sumter clay is without a doubt derived from Houston clay which has lost most of its organic matter from the top horizons through erosion.

Climatic.—The average elevation of the Black Belt area is about 200 feet above sea level. The average annual rainfall is approximately 50 inches. In the year 1904, 36 inches of rain fell in Dallas county; this year was the driest one in a period of 50 years. In 1929, 76 inches of rain fell giving the wettest year of this same period.

The winters are short and mild and the summers are hot with high humidity prevailing. The mean annual temperature is about 65°F. The average temperature for the colder months of the year, December, January, February, and March is about 48°F. and the average temperature for the warmer months, June, July, and August is about 79°F. The average dates for the first and last killing frost in the fall and spring are about November 8 and March 19, respectively. Climatic factors are favorable for erosion to continue throughout the year.

The climate, particularly temperature, has manifested its influence in the development of the Oktibbeha soil series which is the most highly weathered soil in the Black Belt. According to a recent study (6) of a Susquehanna fine sandy loam, located within the eastern end of the Belt, the weathering of the soils in the Black Belt soil province is lateritic in character. Due to the highly colloidal and impervious nature of the parent materials of the majority of the soils in this province, the climatic factors have been minimized as to their influence on soil development. The relatively high rainfall has contributed in keeping the soils immature as weathering products have been extensively removed by erosion.

Geological.—The area known as the Black Belt is to a great extent the outcropping of a deposit of chalky limestone. According to Stevenson (32) this limestone was deposited in a sea floor at the closing of the Cretaceous period and is known as the Selma chalk formation. This formation lies as a great lens on the Eutaw formation (Fig. 2.), a deposit that gives rise to a portion of the upper Coastal Plain soil province. The Selma chalk lens slopes toward the south and, at the southern boundary of the Belt, passes under deposits of the Midway formation.

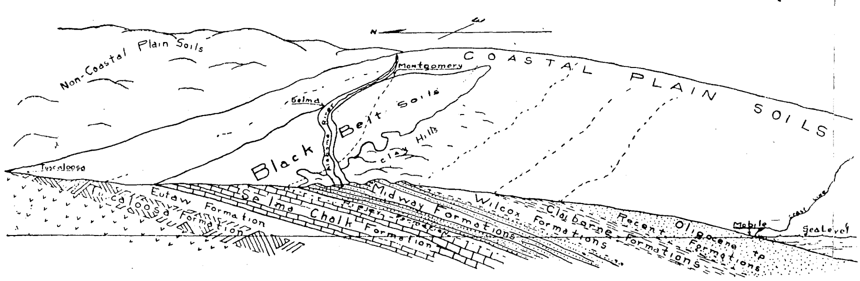

FIGURE 2.—A diagrammatic sketch showing a cross section of the geological formation associated with the Black Belt and Coastal Plain soil provinces. (Geological formations after Stevenson)

The Midway formations lie with unconformity on the Selma chalk. It appears that eroded remnants of heavy clays from the Midway extend over the Selma chalk in the western two-thirds of the Belt. Toward the eastern end of the Belt, the Selma chalk grades into portions of the Ripley formation. Some of the

Ripley formations contain heavy clays and sandy clays with occasional calcareous material. Stevenson says, "The Ripley may be regarded as resting with conformable relations upon the Selma, though with transgressing and overlapping boundary". The lower deposits of the Midway formation furnish the materials that give rise to the "clay hills" that bound the southern border of the Black Belt.

Since the time of deposition of the Ripley and Midway clays that lap onto the Selma chalk, years of extensive erosion have altered much of these deposits. Rivers and streams have cut courses through the deposits and have built new terraces on their banks from materials which they carried in recent geological years.

These geological deposits have been studied and correlated with the soil series of the Belt. The relationship between the geological formations and the main soil series is shown diagrammatically in Figure 3.

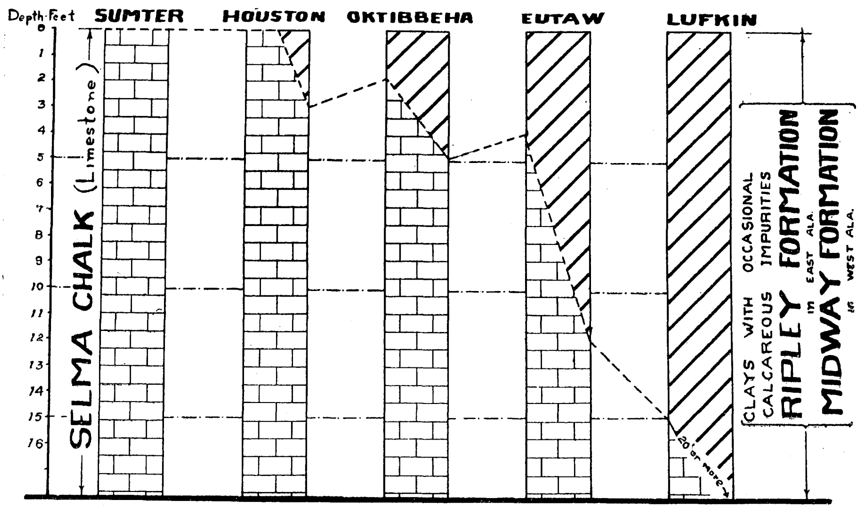

FIGURE 3.—The relationship between the geological formations and the main soil series in the Alabama Black Belt.

Unquestionably the Selma chalk is the parent material for the Sumter and Houston soil series. The clay deposits that are superimposed on the Selma chalk are the common parent material of the Oktibbeha, Eutaw, and Lufkin soil series.

Description of the Soil Types

As recent soil survey reports of each of the Black Belt counties have not been completed, it is impossible to measure accurately the amounts of the different soil types that occur in the entire area or in the different counties; however, a careful ap-

TABLE 2.—Main Soil Types in the Alabama Black Belt

Black Belt soil types	Estimated	
	Per cent of type in area	Acreage of type in area
Sumter Clay	30.0	699,300
Oktibbeha Clay	25.0	582,750
Eutaw Clay	15.0	349,650
Houston Clay	5.0	116,550
Bell Clay	3.0	69,930
Lufkin Clay	2.0	46,620
Catalpa Clay	1.5	34,965
Leaf Clay	0.5	11,655
Total Black Belt types	82.0	1,911,420
Other soil series in Belt: Susquehanna, Norfolk, Ruston, Greenville, Kalmia, Cahaba	18.0	419,580
Total Black Belt area	100.0	2,331,000

proximation of the amounts of the different soil types in the Belt has been made, and is given in Table 2.

There are eight major soil types associated with this soil province. These types are: Sumter, Houston, Oktibbeha, Eutaw, Lufkin, Bell, Leaf, and Catalpa clays. There are also several types belonging to the Coastal Plain and to the River Terrace soil provinces found throughout the Belt. These types belong to the Norfolk, Ruston, Greenville, Kalmia, Cahaba, and Susquehanna soil series. The Susquehanna series occurs frequently in the eastern end and along the southern border within the Belt, but is usually classified as belonging to the Coastal Plain soil group. This investigation deals only with the true Black Belt soils.

Although the soil types of the Black Belt soil province have been described in other publications (8, 10, 20, 30, 33), a description of eight of the most important types in the Belt is tabulated in Tables 3-a to 3-h with a brief descriptive note about the local names, origin or parent material, abundance, and usage of the soils.

A study was made of the genetic relationship between the various soil series in the Belt. This relationship is diagrammatically shown in Figure 4. This diagram shows the Sumter and Houston clays as coming from the Selma chalk limestone. Where weathering of the chalk has progressed without much removal of the weathered clay residue, which occurred as impurities in the chalk, and where organic matter has accumulated to a depth of more than 15 inches the soil is classified in the Houston soil series.

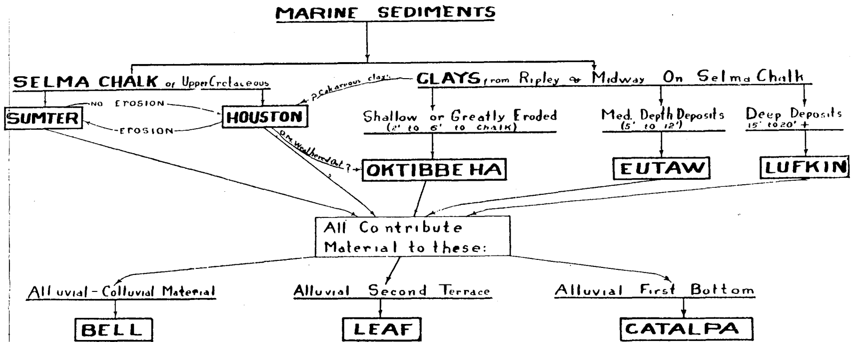

FIGURE 4.—Relationship between the main soil series of the Alabama Black Belt.

TABLE 3a.—Houston Clay

Locally called "Black Prairie, Black Crawfish and Houston clay"; residual from Selma chalk (some may be from calcareous clays); was noted for high production, now in a low state of fertility; principal crops are Johnson grass, cotton, corn, and sweet clover; some alfalfa. About 5 per cent of the Belt, or 116,500 acres, is Houston clay. Before Belt was exposed to excessive erosion by cultivation, there was likely more soil that would have been called Houston. Very often this soil contains crawfish where the subsoil drainage is poor.

Horizons		Profile characteristics					
		A		B		C	
		0 to 6″	6 to 10″	10 to 18″	18 to 22″	22 to 28″	28″
Color		Black to dark grey brown	Black to blue-black	Blue-black glossy with grey mottling	Grading from grey-black to brownish yellow	Yellow-grey to grey-white	White, like color of the chalk
Structure	Wet	Sticky, waxy, and greasy	Very sticky and plastic			Friable or like parent material	
Structure	Dry	Gran-ulates Friable	Becomes granulated and cubical. Cracks badly			No change	
Character of material		Very high in waxy organic matter		High accumulation of colloids	Contains calcareous concretions	Same as parent material	
Aeration and drainage		Sufficient	Slow; more is necessary	Slow and deficient		Not a consideration	
Reaction (pH)		Usually 7.0 to 7.5. May be acid	6.5 to 7.5 usually basic	Calcareous 7.5			

TABLE 3b.—Sumter Clay

Locally called "Lime-land, White-land, and Sumter clay"; residue from weathered Selma chalk; badly eroded; productivity usually low; not generally producing good cotton or corn. Most of this type is in Johnson grass. Is very abundant in the Belt. Approximately 30 per cent of the Belt, or 700,000 acres, is Sumter clay. Early soil surveys may have termed most of this soil "Houston clay".

Horizons		Profile characteristics			
		A		B	C
		0 to 4″	4 to 8″	Erosion has kept pace with weathering; therefore, no true horizons	
Color		White to grey-black or black	Grey to yellowish grey-brown	The subsoils are colored as the parent chalk material—whitish grey	
Structure	Wet	Friable, can be cultivated. Will not "bake"		Unaltered	
	Dry	Very friable in cultivation. No hard clods or big cracks		Unaltered	
Character of material		High in O.M. and $CaCO_3$. Lower than Houston	High in $CaCO_3$	May be "rotten" chalk. No organic matter	
Aeration and drainage		Excellent	Sufficient, may be too dry in dry seasons		
Reaction (pH)		Calcareous throughout profile. 7.3 to 8.0			

There exists some evidence that certain soil material classified by the survey as Houston clay may have come from the most highly calcareous clays of the marine deposit which contributed parent material to the Oktibbeha, Eutaw, and Lufkin soil series. For example, the material which gives rise to the Oktibbeha, Eutaw, and Lufkin series sometimes grades into a "Houston clay" with no definite boundary between these types and the Houston. The soil material in such a Houston profile may be acid to a depth of two or more feet. The acidity is not a characteristic of true Houston clay.

Where erosion has kept pace with the weathering of the chalk and the organic matter, and clay residue is present is only a shallow A horizon, the soil is classified as Sumter clay.

According to theories of mature soil development (5, 6, 7, 13, 15, 19) the Houston clay, which is a Rendzina soil, would lose its organic matter and free calcium carbonate and finally develop a red B horizon as it weathered toward maturity in this climate. If any of the Houston profiles have matured sufficiently to become red in their subsoils instead of black and brownish yellow, one would probably be lead to the deduction that

TABLE 3c.—Oktibbeha Clay

Locally called "Red Postoak, Postoak, Red Prairie and Oktibbeha"; residual from the marine clays over the Selma chalk; associated with the shallow clay deposits (2 to 5′). (Some soils in this type may have come from weathering out of organic matter of the Houston.) Production is not high; commonly in cotton and corn; in virgin state was heavily timbered. Lespedeza does well only where soil is acid. About 25 per cent of the Belt, or 580,000 acres, is in this type. Eutaw and Lufkin are often called "Potash" and not differentiated from Oktibbeha. If Eutaw and Lufkin are included with the Oktibbeha in acreage estimations, the total acreage of these three soils is 980,000, or 42 per cent of the Belt.

Horizons	Profile characteristics					
	A		B		C	
	0 to 2″	2 to 6.5″	6.5 to 16″	16 to 36″	36 to 42″	2 to 5′
Color	Virgin: Dark grey brown T.C.L. Cultivated: Horizon zone	Red-brown	Red mottled with yellow	Yellow mottled red and grey	Light yellow to grey-yellow	Grey-white chalk
Structure: Wet	Sticky, cannot be cultivated. "Bakes" easily		Sticky		Unaltered. Is friable	
Structure: Dry	Clods, small cracks. Very hard. Fair to cultivate		Forms cubical structure. Cracks		Unaltered. Does not dry out	
Character of material	Low in O. M. Free from $CaCO_3$. Slight eluviation. Well oxidized		Slight illuvation. Actual oxidation		Not as plastic as "B". May have sharp boundary with chalk	
Aeration and drainage	Fair to sufficient		Fair. Better than Eutaw in "B"		Chalk stratication seems to help drainage	
Reaction (pH)	Usually acid, 4.5 to 7.1. Is neutral where overflowed from Sumter		Typically acid		Becomes neutral near the chalk	

the Oktibbeha series was matured Houston. However, no evidence has been noted that would support such a deduction.

On the other hand it is evident, by the abrupt contact that the subsoil clay horizons of the Oktibbeha series make with the chalk deposit and the acid nature and morphological characteristics of the profile, that the parent material for this soil came from a marine deposit of clays that was superimposed on the Selma chalk. This clay deposit is also the common parent material of the Eutaw and Lufkin series. Where this clay deposit is shallow, it appears that the aeration and drainage of the chalky subsoil have promoted a more rapid weathering than where the deposit is thick. This more favorable condition for

TABLE 3d.—Eutaw Clay

Locally called "Postoak, Brown or Grey Postoak, and Eutaw". Sometimes it has been mistaken for Oktibbeha clay. Material for this type is of the same marine clay deposit as for Oktibbeha clay, except it is deeper to the chalk or calcareous material. Its productivity is hardly as good as for the Oktibbeha clay. It is a good pasture soil, not a big corn or cotton producer, although much in cultivation. About 15 per cent of the Belt, or 349,650 acres, is in this type. This type seems to be intermediate in stage of weathering between the Oktibbeha and Lufkin series.

Horizons		Profile characteristics			
		A		B	C
		0 to 4″	4 to 8″	8 to 36″	
Color		Light brown to brown	Grey-brown, mottled grey and yellow	Highly mottled with grey and yellow. Reddish yellow fades out	Grey-blue, mottled with yellow and reddish yellow
Structure	Wet	Very sticky, not fit for cultivation		Extremely sticky, plastic, and greasy	
	Dry	Clods hard. Is crumbly at optimum moisture		Same as the wet. Seldom is dry	
Character of material		Soil material only weathered a small degree. Mottling indicates some weathering of parent material			
Aeration and drainage		Fair to poor. Usually needs more	Movement of air or water is very slow. Not as slow as Lufkin, slower than Oktibbeha. Needs better drainage		
Reaction (pH)		Almost always very acid throughout profile. pH range from 4.5 to 6.1			

weathering is evident in the soil profile of the Oktibbeha series which has a subsoil of a characteristic red and yellow color as compared to the grey-blue color of the Lufkin subsoil. The Oktibbeha clay is usually red in plowed fields. The red color belongs primarily to the subsoil because the surface soil has been washed away in most cultivated fields.

Soil material that has been deposited in water and not exposed to further weathering tends to be grey-blue in color, possibly because of the reduced state of the iron oxides. It does not have the mottled colors of red and yellow that are characteristic of deficiently drained and partially aerated and weathered materials. It has been noted that, as weathering of such soil material proceeds in a humid subtropical and tropical climate, the effect on the color is for the grey-blue to change to a mottled yellow and red. As the weathering becomes more advanced the mottling tends to decrease and the proportion of solid red increases until the soil takes on a uniform red, yellow, or brown color. The nature of this uniform color will depend upon the

TABLE 3e.—Lufkin Clay*

Locally called "Grey Postoak and Lufkin". Parent material is the same marine clays as for the Oktibbeha and Eutaw clays. This type is found where the marine clay is 15 feet thick or more. Seems to be more productive than Oktibbeha. Needs thorough cultivation for best production. Is fair cotton land. It is estimated that 2 per cent of the Belt, or 46,620 acres, is in this soil type. This soil seems to be very little weathered. Soil is much like the parent material.

Horizons	Profile characteristics			
	A		B	C
	0 to 4"	4 to 8"		
Color	Grey-brown to mottled grey	Grey, highly mottled	Characteristic color of all subsoil is a grey-blue color. Shows only very slight oxidation	
Structure: Wet	Extremely sticky, extremely difficult to handle		Most extremely sticky, plastic, greasy and compact	
Structure: Dry	Hard, cracks. Difficult to cultivate, clods badly		Same as for wet. Never dries out	
Character of material	Slightly weathered only	Subsoil begins here	Seems to be unaltered to only a very slight degree from parent material. Highly colloidal	
Aeration and drainage	Fair to poor	Drainage and aeration are extremely slow. Soil almost impervious to water		
Reaction (pH)	Usually very acid throughout profile. pH range 4.8 to 5.8. Has 5¼ tons $CaCO_3$ requirement to bring pH from 4.9 to 6.5			

* This type occurs chiefly in Wilcox and Marengo Counties and is not uniformly true to type in large areas because various degrees of oxidation have resulted where the topography facilitated better surface run-off and aeration. The soil survey has found it difficult to separate the typical Lufkin clay and has, therefore, classified it as a mixed phase.

organic matter content, the temperature of the climate, and the stage of maturity.

Data presented later in this paper on the chemical composition of the colloids and titration curves of the electrodialized insoluble acids of these soils show that the Oktibbeha series is more highly weathered than the Eutaw series while the Lufkin series is the least weathered. One characteristic of the unweathered parent material of these soil series is that it is very impermeable to movements of air and moisture. Thus a deep deposit would not weather as rapidly as a shallow deposit. The subterranean formation of chalk appears to be more permeable to water than the parent material of the Oktibbeha, Eutaw, and Lufkin series. Therefore, where the marine clay deposit is shallow, weathering processes have progressed rapidly as compared with those in the deep deposit where they were very much slower. The first condition resulted in the Oktibbeha

TABLE 3f.—Bell Clay

Locally called "Trinity clay and Black Bottom"; sometimes mistaken for "Houston clay"; a secondary soil which receives material from all upland Black Belt soils; formed from sheet-eroded material of surrounding hills; a colluvial-alluvial deposit is the most fertile type in the Belt. Very excellent for cotton. Natural production is high. Estimated that 3 per cent of the Belt, or 70,000 acres, is in this type. Is never found in large, single areas.

Horizons		Profile characteristics		
		A	B	C
		No definite soil profile		
Color		Black to grey-black throughout profile		
Structure	Wet	Sticky, about like Houston clay. Not as sticky as Oktibbeha clay		
	Dry	Friable, easy to cultivate		
Character of material		High in organic material. Much like Houston clay in surface		
Aeration and drainage		Usually satisfactory. Position is low but permeability seems high		
Reaction (pH)		Usually neutral. Seldom acid		

TABLE 3g.—Leaf Clay

Sometimes known as "Second Bottom or High Terrace". An alluvial soil left as a second terrace, material comes from all Black Belt upland soils; overflows only in extreme floods; very seldom in crop. Not abundant in the Belt and is of minor importance.

Horizons		Profile characteristics		
		A	B	C
		0 to 15″	15 to 30″	30″
Color		Light grey to mottled grey	Grades to yellow, mottled with grey and reddish yellow	Blue-grey, mottled with yellow
Structure	Wet	Sticky, plastic, resembles Susquehanna clay	Very plastic	Tight
	Dry	Crumbles into cubes	Seldom if ever dries out	
Character of material		May be high in organic matter	Not weathered much since deposition	
Aeration and drainage		Usually very deficient		
Reaction (pH)		Usually slightly acid, may be neutral		

TABLE 3h.—Catalpa Clay

Locally known as "First Bottom and Overflow Land'. This is an alluvial first bottom deposit of material from all soil types in the Belt; is very productive; excellent for cotton and corn, but subject to much flooding. Is of minor importance.

	Horizons	Profile characteristics	
		A 0 to 6"	No definite profile
	Color	Dark brown to brown	Mottled drab and brown or brown and yellow
Structure	Wet	Sticky and plastic	
	Dry	Seldom dries in subsoil	
	Character of material	May be high in organic material	
	Aeration and drainage	Fair in some areas. Usually is deficient	
	Reaction (pH)	Acid to neutral. Frequently is calcareous in surface soil	

series and the latter in the Lufkin series; whereas the Eutaw is an intermediate series.

Recently Mr. J. F. Stroud of the Alabama Soil Survey made a separation between the Oktibbeha and the Eutaw series of a soil series which is called Vaiden. Its characteristics are intermediate between those of the Oktibbeha and the Eutaw soils. The Bell, Leaf, and Catalpa series are secondary soils without very definite horizons. The Bell is formed as an alluvial-colluvial deposit on the bottoms of slopes from soil material carried down from higher positions by sheet erosion. The Leaf series receives material from all the upland soils in the Belt. Streams have deposited the material for this soil in terraces along banks. In subsequent years the streams have cut new and lower bottoms which give rise to the Catalpa soil series.

GREENHOUSE STUDIES

Fertilizer Response

The first greenhouse tests to be conducted on the Black Belt soils were planned to study the response of various typical soil types to potassium, phosphorus, and lime fertilization. Nitrogen was applied to all the pots in these experiments to eliminate it as a factor. For this purpose 8 virgin and 14 cultivated soils were collected from representative soil types throughout the Black Belt.

The soils were dried, mixed, and potted in glazed two-gallon pots and the fertilizers applied as follows: the soil was placed into a suitable pan and the superphosphate, lime, and muriate of potash added. These were mixed thoroughly, returned to the pot, and compacted. The nitrogen was applied in solution as sodium nitrate with the first watering after the seed were planted. Three crops were grown on each soil. The crops were rape, oats, and Johnson grass or soybeans on the cultivated soils, and Sudan grass, rape, and oats on the virgin soils.

Figures 5 to 8, inclusive, show photographs of some of the

FIGURE 5.—Soybeans on a Eutaw clay from Perry County.

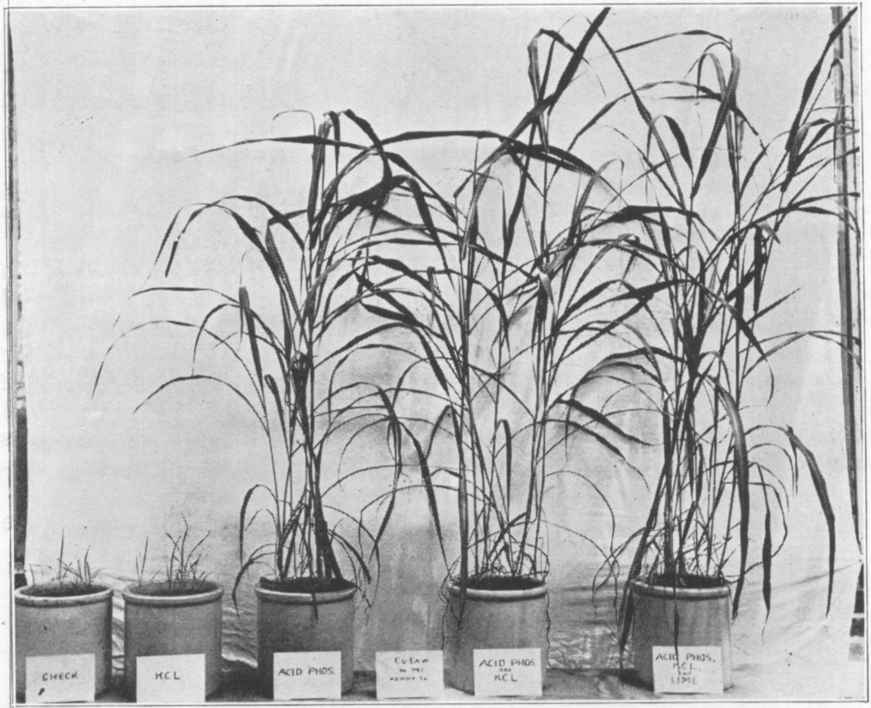

FIGURE 6.—Johnson grass on a Eutaw clay from Perry County.

FIGURE 7.—Rape on a Lufkin clay from Wilcox County.

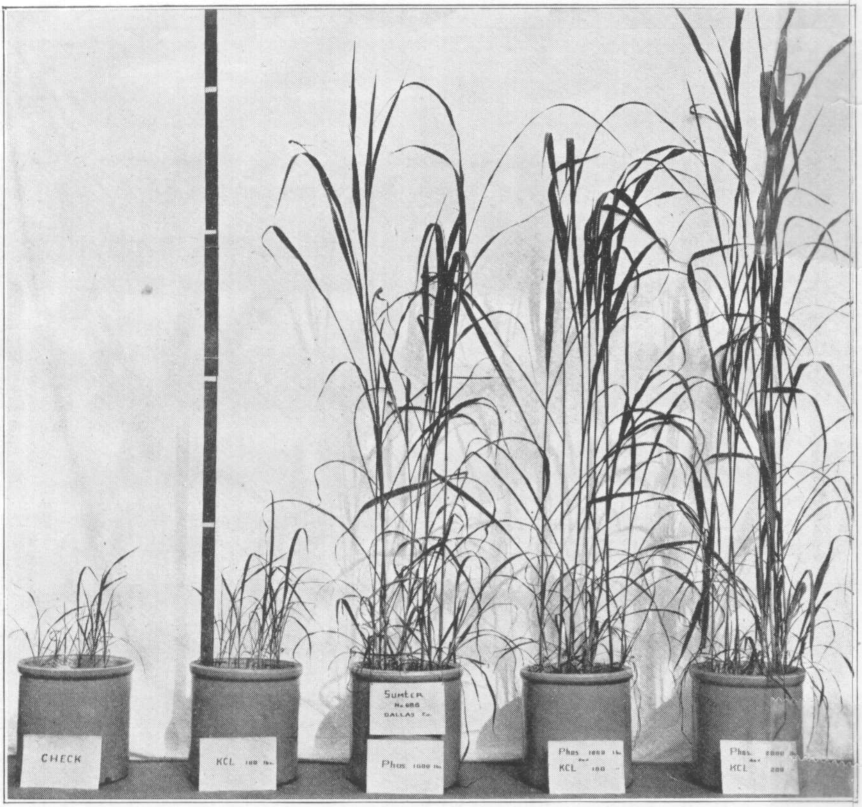

FIGURE 8.—Sudan grass on a Sumter clay from Dallas County.

typical results with different soils and crops. The detailed results of this experiment are graphically given in Figures 9 to 13, inclusive, which are summaries of the results where the yields of the three crops in grams dry weight have been added for each treatment.

The outstanding fact found from these tests was the very great response to heavy applications of superphosphate. It was surprising that nearly all the Black Belt soils responded greatly to phosphorus fertilization with the exception of 739 Houston clay, 740 Bell clay, and 743 Lufkin clay. The Houston and Bell clays were recognized in the field as being very fertile and were tested chiefly to verify this fact in the greenhouse. The soil 742 Lufkin clay, however, gave a high response to superphosphate with rape.

It will be noted that with all the soils, except the Bell and Houston clays, where 2,000 pounds of superphosphate per acre were used, that the yield was greater than where the super-

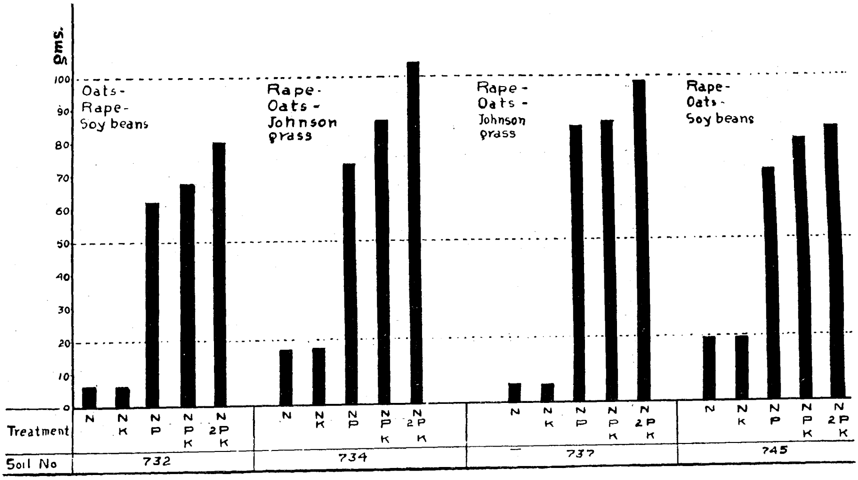

FIGURE 9.—Summary of fertilizer response with three crops on cultivated Sumter clays. The growth is measured in grams of dry weight. N = 500 lbs. nitrate of soda per acre; P = 1,000 lbs. superphosphate per acre; K = 100 lbs. muriate of potash per acre.

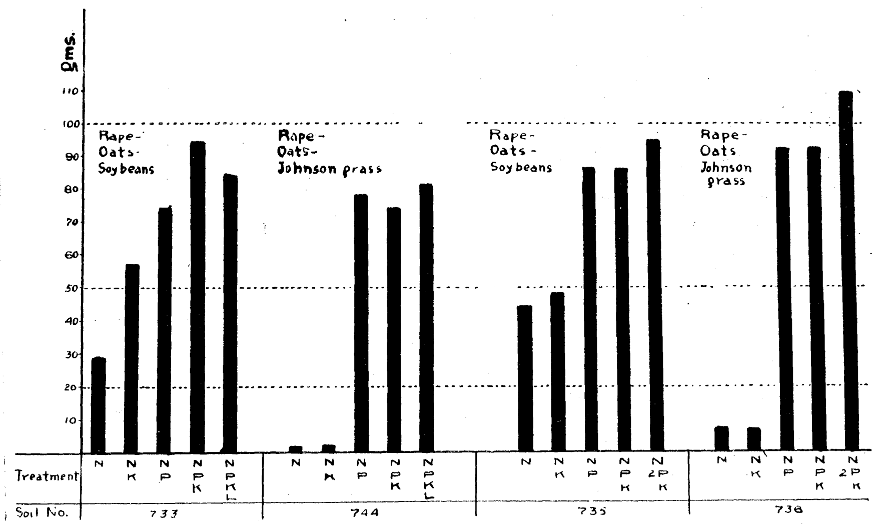

FIGURE 10.—Summary of fertilizer response with three crops on cultivated Oktibbeha clays.

phosphate rate was 1,000 pounds per acre. It is very interesting to note that the 1,000-pound rate was too low to produce the maximum growth. It should be borne in mind that these plants were grown in greenhouse pots where such factors as temperature and moisture were favorable for a rapid plant growth and the limiting factor would be accentuated. The rates may not

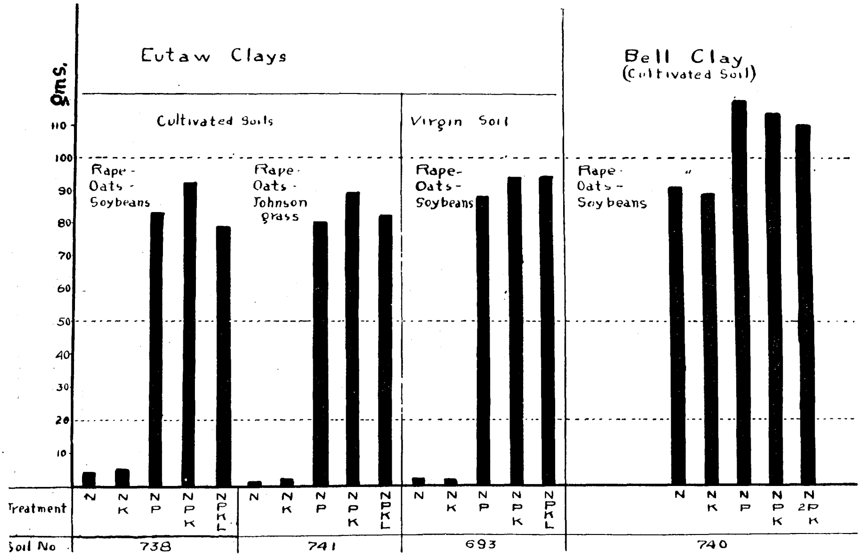

FIGURE 11.—Summary of fertilizer response with three crops on three Eutaw and one Bell clay soils.

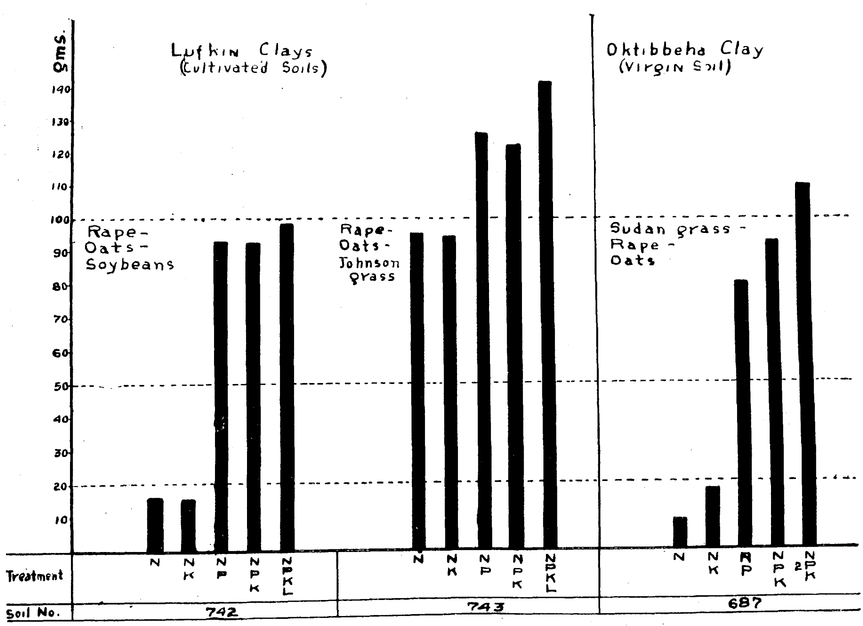

FIGURE 12.—Summary of fertilizer response with three crops on two cultivated Lufkin clays and one virgin Oktibbeha clay.

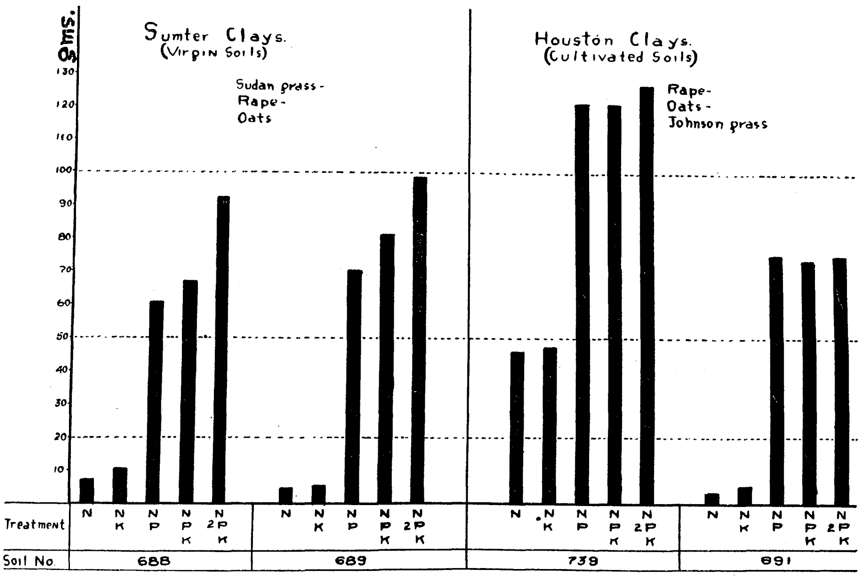

FIGURE 13.—Summary of fertilizer response with three crops on Sumter and Houston clays.

be strictly comparable to similar rates in the field; yet it seems that the differences between the two high rates are significant. The increased growth obtained by the higher rates and the small growth obtained by the smaller rates suggested that the Black Belt soils have great phosphate-fixing powers and that small phosphate applications would be practically useless. This suggestion formed the basis of the plans for the experiments on the rate and degree of phosphate fixation reported later in this publication.

The response to potassium fertilization when the potassium was used without phosphorus was practically nil, except with soils 687, 688, and 733, which showed slight benefits. A small response to potassium when used with superphosphate was evident in about 50 per cent of the soils tried. Oats showed the greatest benefit to potassium fertilization.

Lime benefited the rape generally, but did not give any great differences with Sudan grass, soybeans, or Johnson grass on the acid soils used in this experiment. The oats were usually depressed by this treatment.

Rate and Degree of Phosphorus Fixation

The first greenhouse experiments had demonstrated that crops on the Black Belt soils responded greatly to phosphate fertilization, and that it required relatively high applications of superphosphate to get the maximum response. The results suggested that the phosphorus-fixing powers of the soils were great. The following experiments were therefore conducted to test the rate and degree of fixation of superphosphate on six Black Belt soils.

Fixation During a 180-Day Period.—This experiment was conducted on a Sumter clay, Oktibbeha clay, and Lufkin clay in greenhouse pots. Different rates of superphosphate were mixed into the soil 180, 90, 30, and 0 days before planting soybeans. Nitrogen and potassium were added to all the pots to eliminate them as limiting factors. When the soybeans had reached full growth in the best pots, which was 48 days after planting, the crops was harvested, dried, and weighed.

The plant response was sufficiently similar on the three soils to make it possible to picture the results in Figure 14 as a summary graph. The growth of the soybeans increased with increasing amounts from 250 to 1,000 pounds per acre of superphosphate when the phosphate was applied at planting time. However, when the phosphate was applied 30 days or longer before planting, the maximum growth was not reached until 2,000 pounds of superphosphate were used. Two hundred and fifty pounds applied at planting made as much growth as 1,000 pounds of superphosphate applied 180 days before planting. This demonstrates that these soils have a great capacity for fixing phosphorus in such a form that the plant is unable to use it.

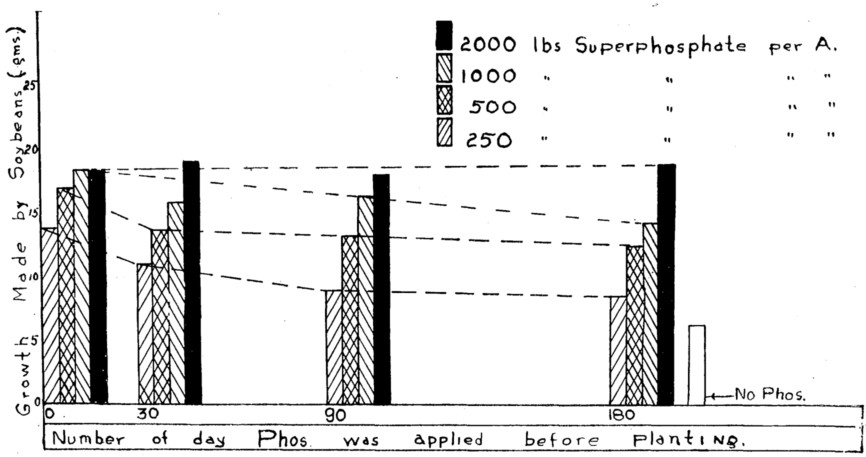

FIGURE 14.—Average yield of soybeans as influenced by time and rate of phosphate applications. The average of the results on No. 732, Sumter Clay; No. 733, Oktibbeha clay; and No. 742, Lufkin clay.

The graph shows that most of the fixation of the phosphate took place in the first 30 days. It should be borne in mind that when the soybeans had been growing 30 days the phosphate had been in contact with the soil for 30 additional days. At this stage the fixation of the phosphate in the soils where the phosphate was applied at planting would be as represented in the graph at 30 days before planting. Only the 2,000-pound rate was able to maintain maximum growth where the application was 180 days before planting. The yield with 250 pounds superphosphate per acre applied 180 days before planting was only slightly better than that with no phosphorus.

Fixation During a 365-Day Period.—This experiment was conducted using a Eutaw clay, Vaiden clay, and Sumter clay. In this experiment different rates of superphosphate were applied at periods of 365, 180, 30, and 0 days before planting. Lime was used on the two acid soils to test its effect on the plant growth when applied at different periods before planting. The crop used was oats. The oats were harvested 100 days after planting at which time the oats in the best pots were in full head.

Figures 15 to 19, inclusive, show a graphic presentation of the results. From these graphs it will be noted that the three soils behaved similarly to the soils used in the 180-day experiment in their reaction to the different phosphate treatments. The growth made by the oats increased with each increment of superphosphate up to 2,000 pounds per acre. Where the phosphate had been applied at different time intervals before planting its efficiency dropped as the time interval increased from the time of planting to one year.

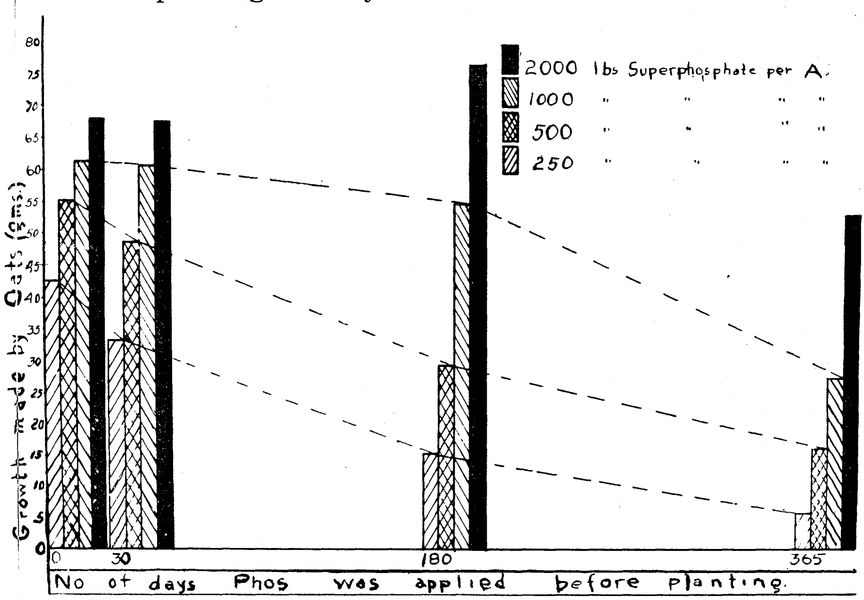

FIGURE 15.—The effect of varying the rate and time of application of superphosphate on the growth of oats on a virgin Eutaw clay, No. 761.

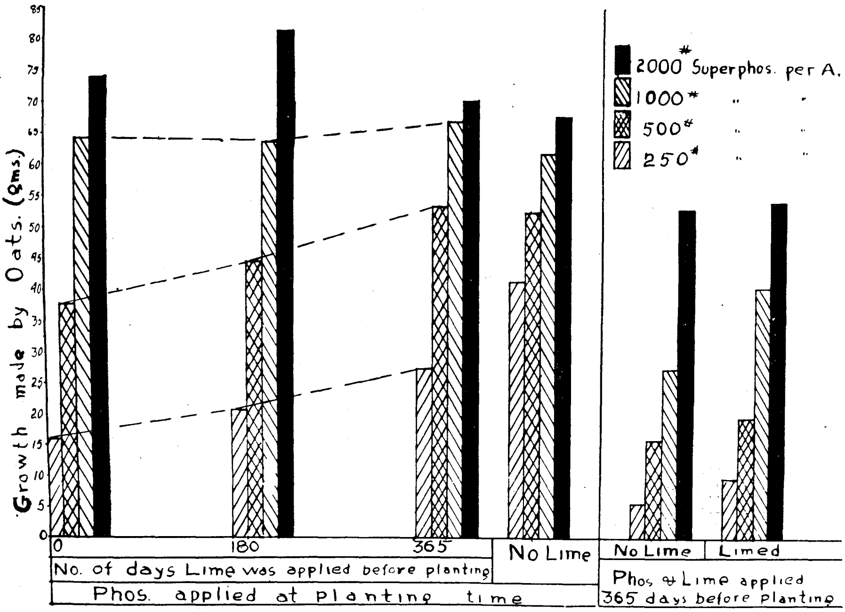

FIGURE 16.—The effect of varying the time of application of lime on the growth of oats where the rates of superphosphate are varied on a virgin Eutaw clay, No. 761.

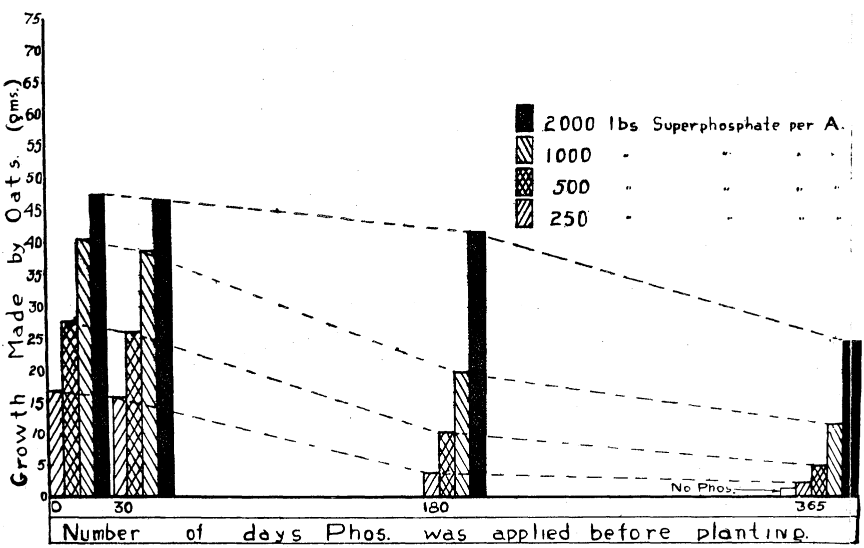

FIGURE 17.—The effect of varying the rate and time of application of superphosphate on the growth of oats on a Vaiden clay, No. 762.

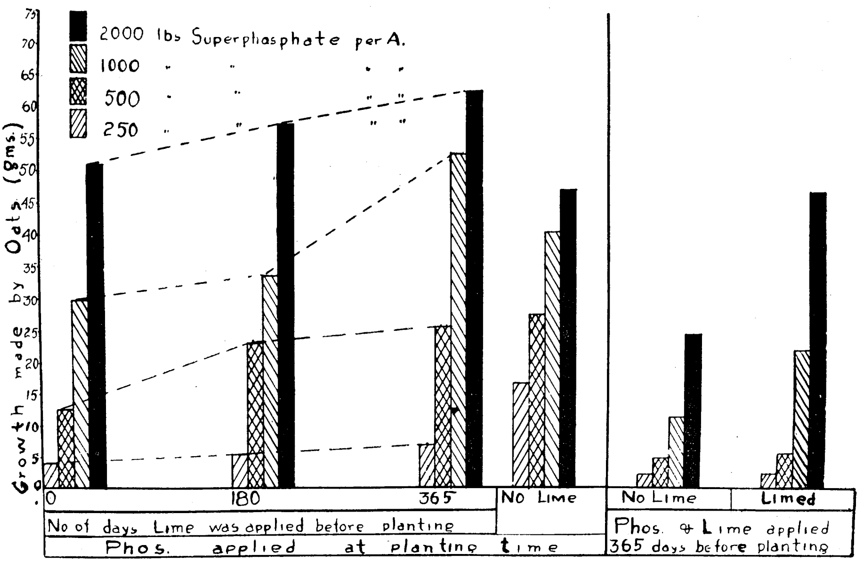

FIGURE 18.—The effect of varying the time of application of lime on the growth of oats where the rates of superphosphate are varied on a Vaiden clay, No. 762.

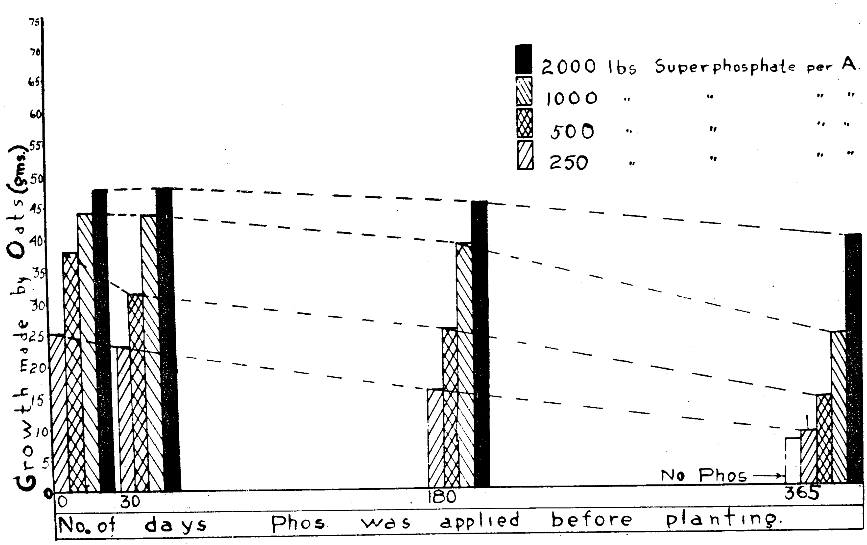

FIGURE 19.—The effect of varying the rate and time of application of application of superphosphate on the growth of oats on a Sumter clay, No. 757.

A study of the yields of oats from the Eutaw clay, as shown in Figures 15 and 16, reveals that the 2,000-pound rate of superphosphate made 1.6 times as much dry matter as the 250-pound rate where both were applied at planting time. The effect of time of application of the phosphate can be best noted with the 250-pound rate. Where the phosphate had been in the ground 365 days before planting it was only 13 per cent as efficient as where applied at planting. At 180 and 30 days it was 36 and 78 per cent, respectively, as efficient as where applied at planting. Superphosphate applied at the rate of 500 pounds 30 days before planting, 1,000 pounds 180 days before planting, and 2,000 pounds 365 days before planting produced only slightly more growth than 250 pounds applied at planting. Lime caused a marked depression in the efficiency of the low rates of superphosphate. This depression was most pronounced where the lime had been in the ground the shortest period. Where the phosphate was applied at 1,000- and 2,000-pound rates the lime was beneficial and the time of application of the lime produced no great differences.

A study of the yields from the Vaiden clay, given in Figures 17 and 18, shows that all the results with the superphosphate and lime are similar to those on the Eutaw clay except the degree of fixation of the phosporus was greater in the Vaiden clay. The 2,000-pound rate of superphosphate made 2.8 times as much dry weight of oats as the 250-pound rate where both were applied at planting. Where the 250 pound rate of superphosphate had been in the ground 365, 180, and 30 days before planting it was 12, 22, and 94 per cent as efficient, respectively, as where applied at planting.

Figure 19 shows the yields from the Sumter clay. This soil is calcareous and therefore was not treated with lime. Its response to and fixation of superphosphate was very similar to that with the Eutaw and Vaiden clays.

Miscellaneous Pot Tests

Placement of Superphosphate.—When it was learned that crops on the Black Belt soil responded generally to high applications of superphosphate and that the soils had a high phosphate-fixing power, it became of interest to learn if superphosphate applied in a localized area in the soil would be more efficient than when mixed throughout all the soil. A short test was, therefore, conducted on a Sumter clay and Oktibbeha clay in which the superphosphate was mixed into a one-inch layer of soil one inch below the surface for the localized treatment, and for comparison a like rate of superphosphate was mixed throughout the soil in the pot.

Table 4 gives the details of the treatments and the results with oats on the two soils used. Four weeks after planting, the growth with 250 pounds superphosphate per acre rate with the

TABLE 4.—The Effect of Localizing the Superphosphate in One Inch of Soil One Inch Below the Surface on the Yield of Oats on a Sumter and on an Oktibbeha Clay.

Treatment*	Yield of oats** (dry weight grams)	
	No. 732 Sumter clay	No. 733 Oktibbeha clay
Check	7.9	28.1
250 lbs. superphosphate localized	24.5	29.6
250 lbs. superphosphate mixed throughout soil	27.2	47.4
500 lbs. superphosphate localized	46.4	43.1
500 lbs. superphosphate mixed throughout soil	45.8	48.2
1,000 lbs. superphosphate mixed throughout soil	55.0	61.7

* All pots received nitrogen and potassium.
** Average of duplicate treatments.

localized treatment was equal to that with 1,000 pounds mixed throughout the soil. At this period, the plants with 250 pounds superphosphate mixed throughout the soil were much smaller than those with the localized treatment, although better than the check pot with not phosphate. The difference between 500-pound rates localized and mixed throughout was not as great as in the 250-pound cases, although the 500-pound rate localized was better than this amount mixed throughout the soil.

At the time of harvesting the oats, 120 days after planting, the results were reversed from those just described. The mixed treatment yielded more dry matter at this stage than the localized treatment.

Tests With Soils from the Black Belt Substation.—The site for the Black Belt Substation was located during the course of the present investigation. Several large soil samples were collected from the area selected and tested in the greenhouse. The information gained from this study was used as a guide in planning the treatments on the experimental plots on this substation.

Table 5 gives the soils, the treatments and the crops used, and the yields of the various crops on the different soils with the treatments indicated. In general, these results are similar to those obtained in the first greenhouse experiments reported. The Bell clay is very fertile and shows very little response to any treatment as compared to the other soil types. The Houston clay ranks next in fertility and shows a greater increased growth due to the phosphate. The Sumter, Vaiden, and Eutaw clays are all very infertile and showed marked benefits from the phos-

TABLE 5.—Yields of Dry Matter of Alfalfa and Oats on Sumter, Bell, and Houston Clays from the Fertilizer Treatments Indicated.

Treatment*	Sumter clay No. 796		Bell clay No. 797		Houston clay No. 798	
	Alfalfa	Oats	Alfalfa	Oats	Alfalfa	Oats
	gms.	gms.	gms.	gms.	gms.	gms.
0	1.8	6.0	11.6	34.6	4.1	14.0
N K	2.1	5.2	15.5	37.1	3.5	11.7
N P	15.6	43.7	23.8	60.3	17.6	55.3
N P K	15.0	43.4	25.8	62.3	15.8	52.1
N 2P K	15.9	44.9	27.3	64.6	18.7	59.7
N P K S	13.8	43.5	22.2	——	——	——

* N = 500 lbs. $NaNO_3$ per acre
P = 1,000 lbs. Superphosphate per acre
K = 100 lbs. KCl per acre
S = 25 lbs. Sulphur per acre

phate fertilization. Potassium showed no increased growth and sulphur tended to depress the alfalfa yields on the Sumter and Bell clays.

CHEMICAL STUDIES

The pH Values of the Soil Samples

During the course of the field studies more than one hundred soil samples were collected for pH determinations and laboratory studies.

The pH values were determined by the colorimetric buffer solution method of Clark and Lubs (11). The collodion sack method of Pierre and Parker (26) was used at first to obtain clear extracts but it was found that this method with some soils gave values that were high compared to values obtained by the hydrogen electrode method in the soil suspension. The Kuhn method (14) using "X-Ray purity" $BaSO_4$ for clarifying the soil suspension gave results which checked closely to those with the hydrogen electrode. Therefore, the pH values reported here are from the clarified soil suspension by the $BaSO_4$ method.

The pH values of the soil samples from the different horizons are summarized in Table 6. Only the mean, minimum, and maximum values are reported.

Thirty-eight samples of Oktibbeha clay soil material ranged in pH values of the surface soils from 4.5 to 7.1 with a mean pH value of about 5.6. Wherever the reaction was above pH 6.0, it was evident from field observations that such a soil had received washings from Sumter clay areas, which are always calcareous. The subsoil material, i.e., the material below six inches and above the Selma chalk, ranged in pH values from 4.6 to 6.9 with a mean value of about 5.2. Nine Vaiden clay soil samples had a mean pH value of about 5.1 in the surface soil and 4.7 in the

TABLE 6.—The Mean, Minimum, and Maximum pH Values of the Soil from Different Horizons of the Major Black Belt Soil Types.

Soil types	Horizons	Number tested	Mean	Minimum	Maximum
			pH	pH	pH
Oktibbeha clay	A	20	5.6	4.5	7.1
	B_1	12	5.2	4.7	6.9
	B_2	4	5.1	4.8	5.3
	Chalk	2	—	7.5	8.0
Vaiden clay	A	5	5.1	4.3	5.8
	B_1	3	4.8	4.4	5.2
	B_2	1	4.9	—	—
Eutaw clay	A	11	5.3	4.7	6.4
	B_1	6	4.9	4.5	6.2
	B_2	2	—	5.2	6.1
Lufkin clay	A	2	4.9	—	—
	B_1	1	4.9	—	—
Sumter clay	A	18	7.4	7.3	8.0
	Chalk	4	7.5	7.4	7.7
Houston clay	A	4	7.1	6.8	7.4
	B_1	2	—	6.8	7.3
	B_2	3	7.3	7.3	7.4
Bell clay	A	2	7.5	—	—
Catalpa clay	A	1	7.5	—	—
Leaf clay	A	1	4.7	—	—
Susquehanna clay	A	5	5.0	4.4	5.2
	B_1	3	4.6	4.3	4.7
	B_2	3	4.4	4.1	4.7
	C	4	4.6	—	4.7

subsoil. Nineteen Eutaw clays had a pH range in the surface soil of 4.7 to 6.4 with a mean value of about 5.3. The mean pH value for the subsoils of this type was about 4.8. The pH value for each of the three Lufkin samples was 4.9. The Sumter clays are always alkaline and range between pH 7.3 and 8.0. The Houston clays are usually not as alkaline as the Sumter clays and rank nearer pH 7.0. The Bell and Catalpa clays are always alkaline as they always receive some washings from calcareous uplands. The Leaf clays are frequently neutral in the low areas where they are flooded during heavy rains, but are usually acidic where they occur on second terraces.

Fixation of Phosphorus and Potassium

Limited reports from Black Belt farmers indicated that they had not received much response from phosphorus fertilization when applied in amounts common in farm practice, i.e., 150 to 400 pounds per acre of superphosphate. These studies pointed to the probability that the Black Belt soils possessed very great capacities for fixing soluble phosphates into forms unavailable for plants.

This experiment was, therefore, planned to study the capacities of eight Black Belt soils for fixing water-soluble phosphates into water-insoluble forms. At the same time these soils were treated with muriate of potash to study their capacities for absorbing potassium.

Ordinary glass tumblers were filled with 250 grams of air-dried soil that had been passed through a 20 mesh sieve. Each soil tested as indicated in Tables 7 and 8 was set up in a series of 10 tumblers. The phosphorus and potassium were applied in solution, as $CaH_4(PO_4)_2$ and KCl, respectively; these materials were mixed thoroughly with the treated soils. Fifty cubic centimeters of water were added to the soil in each tumbler. The soils were moistened from time to time for a period of six months in order to keep the moisture content approximately at optimum conditions. At the end of five months a portion of the soils were tested for water-soluble PO_4 according to a modification of the method of Deniges (22), using a 1:5 soil-water ratio and collodion sacks. The water-soluble potassium was determined at the end of six months by the colorimetric method described by Briggs (9) from 1:5 soil-water extracts.

TABLE 7.—The Fixation of PO_4 in Soils in a Five-Month Period.

Soil	Treatment—superphosphate	PO_4 in superphosphate. Dry soil basis	PO_4 soluble in 1:5 H_2O extract after 5 months. Dry soil basis	Per cent of PO_4 fixed
	Lbs. per acre	p.p.m.	p.p.m.	
No. 687	None	None	None	——
Oktibbeha clay	1,000	107	None	100.0
	4,000	427	0.475	99.88
No. 688	None	None	None	——
Sumter clay	1,000	107	0.225	99.80
	4,000	427	2.085	99.51
No. 689	None	None	None	——
Sumter clay	1,000	107	0.150	99.85
	4,000	427	0.962	99.77
No. 690	None	None	None	——
Houston clay	1,000	107	0.150	99.85
	4,000	427	0.720	99.83
No. 691	None	None	None	——
Houston clay	1,000	107	0.150	99.85
	4,000	427	1.250	99.71
No. 692	None	None	None	——
Leaf clay	1,000	107	0.195	99.82
	4,000	427	3.100	99.27
No. 693	None	None	None	——
Eutaw clay	1,000	107	0.150	99.85
	4,000	427	1.800	99.57
No. 694	None	None	None	——
Oktibbeha clay	1,000	107	None	100.00
	4,000	427	0.600	99.86

The PO_4 removed in the water extract at the end of five months is given in Table 7. It will be noted that there was no water-soluble PO_4 in any of the untreated soils. This is in accord with the very poor growths obtained in the greenhouse where no phosphorus was applied. There was no water-soluble PO_4 in the extracts from the two Oktibbeha clays where the amount of PO_4 added was equivalent to 1,000 pounds or less of superphosphate per acre. The remainder of the soils had from 0.15 to 0.22 p.p.m. water-soluble PO_4 with the 1,000 pound rate. The extra high phosphate application, equivalent to 4,000 pounds per acre of superphosphate, gave only a recovery of less than 1 per cent of water-soluble PO_4. These data indicate that the soils used possessed very high capacities for fixing phosphates into water-insoluble forms.

The data of the potassium recovered in the water extracts from the different soils are shown in Table 8. Soils 688, 689, 692, and 694 contained from a trace to no water-soluble potassium. These soils showed slight responses to potassium fertilization when the phosphorus had been removed as a limiting

TABLE 8.—The Fixation of K in Soils in a Six-Month Period.

Soil	Treatment—KCl	K in KCl. Dry soil basis	K soluble in 1:5 H_2O extract after 6 months. Dry-soil basis	Per cent of material fixed
	Lbs. per acre	p.p.m.	p.p.m.	
No. 687 Oktibbeha clay	None	None	0.24	—
	100	26.2	3.19	88.7
	500	131.1	31.96	75.8
No. 688 Sumter clay	None	None	Trace	—
	100	26.2	2.60	90.0
	500	131.1	12.45	90.5
No. 689 Sumter clay	—	None	None	—
	100	26.2	13.73	47.5
	500	131.1	16.70	87.2
No. 690 Houston clay	None	None	2.51	—
	100	26.2	4.78	91.3
	500	131.1	12.07	92.7
No. 691 Houston clay	None	None	1.20	—
	100	26.2	2.50	95.4
	500	131.1	8.24	94.6
No. 692 Leaf clay	None	None	None	—
	100	26.2	5.25	79.9
	500	131.1	6.85	94.7
No. 693 Eutaw clay	None	None	1.59	—
	100	26.2	16.70	42.3
	500	131.1	34.82	74.6
No. 694 Oktibbeha clay	None	None	None	—
	100	26.2	1.59	93.9
	500	131.1	11.26	91.4

factor. The data show that potassium is absorbed by the soil too much less extent than phosphorus. From 42.3 to 95.0 per cent of the K applied, at the rate equivalent to 100 pounds KCl per acre, was absorbed by the soil.

Relation of the Phosphorus Content of the Soil to the Growth of Oats

A study was made of the relationship between the total P_2O_5 content of the soil, the electrodializable P_2O_5, and .002 N H_2SO_4 soluble P_2O_5 by the Truog method (35) and the growth made by oats in the greenhouse pot tests on 22 different soils from the Black belt.

The results of the analyses are given in Table 9. There was no correlation between the total P_2O_5 contents of the soils and the greenhouse results. It is interesting to note, however, that some of the Black Belt soils have very high total phosphorus contents. The Bell clay, No. 740, contained 13,180 pounds of P_2O_5 in two million pounds of soil (one acre, 6⅔ inches in depth). This was a very fertile soil in the field and greenhouse. On the other hand a Sumter clay, No. 734, contained 12,180 pounds of P_2O_5 per two million pounds of soil, yet was quite infertile in the field and showed a high response to phosphate fertilization in the greenhouse.

The electrodializable P_2O_5 was determined in a Bradfield three-compartment cell, using a current of 105 volts. The electrodializable phosphorus was determined at the end of 6, 21, and 48 hours. The results at the end of 21 hours are not reported in the table. The calcareous soils, i.e., Sumter, Houston, and Bell clays, were decomposed by the electric current and gave high yields of P_2O_5. No relationship was observed between these data and the greenhouse results.

It was found that the phosphorus determined by the .002 N H_2SO_4 extraction method gave a high degree of correlation to the growth made by oats in the pots where nitrogen and potassium had been applied to eliminate them as factors. This correlation is shown graphically in Figure 20. In this figure each dot represents a different soil. The phosphorus by the Truog method, calculated as pounds P_2O_5 per acre, is plotted as the abscissa against the growth made by the oats. A second degree parabola was fitted to these data and the index of correlation calculated to be .884.

Although the number of cases is limited in the upper part of the curve, the curve shows some interesting facts. The broken lines on the graph show the "standard error of estimate", which represents the boundary wherein about 68 per cent of the cases should fall if these data were used as a basis for predicting the phosphorus needs of other Black Belt soils.

It is apparent that soils with less than 30 pounds of P_2O_5 by

TABLE 9.—Total, Electrodializable, and .002 N H_2SO_4 Soluble P_2O_5 in Black Belt Soils, and the Growth Made by Oats with Nitrogen and Potassium Fertilization in Greenhouse Pot Tests.

Soil No.	Soil type	Pounds P_2O_5 per 2,000,000 pounds of soil				Growth made by oats with N and K (grams dry weight)
		Total P_2O_5	Electrodializable P_2O_5 at end of indicated hours		Truog Method, .002 N H_2SO_4	
			6 hours	48 hours		
732	Sumter clay	404	2.15	13.99	3.42	3.4
690	Houston clay	1,718	3.18	6.17	5.59	.8*
689	Sumter clay	2,163	15.94	25.53	7.98	4.0
738	Eutaw clay	1,680	1.97	3.94	8.61	2.9
694	Oktibbeha clay	1,181	.33	1.51	8.67	.8*
744	Oktibbeha clay	1,338	2.63	8.43	8.97	1.5
741	Eutaw clay	1,480	.98	2.69	10.94	1.8
693	Eutaw clay	1,728	1.06	2.24	11.36	.3
737	Sumter clay	4,530	98.15	324.41	11.36	4.9
745	Sumter clay	8,825	141.00	434.25	12.92	12.3
736	Oktibbeha clay	3,120	.89	2.15	16.15	5.5
688	Sumter clay	5,006	35.76	81.20	19.14	4.5
734	Sumter clay	12,180	12.26	73.55	22.13	9.5
742	Lufkin clay	3,432	2.12	5.11	22.54	12.6
733	Oktibbeha clay	1,910	.67	11.58	23.32	47.2
687	Oktibbeha clay	1,542	1.07	1.07	24.04	2.8
691	Houston clay	2,364	Nil	Nil	32.17	3.8
739	Houston clay	2,341	2.63	5.47	48.14	33.9
692	Leaf clay	1,760	2.33	9.18	52.02	29.2
735	Oktibbeha clay	1,467	.79	2.44	59.92	35.7
743	Lufkin clay	3,829	.53	3.10	71.16	53.4
740	Bell clay	13,180	190.68	319.46	107.60	66.7

* Sudan grass.

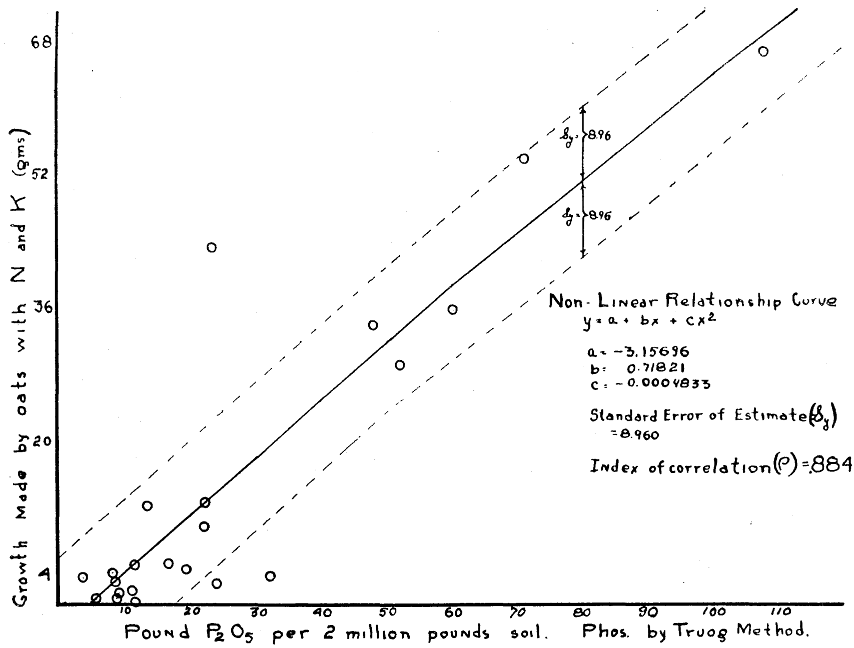

FIGURE 20.—The correlation between the phosphorus determined by the Truog .002 N H_2SO_4 extraction and the growth made by oats in greenhouse pots with nitrogen and potassium fertilization.

the Truog method made very poor yields of oats without phosphate fertilization. The Bell clay, No. 740, which was a very fertile soil in the field and made maximum yields of oats in the greenhouse, contained over 100 pounds of available P_2O_5 per acre by the Truog test.

Exchangeable Cations and Anions

In order to better understand the nature and properties of the highly colloidal soils of the Black Belt it was desirable to study their exchangeable ions. On account of the high colloid content of these soils the determination of the exchangeable bases by leaching methods presented difficulties in filtering. An adaption of Bradfield's electrodialysis apparatus was therefore used and data were obtained from 22 soils. These soils had also been used in the greenhouse tests and other laboratory studies.

In the electrodialysis procedure air-dried soils were used. Corrections for the moisture content of the soil were made in the weighing so that exactly 10 grams of dry soil were electrodialyzed, thus necessitating no moisture corrections in the results obtained. At the end of 6, 21, and 48-hour periods the electrode chambers were emptied, and the contents titrated with N/10 $Ba(OH)_2$ or N/10 HCl. The anode solution was boiled to expell the CO_2 before titration and an excess of standard HCl added to be titrated back with standard NaOH. The titration values for the cations and anions were plotted as in Figure 21

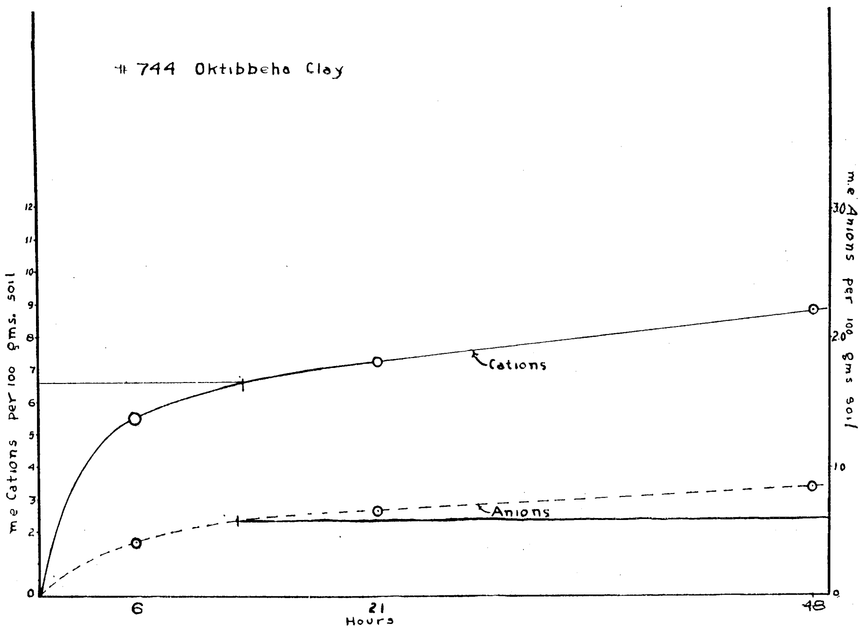

FIGURE 21.—Typical graph of the results of electrodialysis plotted to obtain the total electrodializable bases and acids.

(a typical case), in order to obtain the total electrodializable bases and the total electrodializable acid ions, exclusive of the CO_2 ion. The points in the cation and anion curves where the breaks in the straight lines occurred were taken as the values for the total electrodializable ions, the straight part of the curves being considered as due to the solubility of unexchangeable ions.

Exchangeable magnesium cannot be obtained in the cation solution to any extent because $Mg(OH)_2$ is insoluble in an alkaline solution, thus preventing its passage through the membrane out of the acid center chamber into the alkaline cathode chamber. The percentage base saturation and exchangeable hydrogen reported are, therefore, subject to the discrepancy caused by the omission of the exchangeable magnesium.

The total base exchange capacities of the acid soils were determined from the electrometric-titration buffer curves determined from the electrodialized soils. (See Buffer Action and Nature of Soil Acids.) The data obtained by the electrodialyses of the calcareous soils give no information about the exchangeable ions. The calcium and PO_4 obtained from these soils at the end of 48 hours of electrodialysis are given in Table 10. The high yields of Ca and PO_4 are undoubtedly the result of the breaking down of $CaCO_3$ to liberate Ca, and $Ca_3(PO_4)_2$ to liberate Ca and PO_4.

TABLE 10.—Calcium and PO_4 Removed by Electrodialysis from Eight Calcareous Soils

Soil No.	Type	m.e. Ca/100 gms. soil electrodialized in 48 hours	m.e. PO_4/100 gms. soil electrodialized in 48 hours
688	Sumter clay	153.2	.1715
689	Sumter clay	153.9	.0538
732	Sumter clay	121.2	.0294
734	Sumter clay	223.1	.1445
737	Sumter clay	144.2	.686
743	Sumter clay	266.6	.915
690	Houston clay	49.4	.0129
740	Bell clay	145.0	.995

Table 11 gives the data obtained with the acid soils with the exception of Soil No. 691, Houston clay which contained 0.61 per cent $CaCO_3$. It will be noted in this table that the total base exchange capacity of the acidic soils ranged from 14.2 m.e. to 36 m.e. base per 100 grams of soil.

The percentage base saturation was 34.0 for the average of two Lufkin clays, 43.3 for the average of three Eutaw clays, and 52.8 for the average of six Oktibbeha clays. The range of percentage base saturation with the Oktibbeha clays was 38.5 to 100. The soils of this type which were saturated or nearly saturated with bases had received lime washings in the field.

Calcium made up nearly 100 per cent of the bases removed; therefore, the amounts of sodium and potassium electrodialized were exceedingly small.

Buffer Action and Nature of Soil Acids

Titration curves were determined on fourteen of the soils representing five soil types: Lufkin, Eutaw, Oktibbeha, Leaf, and Houston clays. The object of these determinations was to study the characteristics of the clay acids and to find the total base exchange capacities and buffer values of these soils.

Ten gram samples of soil were freed of replaceable ions by electrodialysis and titrated with N/10 NaOH by means of the hydrogen electrode. The pH values were determined after the base had been shaken with the soil for 22 hours to insure equilibrium. The total exchange capacities were measured according to the procedure of Bradfield (7). The buffer capacities were calculated according to the equation of Baver (3).

TABLE 11.—Electrodialytic Data of Acid Soils.

Soil No.	Soil type	Cations as m.e. per 100 grams of soil					Per cent base saturation	Anions as m.e. per 100 grams of soil		
		Bases at end of 48 hour electrodialysis	Total exchange capacity	Exchangeable hydrogen	Exchangeable calcium	Electrodializable bases		At end of 48 hour electrodialysis	Total exchange capacity	Electrodializable PO_4 in 48 hours
691	Houston clay*	65.2	16.0	0	——	——	100.0	2.37	1.75	Nil
739	Houston clay	19.9	14.2	0.7	15.5	15.5	95.6	1.74	1.32	0.0115
687	Oktibbeha clay	13.4	18.0	7.0	11.0	11.0	61.1	1.05	0.68	0.0022
694	Oktibbeha clay	9.9	17.0	11.7	5.3	5.3	31.1	0.80	0.55	0.0039
733	Oktibbeha clay	9.0	20.5	12.6	7.9	7.9	38.5	0.63	0.37	0.0044
735	Oktibbeha clay	22.0	16.0	0	16.0	16.0	100.0	0.81	0.58	0.0050
736	Oktibbeha clay	12.1	18.0	9.5	8.5	8.5	47.3	0.70	0.53	0.0046
744	Oktibbeha clay	8.9	17.0	10.4	6.6	6.6	38.9	0.86	0.58	0.0178
693	Eutaw clay	15.4	20.5	10.3	9.2	10.2	49.7	0.79	0.37	0.0150
738	Eutaw clay	17.3	22.6	11.1	10.6	11.5	50.9	1.04	0.70	0.0082
741	Eutaw clay	11.9	27.2	19.2	7.6	8.0	29.2	0.89	0.58	0.0057
742	Lufkin clay	15.4	34.0	22.3	10.4	11.7	34.4	0.98	0.73	0.0106
743	Lufkin clay	17.3	36.0	24.9	11.0	12.1	33.6	0.81	0.76	0.0097
692	Leaf clay	13.2	26.6	14.3	12.0	12.3	46.2	0.74	0.37	0.0189

* Soil contains carbonates.

Figures 22 to 24, inclusive, show the titration curves for ten of the fourteen soils. The curves for a given soil type tend to be similar indicating that the soil acids within each type are similar. The chemical composition of the colloids of the Lufkin, Eutaw, and Oktibbeha clays shows that these soils represent three stages of weathering. The field studies show that the parent material for these soils was common to the three types. The buffer curves for these soils show that for each degree of weathering in this climate there are soil acids characteristic to that degree of weathering.

Bearing in mind that the Lufkin is the most unweathered of these three soils and has the greatest buffering action, it becomes apparent from an inspection of the data given that as weathering progressed the buffering capacity of the soils was reduced. These observations agree with a study made with Baver (5) on the nature of soil acidity where it was found that the nature of the soil acids was a function of the kind and extent of weathering and was independent of the kind of parent material.

The buffer capacities for a few representative samples of Lufkin, Eutaw, and Oktibbeha clays are given in Table 12. The average values are 676.0, 380.8, and 152.5 for the Lufkin, Eutaw, and Oktibbeha clays, respectively. These values are in the order of the degree of weathering. The values for the Eutaw clay, No. 693, and the Oktibbeha clay, No. 733, are not in close agreement with the values for the other types within their respective series; this would indicate that these two soils are not strictly

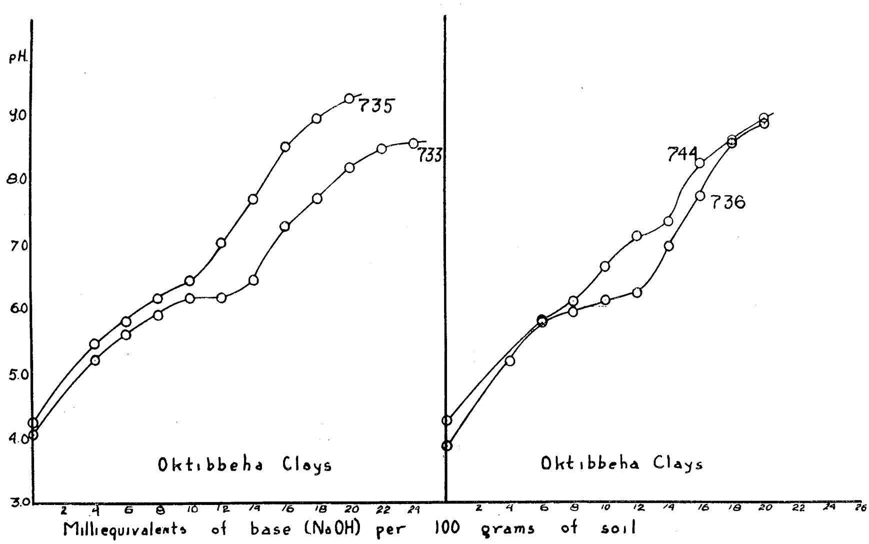

FIGURE 22.—Titration curves of electrodialized Oktibbeha clay soils.

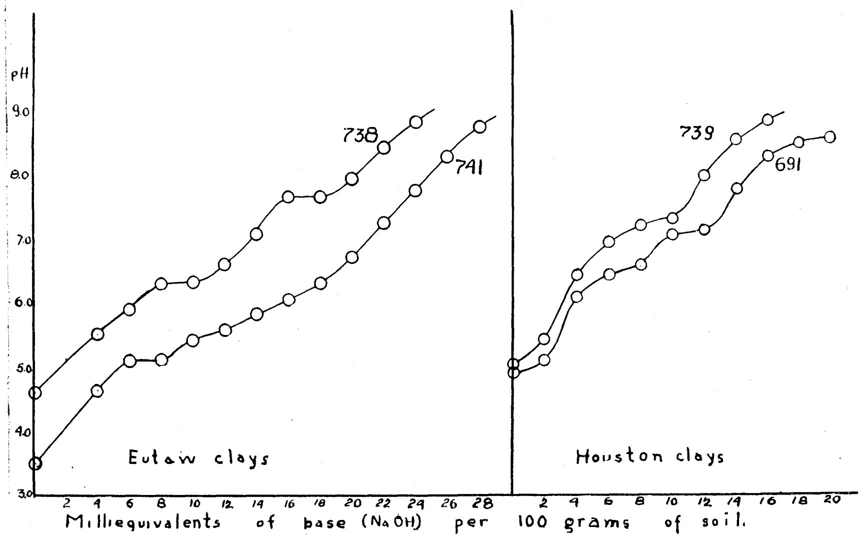

FIGURE 23.—Titration curves of electrodialized Eutaw and Houston clay soils.

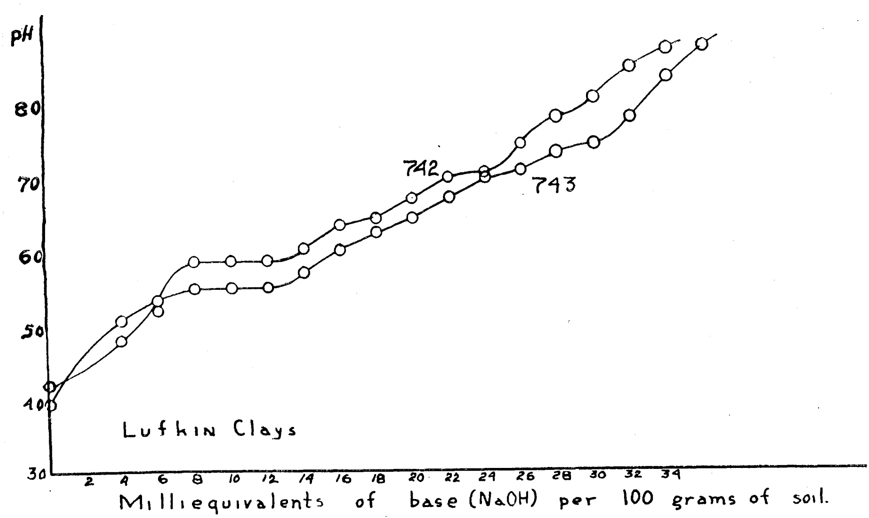

FIGURE 24.—Titration curves of electrodialized Lufkin clay soils.

TABLE 12.—The Buffer Values of Three Important Soil Types From the Black Belt

	Soil type and number							
	Lufkin clay		Eutaw clay			Oktibbeha clay		
	742	743	693	736	741	687	733	744
$\sum \frac{\Delta B}{\Delta pH}$	665.1	688.1	298.3	499.4	344.6	69.9	295.8	91.9
Average	676		380.8			152.5		

typical of their type but tend to approach the boundary of another type.

The total base exchange capacities of the fourteen soils are given in Table 13. It will be noted from the average total exchange capacities for the Lufkin, Eutaw, and Oktibbeha clays that these values also rank in order of the degree of weathering.

TABLE 13.—Total Base Exchange Capacity of Fourteen Black Belt Soils Determined by the Buffer Curve Method.

Soil No.	Type	Total exchange capacity*	Average exchange capacity per type*
691	Houston clay	16.0	15.1
739	Houston clay	14.2	
687	Oktibbeha clay	18.0	17.7
694	Oktibbeha clay	17.0	
733	Oktibbeha clay	20.5	
735	Oktibbeha clay	16.0	
736	Oktibbeha clay	18.0	
744	Oktibbeha clay	17.0	
693	Eutaw clay	20.5	23.4
738	Eutaw clay	22.6	
741	Eutaw clay	27.2	
742	Lufkin clay	34.0	35.0
742	Lufkin clay	36.0	
692	Leaf clay	26.6	26.6

* m. e. per 100 gms. soil.

Chemical Composition of the Colloids

A study was made of the chemical composition of the colloids from six of the most important Black Belt soil types. Colloids were extracted and analyzed from the different well defined horizons. The results are shown in Table 14. The method of isolating the colloidal fraction was analagous to that used by Robinson and Holmes (29) except that no dispersion agent was used and the final drying of the colloid was accomplished under vacuum with the temperature maintained below 60°C. The ob-

TABLE 14.—The Chemical Composition of the Colloids From the Soil Profiles of Typical Black Belt Soil Types and Their Silica-Sesquioxide Ratios.

Soil type and number	Depths	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	TiO	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
		Percent	Percent	Percent	Percent	Percent		
Oktibbeha clay No. 710	0-2″	37.639	28.662	9.550	0.1011	1.370	1.84	2.28
	2-6″	39.623	29.884	10.860	0.0775	1.326	1.83	2.25
	6-12″	42.755	21.227	9.710	0.0378	1.196	1.90	3.42
	12-18″	44.012	33.138	9.070	0.0364	1.154	1.92	2.25
Eutaw clay No. 722	0-4″	43.855	27.850	9.7704	0.1116	0.800	2.18	2.67
	4-14″	45.655	27.848	8.9632	0.0659	0.832	2.31	2.78
Lufkin clay No. 707	0-6″	54.175	18.675	8.1712	0.0594	0.624	3.85	4.92
	6-15″	54.155	18.720	8.4960	0.0474	0.592	3.81	4.91
Susquehanna clay No. 707	0-8″	43.055	25.640	9.8774	0.5480	0.1144	2.29	2.85
	8-20″	43.840	28.419	10.6759	0.7720	0.2030	2.11	2.62
	20-30″	57.550	24.806	8.1606	0.6680	0.0448	3.25	3.94
	At 10′	55.365	22.472	6.8032	0.5910	0.1685	3.50	4.18
Sumter clay No. 732	0-4″	44.440	26.062	8.9032	0.6760	0.0784	2.38	2.89
Houston clay No. 739	0-6″	37.010	27.274	8.9831	0.6500	0.0928	1.90	2.30

ject of these analyses was to determine the silica-sesquioxide ratios of the colloidal fractions from the different soils and their respective horizons.

When it is recalled that the Lufkin, Eutaw, and Oktibbeha clay soils are derived from similar parent material, it is of interest to note that the colloids from the Lufkin clay have the highest values for the SiO_2-sesquioxide ratio, those from the Oktibbeha clay the lowest values, and those from the Eutaw clay intermediate values. The ratios also increase in value with the depth of the horizons from which the colloids were extracted. In other words, the ratio of SiO_2-sesquioxide decreases in value with the degree of weathering. The data, therefore, show that the Lufkin clay is highly unweathered and the Oktibbeha clay highly weathered, with the Eutaw clay intermediate.

In a study of a Susquehanna fine sandy loam from the Black Belt (6), it was shown that this area lies within a climatic region where the soil weathering is subtropical in character, i.e., the silicon is removed and iron and aluminum oxides tend to accumulate as the soil weathers toward maturity.

The chemical analyses of the colloids studied in this investigation show that all of the Black Belt soils are immature with respect to the climate. The Houston and Sumter clays are abnormal soils for this climate because they contain large amounts of calcium carbonate. If erosion were not continually exposing fresh chalk and removing the residue from the weathering of the chalk these soils probably would develop normal profiles and in the course of time become acid, and finally, as maturity was attained, take on the characteristics typical of mature soils for this climate. One of the soil series in Alabama that may be regarded as a typical mature soil for a climate similar to that of the Black Belt is the Cecil of the southern end of the Piedmont soil province. These Cecil soils have a SiO_2/Al_2O_3 value of about 1.8 (7).

It has been pointed out before in this report that the order of magnitude of the buffer and base exchange capacities varies inversely with the degree of weathering, or that they could be expressed as varying inversely in order of magnitude with the SiO_2-sesquioxide ratio. Many investigators (3, 5, 6, 17, 18, 23, 24, 25, 26, 29) have shown how the values for the silica-sesquioxide ratio of colloids are closely related to several properties of the soil. The color of the soil is one of these; the Lufkin clay with a high ratio, 3.85, has a color which has a high percentage of gray, with red and yellow practically absent. The Eutaw clay with an intermediate ratio, 2.31, is highly mottled red, yellow, and gray; and the Oktibbeha clay with a ratio of 1.90 is uniformly red.

It was noted that while the Lufkin, Eutaw, Vaiden, and Oktibbeha clays responded similarly to phosphate fertilization there was a marked tendency for the soils with the lowest SiO_2-

sesquioxide ratios to possess a greater capacity for fixing phosphorus than the soils with the highest SiO_2-sesquioxide ratios.

Baver (4) working with these clay soils found that the Lufkin was more plastic than the Eutaw, and the Eutaw more plastic than the Oktibbeha. The plasticity of these three soils also ranked in order of magnitude with the SiO_2-sesquioxide ratio. The Houston and Sumter clays were the least plastic, a result which would be expected because of their high calcium content.

Calcium Carbonate Requirement and Carbonate Content

All the acid soils used in the greenhouse pot tests received a liming treatment. The lime requirements for these soils were determined by the buffer curve method of Pierre and Worley (25).

Table 15 gives the rates of calcium carbonate per acre neces-

TABLE 15.—Lime Requirement of Some Typical Acid Black Belt Soils.

Soil type	Number	pH of soil	Pounds $CaCO_3$ per acre necessary to bring pH to 6.5
Oktibbeha clay	687	5.7	5,200
Oktibbeha clay	733	5.6	2,240
Oktibbeha clay	744	4.9	15,000
Perry clay	762	5.0	11,474
Eutaw clay	693	5.6	2,200
Eutaw clay	738	5.0	5,240
Eutaw clay	741	4.7	15,740
Eutaw clay	761	5.3	8,250
Lufkin clay	742	4.9	10,500
Lufkin clay	743	4.9	10,500

sary to bring the soil reactions to pH 6.5. The pH values of the soils as they occurred in the field without liming are also given. The calcium carbonate necessary to bring the reactions to pH 6.5 ranged from none to 15,740 pounds per acre. The Oktibbeha clays are frequently neutral because they occur commonly in small patches with the Sumter clays and receive lime washings which remove the acidity which is otherwise typical of the Oktibbeha clays. Soil No. 733 has a lime requirement of 2,240 pounds calcium carbonate, whereas No. 744 of the same type has a calcium carbonate requirement of 15,000 pounds per acre. There can be little doubt but that the former soil has been partially neutralized by washings from the lime lands adjacent to it. The Eutaw and Lufkin clays are always acid and require from 2,000 to 16,000 pounds of calcium carbonate per acre to bring their reaction to pH 6.5. The Sumter clays are derived from a soft chalk. As sheet erosion has removed much of the A horizon of this type, the surface soil material is high in calcium carbonate.

The Houston clays are derived from the same parent material as the Sumter clays but are much less eroded and have a high content of organic matter in the surface soil. The calcium carbonate equivalent was determined on a few typical Sumter and Houston clays together with a Houston black clay from the Texas Black Belt. The calcium carbonate equivalent was determined by the method of Truog (34). The data are given in Table 16. One of the Sumter clays, No. 688, had a calcium

TABLE 16.—Total Carbonates ($CaCO_3$) in Some Typical Calcareous Soils in the Black Belt.

Soil type	Number	Per cent $CaCO_3$	pH
Sumter clay	688	51.9	7.7
Sumter clay	689	9.3	7.6
Sumter clay	796	48.8	7.5
Houston clay	690	3.3	7.5
Houston clay	691	0.6	7.5
Houston black clay	695	17.6	7.5

carbonate content of 51.9 per cent. The Houston clays tested had 3.3 per cent and 0.6 per cent of calcium carbonate. A Texas Houston black clay had a calcium carbonate content of 17.6 per cent.

SUMMARY

This bulletin reports the results of a morphological, greenhouse, and chemical study of the major soil types in the Black Belt soil province of Alabama.

This province consists of an area of about two million acres. The soils of this area are closely related to the geological formations from which the soils are derived. The Selma chalk, a soft limestone of the Cretaceous period, is the chief deposit of the area; where this deposit crops out it gives rise to two of the important soil types of this province—the Sumter and Houston clays. Where erosion has kept pace with the disintegrating and decomposing chalk, the resulting soil is classified as Sumter clay. Where the material from weathering chalk has been left to accumulate, organic matter from decayed plant growth has also accumulated and the soil thus formed is classified as Houston clay.

A shallow deposit of marine clay sediments, which was laid down upon the Selma chalk, gives rise to the Oktibbeha, Eutaw and Lufkin clay soils. Erosion has varied the depth of these clay deposits and weathering has altered their character in varying degrees. Where the marine clay material is shallow, weathering has progressed relatively rapidly and has resulted in the formation of a soil profile classified as Oktibbeha clay. Where the marine clay material is deep, weathering has been slow and the resulting soil is classified as Lufkin clay. Between these degrees of weathering and depths of the marine sediments is a soil material classified as Eutaw clay.

Other important soil types in the Black Belt are the Bell, leaf, and Catalpa clays which are soils built up as alluvial or colluvial deposits from material brought down from all the upland soils in the province.

The greenhouse tests showed that most of the soils in the Black Belt gave great response to heavy applications of superphosphate but little response to potash.

Crop failures were obtained from the majority of the soils when superphosphate was not used even though nitrogen and potassium fertilizers were abundantly supplied. Legumes gave satisfactory yields when heavy applications of phosphate were used without nitrogen and potassium. But in order to obtain satisfactory growth of non-legumes nitrogen was required as well as the phosphate.

The phosphorus experiments on several soils showed that maximum responses to superphosphate fertilization was not obtained until the rate of application was equivalent to 2,000 pounds per acre. The efficiency of this phosphate decreased rapidly with the period of time it was in contact with the soil before planting the crop thus indicating that these soils have a great phosphate-fixing capacity.

A phosphate-fixation experiment conducted in the laboratory over a five month period showed that at the end of this period less than 1 per cent of water-soluble PO_4 was recovered from soils that had received 4,000 pounds superphosphate per acre. Potassium was fixed to a much less extent.

A high degree of correlation ($\rho = +0.884$) was found between the phosphorus determined by the .002 N H_2SO_4 extraction method of Truog and the growth made by oats in greenhouse pots where nitrogen and potassium had been removed as limiting factors.

Exchangeable cations and anions, percentage base saturation, titration curves, and buffer actions were determined on all the soils used in the greenhouse tests.

Some soil properties as degree of weathering, base exchange capacity, buffer values, color, plasticity, and fixation of phosphorus are discussed in their relationship to the SiO_2-sesquioxide ratio of the colloid.

The calcium carbonate requirement of the acid soils shows that some of the soils require up to 16,000 pounds of lime per acre to bring their reaction to pH 6.5. The calcium carbonate content of the Sumter clays frequently varies from 5 to 50 per cent.

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