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Experiments with Commercial Nitrogenous Fertilizers

By
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AGRICULTURAL EXPERIMENT STATION
OF THE
ALABAMA POLYTECHNIC INSTITUTE

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Experiments with Commercial Nitrogenous Fertilizers

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THE YIELDS of common farm crops in the southeastern states are determined more directly by the available nitrogen supply than by any other controllable fertility factor. In the states making up this area, the yield of cotton and corn may be at least doubled and possibly trebled through the application of very large amounts of nitrogen with only moderate amounts of mineral fertilizers. Unpublished experimental data obtained on typical Southeastern Cotton Belt soils by the Alabama Experiment Station indicate that yields of corn and oats may be maintained on higher levels than those obtained on typical Corn Belt soils if large amounts of nitrogen are supplied. On the other hand, experiments show conclusively that when only phosphorus and potassium are applied to these crops the yields are so small that the crops obtained would not pay the cost of cultivation. The importance of nitrogen in crop production in the part of the South referred to is further indicated by reference to the many fertilizer experiments reported in the publications of the state experiment stations.

The dominant need for nitrogen may be better understood when it is explained that practically all soils in this territory, even when first cleared, have a very low nitrogen content. This low initial nitrogen content is rapidly reduced when the soils are put under cultivation and in this section much of the farm land is cultivated. The climatic conditions in this area are highly favorable for a rapid loss of nitrogen: the rainfall varies from 55 to 65 inches annually; summer temperatures are high and winter temperatures are moderate, except for periods of short duration. Most of the soils are of such texture that the aeration is good even when they are uncultivated. The result of the operation of these several factors is a very rapid decomposition of active forms of organic matter and a consequent depletion of the initial store of nitrogen present in average soils. To meet this steadily diminishing supply of available nitrogen, farmers have had to resort to the use of fertilizers containing commercial nitrogen and to the use of leguminous plants for soil improvement purposes.

Since nitrogen has been the most expensive fertilizer element, it has usually comprised only a small part of the total plant food

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content of commercial fertilizers. The less expensive elements, phosphorus and potassium, have usually constituted more than three-fourths of the total plant food in fertilizers. However, recent developments in the manufacture of nitrogenous fertilizers indicate that the cost of commercial nitrogen may be much lower in the future than in the past and, with this lower cost, it is highly probable that there will be a higher percentage of nitrogen used in the average complete fertilizer.

The consumption of fertilizers in the southeastern states is greater than in any other section of the United States. Five states in this territory use approximately half of the total commercial fertilizer tonnage of the country. It has been estimated that the nitrogen used in commercial fertilizers has amounted to approximately 290,000 short tons annually, which at a conservative price represents an annual expenditure of nearly $60,000,000 for nitrogen alone. It is evident, therefore, that the subject of commercial fertilizer nitrogen is of greater importance to a few states in this territory than to any other section of the country.

There are various forms of nitrogen available for distribution. These may be classified as organic and inorganic, physiologically acidic and physiologically basic, readily and slowly available, and rapidly and slowly leachable forms. With the development of new manufactured materials and a consequent lowering of the price of nitrogen, inorganic forms of nitrogen are becoming relatively more important in the manufacture of fertilizers than are the old standard organic forms. Practically all of the so-called organic forms, except cyanamid, and all ammonium forms of nitrogenous fertilizers develop an acid reaction when they are used as fertilizers. This means that practically all of the manufactured materials are acidic in nature. Nitrate forms are generally supposed to be more readily available than those that must undergo some degree of transformation in the soil before they are in the best form for plant use. However, crop response to ammonium-nitrogen is nearly as rapid as it is to nitrate-nitrogen under average conditions. This is especially true on crops that grow in warm seasons. Nitrate-nitrogen is commonly classed as "leachy" while ammonium and organic forms are at least temporarily absorbed in large part and held by the soil.

The above considerations indicate clearly that it may be too much to expect any one form of nitrogen to be best for all crops and under all conditions. As a matter of fact, the evidence available in the literature from the experiment stations indicates that for some crops an acid-forming fertilizer may be better than one which tends to produce an alkaline reaction. Some crops may respond better to ammonium-nitrogen than to other forms. Nitrate-nitrogen may be largely lost by leaching if it is applied to a crop like cabbage which, in the Gulf Coast section, is fertilized during a period of very high rainfall.

Still another factor that is important in the consideration of nitrogenous fertilizers is that of concentration. Some of the materials recently produced may contain more than 50 per cent of plant nutrients. It is now possible for the fertilizer manufacturer to put on the market a much more concentrated material than has been offered in the past. Other things being equal, the more concentrated fertilizers should be quite desirable because of the reduction in freight cost, hauling charges, and labor of distribution. However, experimental trials with a number of these concentrated forms indicate very strongly that some supplementary material may be necessary to avoid injurious results with certain crops on some soils. This preliminary work indicates that such materials as di-ammonium phosphate and mono-ammonium phosphate will need to be supplemented with a sulfate when used for cotton grown on sandy soils. These instances are cited to indicate the complicated problem involved in dealing with nitrogenous fertilizers for a number of crops and a wide range of soil conditions.

The effect of a nitrogenous fertilizer on the reaction of a soil is so important that it deserves special consideration. It is a simple matter to calculate the amount of mineral acids produced from the application of a given amount of nitrogen in either organic or ammonium forms. Regardless of whether or not the calculated amounts of acid are actually developed in a soil, the fact remains that these forms of nitrogen develop an acid condition in the soil to which they are applied. Since an acid condition may be quite harmful in a general scheme of economical crop production, it is very important that this question be fully understood. The liberal use of certain forms of nitrogen may in the beginning produce very satisfactory crop yields but the continued use of such amounts of nitrogen may in a few years develop a degree of acidity that is quite inimical to the growth of most farm crops. Under the changing conditions of soil reaction, the relative efficiency of acid and non-acid forming fertilizers will vary for a considerable period of years.

In view of the importance of the nitrogen problem from the standpoint of practical agriculture in the southeastern states, and especially in Alabama, the experimental work herein reported was started a number of years ago. The field results set forth in the following pages are divided into two classes, depending upon whether they were obtained from experiments conducted on the same land for a number of years so that harmful acidity might be developed or whether they were obtained in tests of short duration intended to show only the immediate relative efficiencies of the several nitrogen fertilizers tested. In addition, this bulletin discusses factors that determine the relative value of different nitrogenous fertilizers and methods of correcting the acidity developed in soils from physiologically acid fertilizers.

FIELD EXPERIMENTS WITH DIFFERENT SOURCES OF NITROGEN

Experiments of Short Duration

A study of the relative values of the more common sources of nitrogen when used for short periods for cotton on the various Alabama soil regions was made by this station during the years 1927-1931, inclusive. Within this period 222 conclusive experiments were conducted in cooperation with a number of carefully selected Alabama farmers. The average results from these experiments are reported in the pages which immediately follow.

Most of these experiments were conducted on the Clarkesville soils of the Highland Rim; the Decatur, Dewey, Holston, and Elk soils of the Limestone Valleys; the Hartselle and Hanceville soils of the Appalachian Plateau; the Cecil soils of the Piedmont Plateau; the Oktibbeha soils of the Black Belt; and Greenville, Cahaba, Orangeburg, Ruston, and Norfolk soils of the Coastal Plain. For convenience in tabulating and reporting the data, similar soils have been grouped and each group has been named for the soil series on which the majority of the experiments within the group were conducted.

The different sources of nitrogen used for the full five-year period were sodium nitrate, ammonium sulfate, Ammo-Phos A and sodium nitrate, Leunasalpeter, urea, and cottonseed meal. Calcium nitrate was used in the experiments conducted in 1927 and 1928, and Calnitro and Calurea were included in 1929, 1930, and 1931. Each plot received 64 pounds of phosphoric acid and 25 pounds of potash per acre. Each nitrogen-treated plot received 30 pounds of nitrogen per acre. Due to the fact that a fertilizer carrying the above quantities of nitrogen and phosphoric acid could not be made from Ammo-Phos A alone, it was necessary to supplement the Ammo-Phos A with another source of nitrogen. Consequently, all of the phosphoric acid and one-half of the nitrogen for this plot were from Ammo-Phos A and the remaining one-half of the nitrogen was from sodium nitrate. The cottonseed meal used in these experiments contained seven per cent of ammonia. It was used on the basis of 5.76 per cent nitrogen, 2.5 per cent phorphoric acid, and 1.5 per cent potash. All of the phosphoric acid except that in Ammo-Phos A and in cottonseed meal was from superphosphate. All potash except the small quantity in cottonseed meal was from muriate of potash.

The usual plan of applying the fertilizers was to use one-fourth of the nitrogen, all of the phosphoric acid, and all of the potash at planting time and to apply the remaining three-fourths of the nitrogen just prior to the first cultivation after the cotton was thinned. Exceptions to this general scheme were made in the cases of cottonseed meal and Ammo-Phos A. On the cottonseed meal plot, all fertilizers were mixed and applied immediately before the seed were planted. It should be stated at this point, however, that in the light of further experience the time and method of making this rather heavy application of cottonseed meal are not recommended. Reasons for this statement will be found under the discussion of the results with cottonseed meal on page 14. On the Ammo-Phos A plot, this material was mixed with the muriate of potash and the mixture applied immediately before the planting, whereas the sodium nitrate used to bring the nitrogen application to 30 pounds per acre was applied just prior to the first cultivation after the cotton was thinned.

Table 1 shows the average yields of seed cotton per acre when the different sources of nitrogen were used on various soil groups, while Table 2 records the average and the relative increases from the different nitrogen sources on the same soil groups.

Results on the Various Soil Regions

Highland Rim Soils

Clarkesville Soil Series.—All of the experiments conducted on the Highland Rim soils were located on typical Clarkesville silt loam. The soils of this type have a pale-yellow surface with yellow subsoil. Locally, these soils are known as "Barrens".

The average results from ten experiments on this soil show that sodium nitrate was the most effective source of nitrogen. The increase due to this material was 312 pounds of seed cotton per acre (Table 2). Ammonium sulfate and Leunasalpeter were second and third, respectively, in effectiveness on this soil. When the increase due to sodium nitrate was taken as the basis, the relative increases from the different materials used were as follows: sodium nitrate, 100; ammonium sulfate, 87; Leunasalpeter, 79; urea, 72; cottonseed meal, 71; and Ammo-Phos A supplemented by sodium nitrate, 69.

Limestone Valley Soils

Decatur Soil Group.—The experiments conducted on red soils with red subsoils (Decatur) and on brown soils with yellowish-red or reddish-brown subsoils (Dewey) of the Limestone Valleys have been placed in the Decatur soil group. These soils are found in both the Tennessee and the Coosa River Valleys. Experiments were conducted each year in both valleys on this soil group.

As shown in Table 2, urea and sodium nitrate were the leading sources of nitrogen on this soil group. Increases of 284 pounds of seed cotton per acre were secured from each of these materials. Ammo-Phos A supplemented by sodium nitrate was

TABLE 1.—Average Yield of Seed Cotton, pounds per acre, on Various Soil Regions from Different Sources of Nitrogen, 1927-1931.

Plot No.	Source of Nitrogen[1]	Highland Rim Clarkesville soils	Limestone Valleys		Appalachian Plateau Hartselle soil group	Piedmont Plateau Cecil soil group	Black Belt Oktibbeha soil group	Coastal Plain		General average
			Decatur soil group	Holston soil group				Greenville soil group	Norfolk soil group	
		10 expts.	32 expts.	21 expts.	36 expts.	17 expts.	15 expts.	34 expts.	57 expts.	222 expts.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	No nitrogen	688	538	646	668	556	645	583	634	614
3	Sodium nitrate	974	839	1,080	1,037	894	854	948	949	950
4	Ammonium sulfate	932	804	999	1,036	892	791	936	891	914
6	No nitrogen	653	555	674	677	522	629	569	623	612
7	Ammo-Phos A[2]	877	827	973	991	824	858	915	838	888
8	Sodium nitrate Leunasalpeter	909	811	954	959	870	777	907	890	890
9	Urea	888	839	1,002	990	848	808	905	894	904
10	Cottonseed meal	882	694	926	847	757	654	809	834	805
11	No nitrogen	644	573	668	671	514	626	570	629	614
Average no nitrogen plots		662	555	663	672	531	633	574	629	613

[1]All plots received 64 pounds of phosphoric acid and 25 pounds of potash, and all nitrogen plots received 30 pounds of nitrogen per acre.
[2]One-half of the nitrogen from Ammo-Phos A and one-half from sodium nitrate.

TABLE 2.—**Average and Relative Increases of Seed Cotton on Various Soil Regions from Different Sources of Nitrogen, 1927-1931.**

Plot No.	Source of nitrogen[1]	Highland Rim Clarkesville soils	Limestone Valleys		Appalachian Plateau Hartselle soil group	Piedmont Plateau Cecil soil group	Black Belt Oktibbeha soil group	Coastal Plains		General average
			Decatur soil group	Holston soil group				Greenville soil group	Norfolk soil group	
		10 expts.	32 expts.	21 expts.	36 expts.	17 expts.	15 expts.	34 expts.	57 expts.	222 expts.
		Increase in pounds of seed cotton per acre								
3	Sodium nitrate	312	284	417	365	363	221	374	320	337
4	Ammonium sulfate	270	249	336	364	361	158	362	262	301
7	Ammo-Phos A[2] Sodium nitrate	215	272	310	319	293	225	341	209	275
8	Leunasalpeter	247	256	291	287	339	144	333	261	277
9	Urea	226	284	339	318	317	175	331	265	291
10	Cottonseed meal	220	139	263	175	226	21	235	205	192
		Relative increase								
3	Sodium nitrate	100	100	100	100	100	100	100	100	100
4	Ammonium sulfate	87	88	81	100	99	71	97	82	89
7	Ammo-Phos A[2] Sodium nitrate	69	96	74	87	81	102	91	65	82
8	Leunasalpeter	79	90	70	79	93	65	89	82	82
9	Urea	72	100	81	87	87	79	89	83	86
10	Cottonseed meal	71	49	63	48	62	10	63	64	57

[1]All plots received 64 pounds of phosphoric acid and 25 pounds of potash, and all nitrogen plots received 30 pounds of nitrogen per acre.
[2]One-half of the nitrogen from Ammo-Phos A and one-half from sodium nitrate.

only slightly less effective than the leading sources. The increase on the Ammo-Phos A plot was 272 pounds per acre. On a relative basis, the increases due to the different materials were as follows: sodium nitrate, 100; urea, 100; Ammo-Phos A and sodium nitrate, 96; Leunasalpeter, 90; ammonium sulfate, 88; and cottonseed meal, 49.

Holston Soil Group.—This group includes soils of both the Elk and the Holston series. Elk soils are found largely in the Tennessee River Valley, while the Holston soils are found chiefly along the Coosa River and its tributaries. Both are terrace soils which are not usually subject to overflow. The Elk soils are brown or light-brown with yellowish-brown subsoil. Holston soils are light-gray with pale-yellow subsoil.

On the Holston group, sodium nitrate produced a greater average increase than any of the other sources of nitrogen used for the five-year period. It produced an average increase of 417 pounds of seed cotton per acre as compared with increases of 339 pounds and 336 pounds from urea and ammonium sulfate, respectively. These results are given in Table 2. In relative terms, the increases may be expressed as follows: sodium nitrate, 100; ammonium sulfate, 81; urea, 81; Ammo-Phos A and sodium nitrate, 74; Leunasalpeter, 70; and cottonseed meal, 63.

Appalachian Plateau Soils

Hartselle Soil Group.—Hartselle soils and the related series, Hanceville soils, that make up this group are common to Sand, Brindlee, Lookout, Gunters, and some of the other smaller mountains of North Alabama. The Hartselle soils are yellowish-gray with yellow or yellowish-gray subsoil. Hanceville soils are reddish-brown with red subsoil.

Ammonium sulfate and sodium nitrate produced equal increases in pounds of seed cotton per acre for the five-year period on this soil group. Increases of 364 pounds and 365 pounds of seed cotton per acre, respectively, were obtained from these materials. Ammo-Phos A supplemented by sodium nitrate and urea produced increases of 319 pounds and 318 pounds per acre, respectively. (See Table 2.) The relative increases due to different sources of nitrogen were: sodium nitrate, 100; ammonium sulfate, 100; Ammo-Phos A and sodium nitrate, 87; urea, 87; Leunasalpeter, 79; and cottonseed meal, 48.

Piedmont Plateau Soils

Cecil Soil Series.—All of the experiments on Piedmont Plateau soils were conducted on the Cecil series of this region. Seven experiments were made on the red soils and ten on the gray soils.

On this soil series, sodium nitrate and ammonium sulfate were of equal value under the conditions of these experiments. The increase due to sodium nitrate was 363 pounds and to ammonium sulfate 361 pounds of seed cotton per acre. Leunasalpeter gave the third largest increase, 339 pounds of seed cotton per acre (Table 2). The relative increases due to the different nitrogenous materials were sodium nitrate, 100; ammonium sulfate, 99; Leunasalpeter, 93; urea, 87; Ammo-Phos A and sodium nitrate, 81; and cottonseed meal, 62.

Black Belt Soils

Oktibbeha Soil Group.—The experiments conducted on Black Belt soils were placed in the Oktibbeha soil group. Included in this group will be found all of the experiments that were located on either the Oktibbeha, Lufkin, or the Eutaw series. The experiments on the Oktibbeha group were conducted on soils that may be termed the non-lime or acid soils of this region. These soils are locally known as "post oak" or as "flatwoods" soils.

On the average, the increases due to the different sources of nitrogen were much lower on this than any other soil group. Ammo-Phos A supplemented by sodium nitrate and sodium nitrate gave increases of 225 and 221 pounds of seed cotton per acre, respectively. Urea, ammonium sulfate, and Leunasalpeter gave increases of 175, 158, and 144 pounds per acre in the order named (Table 2). The nitrogen in cottonseed meal, under the conditions of the experiments on this soil group, produced only a slight increase over the yield of the non-nitrogen plots. Relative increases were in the following order: sodium nitrate, 100; Ammo-Phos A and sodium nitrate, 102; urea, 79; ammonium sulfate, 71; Leunasalpeter, 65; and cottonseed meal, 10.

Coastal Plain Soils

Greenville Soil Group.—All of the experiments on red soils with red subsoil and on gray soils with red subsoil of the Coastal Plain region have been grouped into the Greenville soil group. Included in this group will be found all of the experiments conducted on Greenville, Amite, Cahaba, and Orangeburg soil series.

The results obtained on this group show that sodium nitrate and ammonium sulfate were of approximately equal value in these short-time tests. The average increase due to sodium nitrate was 374 pounds as compared with 362 pounds of seed cotton per acre for ammonium sulfate. Other sources of nitrogen gave the following increases: Ammo-Phos A supplemented by sodium nitrate, 341 pounds; Leunasalpeter, 333 pounds; urea, 331 pounds; and cottonseed meal, 235 pounds (Table 2). The relative increases were as follows: sodium nitrate, 100; ammonium sulfate, 97; Ammo-Phos A and sodium nitrate, 91; Leunasalpeter, 89; urea, 89; and cottonseed meal, 63.

Norfolk Soil Group.—All of the experiments conducted on Norfolk and on Ruston soils have been placed in the Norfolk soil group. This group includes all of the upland soils of the Coastal Plain Region which have a gray soil with yellow subsoil or gray soil with reddish-yellow subsoil.

The average results from 57 experiments on this group show that sodium nitrate produced more than any of the other sources of nitrogen tested over the five-year period. The average increase due to sodium nitrate was 320 pounds of seed cotton per acre. Increases of 265 pounds for urea, 262 pounds for ammonium sulfate, and 261 pounds for Leunasalpeter were obtained (Table 2). When reduced to relative terms with sodium nitrate as 100, the remaining increases can be stated as follows: urea, 83; ammonium sulfate, 82; Leunasalpeter, 82; Ammo-Phos A and sodium nitrate, 65; and cottonseed meal, 64.

General Average of Experiments

The average yields, average increases, and relative yields obtained on 222 short-time tests on various Alabama soil types are given in Table 3. Due to the fact that calcium nitrate was discontinued after the first two years and that Calnitro and Calurea were used only the last three years, the data have been averaged for 1927-1928, 1929-1931, and for 1927-31, inclusive. The decrease in efficiency of all sources of nitrogen during the last three years is due to losses from diseases, especially boll rot, during the abnormally wet fall of 1929 and to the unusually small increases from all fertilizers because of excessively dry weather from January to August, inclusive, in 1930.

Sodium nitrate increased the yield of seed cotton an average of 337 pounds per acre in the 222 experiments conducted over the five-year period, 1927-1931, inclusive. This increase is 36 pounds or approximately 11 per cent greater than the increase due to ammonium sulfate which produced the second highest increase over the five-year period.

Over the five-year period, ammonium sulfate produced an average increase of 301 pounds of seed cotton per acre. This increase was exceeded only by the increase from sodium nitrate. On a relative basis the average increase due to ammonium sulfate is 89 if the average increase from sodium nitrate is taken as 100. A study of the relative yields of the different sources of nitrogen by soil groups (Table 2) reveals the fact that on the Hartselle, Cecil, and Greenville soil groups ammonium sulfate gave increases equal to the increases from sodium nitrate on these soils. Ammonium sulfate was slightly less effective than Calurea and Calnitro during the three years that these materials were used.

Urea produced an increase of 291 pounds of seed cotton per acre in the average of 222 experiments conducted on all soils over the five-year period. It was on the average only slightly

TABLE 3.—Average Yield of Seed Cotton and Average and Relative Increases Obtained from Different Sources of Nitrogen in Short-Time Experiments.

Plot No.	Source of nitrogen[1]	Yields and increases in pounds of seed cotton per acre						Relative increases due to nitrogen		
		Average yields			Average increases due to nitrogen					
		82 expts. 1927 and 1928	140 expts. 1929, 1930, 1931	222 expts. 1927-1931	82 expts. 1927 and 1928	140 expts. 1929, 1930, 1931	222 expts. 1927-1931	82 expts. 1927 and 1928	140 expts. 1929, 1930, 1931	222 expts. 1927-1931
1	No nitrogen	583	631	614	—	—	—	—	—	—
2	Calcium nitrate 1927, 1928									
	Calnitro 1929, 1930, 1931	958	916	—	376	284	—	99	91	—
3	Sodium nitrate	960	944	950	378	312	337	100	100	100
4	Ammonium sulfate	939	900	914	357	268	301	94	86	89
6	No nitrogen	591	625	612	—	—	—	—	—	—
7	Ammo-Phos A[2]	911	875	888	329	243	275	87	78	82
	Sodium nitrate									
8	Leunasalpeter	909	879	890	327	247	277	87	79	82
9	Urea	912	899	904	330	267	291	87	86	86
10	Cottonseed meal	784	818	805	202	186	192	53	60	57
11	No nitrogen	571	639	614	—	—	—	—	—	—
12	Calurea	—	924	—	—	292	—	—	94	—
Average of no nitrogen plots		582	632	613	—	—	—	—	—	—

[1]All plots received 64 pounds of phosphoric acid and 25 pounds of potash, and all plots except 1, 6, and 11 received 30 pounds of nitrogen per acre.
[2]One-half of the nitrogen from Ammo-Phos A and one-half from sodium nitrate.

less effective than ammonium sulfate. On the basis of sodium nitrate as 100, the relative increase due to urea was 86. Urea was as effective as sodium nitrate only on the Decatur soil group.

Leunasalpeter ranked fourth with an average increase of 277 pounds of seed cotton per acre for the five-year period. The relative increase due to Leunasalpeter was 82 in comparison with 100 for sodium nitrate, 89 for ammonium sulfate, and 86 for urea. Best results with Leunasalpeter were obtained on the Decatur, Cecil, and the Greenville soil groups.

Ammo-Phos A supplemented by sodium nitrate ranked next to Leunasalpeter over the five-year period covered by these experiments. If the increase due to sodium nitrate is taken as 100, the relative increase on the Ammo-Phos A-sodium nitrate plot is 82. The average increase obtained on this plot was 275 pounds of seed cotton per acre. The best results were obtained on the Decatur and the Oktibbeha soil groups, while the poorest results came from the Clarkesville and the Norfolk groups.

Cottonseed meal produced an average increase of only 192 pounds of seed cotton per acre under the conditions of these experiments. This is in comparison with increases of 337 pounds for sodium nitrate and 301 pounds for ammonium sulfate. However, this increase should not be taken as the true fertilizer value of meal because the heavy application of this material necessary to supply 30 pounds of nitrogen per acre resulted in serious stand injury on many of the experiments. Better incorporation of the meal with the soil or applying it ten days to two weeks before planting would probably have resulted in much improved yields with this source of nitrogen. Earlier experiments by this station in which 15 pounds of nitrogen per acre from sodium nitrate were compared with 13 pounds of nitrogen from cottonseed meal showed that the two sources of nitrogen were of practically equal value in increasing the yield of cotton.

Calcium nitrate, used only the first two years of the five-year period, was as effective as sodium nitrate in increasing the yield. The average increase due to sodium nitrate was 378 pounds and to calcium nitrate was 376 pounds of seed cotton per acre on 82 experiments during the two-year period.

Calnitro and Calurea were used in 140 experiments during the years 1929, 1930, and 1931. Increases of 284 pounds and 292 pounds of seed cotton per acre, respectively, were received from these two materials. On a relative basis these increases were: sodium nitrate, 100; Calurea, 94; and Calnitro, 91.

Ammonium Sulfate with Different Sources of Phosphorus

Basic slag would appear to be an ideal material for use with ammonium sulfate because it carries both active lime and phosphorus. Consequently, a plot on which ammonium sulfate, basic slag, and muriate of potash were used was placed in the experiment for comparison with the ammonium sulfate, superphosphate, and muriate of potash plot. The results obtained on these two plots as well as the results from a plot fertilized with sodium nitrate, superphosphate, and muriate of potash have been averaged and are recorded in Table 4.

A much smaller increase from ammonium sulfate was obtained on all soil divisions except the Black Belt when basic slag was used instead of superphosphate as the source of phosphorus. On the Appalachian Plateau, the Piedmont Plateau, and the Greenville soil group of the Coastal Plain, the increases from ammonium sulfate in connection with superphosphate were approximately equal to the increase from sodium nitrate; however, when the source of phosphorus used with ammonium sulfate was basic slag, the increase was in favor of sodium nitrate by 111 pounds of seed cotton per acre on the Appalachian Plateau, by 94 pounds on the Piedmont Plateau, and by 76 pounds on the Greenville soil group. Where superphosphate was used the average of all experiments carried for the five-year period shows that the increase from ammonium sulfate was 36 pounds less than the increase from sodium nitrate; however, when basic slag was used as the source of phosphorus with the ammonium sulfate the increase from sulfate was 98 pounds less than the sodium nitrate increase. This difference of 62 pounds of seed cotton per acre may be more likely explained by the difference in the availability of the phosphorus from the two sources than from a difference in the efficiency of ammonium sulfate under the two conditions.

It has been previously stated that one-fourth of the ammonium sulfate was used at planting time and the remaining three-fourths were used at the time of the first cultivation. In 1927-1929, inclusive, the ammonium sulfate used at planting time was mixed with the basic slag and the muriate of potash approximately three weeks before the mixture was applied. Analyses of similar mixtures during the summer of 1929 revealed the fact that there was a loss of ammonia when basic slag was used as the source of phosphorus. Consequently, on the basic slag plot in 1930 and 1931 the ammonium sulfate used at planting time was applied in the same furrow with the slag-potash mixture as a separate ingredient. This change in the method of application resulted in an increase of only 12 pounds of seed cotton per acre.

Ratios of Organic to Inorganic Nitrogen for Cotton

A study of the proper ratio of organic to inorganic nitrogen in fertilizers for cotton is being made on Greenville fine sandy loam on the Prattville Experiment Field and on Decatur clay loam on the Alexandria Experiment Field. An application of 600 pounds of a 10-6-4 fertilizer was made on all plots which

TABLE 4.—Yield of Cotton Fertilized with Ammonium Sulfate and Different Sources of Phosphorus, 1927-1931.

Plot No.	Fertilizer treatment	Highland Rim	Limestone Valleys		Appalachian Plateau	Piedmont Plateau	Black Belt	Coastal Plain		General average
			Decatur soil group	Holston soil group				Greenville Soils group	Norfolk soil group	
	pounds per acre	10 expts.	32 expts.	21 expts.	36 expts.	17 expts.	15 expts.	34 expts.	57 expts.	222 expts.
		Yield in pounds of seed cotton per acre								
1, 6	400 Superphosphate 50 Muriate of potash	671	547	660	673	539	637	576	629	613
3	200 Sodium nitrate 400 Superphosphate 50 Muriate of potash	974	839	1,080	1,037	894	854	948	949	950
4	150 Ammonium sulfate 400 Superphosphate 50 Muriate of potash	932	804	999	1,036	892	791	936	891	914
5	150 Ammonium sulfate 600 Basic slag (10-1/2%) 50 Muriate of potash	787	739	970	926	800	796	872	855	852
		Increase from nitrogen in pounds of seed cotton per acre								
3	200 Sodium nitrate 400 Superphosphate 50 Muriate of potash	303	292	420	364	355	217	372	320	337
4	150 Ammonium sulfate 400 Superphosphate 50 Muriate of potash	261	257	339	363	353	154	360	262	301
5	150 Ammonium sulfate 600 Basic slag (10-1/2%) 50 Muriate of potash	116	192	320	253	261	159	296	226	239

received nitrogen. The average of the first three years' results of this work is given as a progress report in Table 5. The results during the three years that these tests have been in operation may be materially changed by the addition of the results for other years. This statement is based on the fact that each of the last three years has been a season of low rainfall during the months of June, July, and August.

The greatest increase from the use of nitrogen on both soils was obtained where all of the nitrogen was applied in the form of sodium nitrate at planting time. The second largest increase was obtained on the Greenville soil when the nitrogen was derived equally from sodium nitrate, ammonium sulfate, and cottonseed meal applied at planting time and on the Decatur soil when 10 per cent of the nitrogen came from cottonseed meal and 90 per cent from sodium nitrate.

LOW- VS. HIGH-ANALYSIS FERTILIZERS FOR COTTON[1]

In the past, fertilizers have been sold on the basis of their content of nitrogen, phosphoric acid, and potash. Studies have shown, however, that the value of a fertilizer may be influenced by its content of elements other than nitrogen, phosphorus, and potassium or by the residual effect on the soil. Most of the high-analysis materials are physiologically acid and their effect on soil acidity, when used over a period of years on soils low in clay content and deficient in calcium, has been pointed out (17). The soils of the southeastern states are typical sandy loam with an acid reaction and a low calcium content. The low-grade fertilizers which have been largely used in the past usually contained calcium, sulfur, and small quantities of magnesium. As the plant nutrient content of the fertilizers is increased, the content of the so-called impurities must obviously decrease.

Several high-grade materials such as Ammo-Phos A and B, which contain little or no calcium, have been placed on the market. A number of questions have been raised as to their relative efficiency as compared with low-grade materials.

It was the purpose of this study to compare the efficiency of a commonly used fertilizer mixture (superphosphate, ammonium sulfate, sodium nitrate, and muriate of potash) with a mixture (Ammo-Phos A and B and muriate of potash) which had a much higher analysis; these were compared with and without limestone.

Uniform areas of land were selected in various sections and on several of the important soil types of Alabama. These areas were divided into ten 1/20 acre plots. The fertilizer rates per acre were as follows: 64 pounds of phosphoric acid, 29.6 pounds

[1]The field tests reported in this topic were financially supported by the American Cyanamid Company of New York and supervised by Mr. H. Sherard, formerly a graduate student in the Department of Agronomy Soils.

TABLE 5.—Yield of Cotton from Applications of Varying Percentages of Organic and Inorganic Nitrogen on Greenville Sandy Loam and Decatur Clay Loam Soils.

Plot No.	Fertilizer Formula (600 lbs. per acre)	Percentage nitrogen from			Average yield seed cotton in pounds per acre—1929, 1930, and 1931		
		Cottonseed meal	Sodium nitrate	Ammonium sulfate	Greenville sandy loam Prattville Field	Decatur clay loam Alexandria Field	Average
1	10-0-4	—	—	—	527	389	458
2	10-6-4	75	25	—	873	648	761
3	10-6-4	50	50	—	861	570	715
4	10-6-4	35	65	—	899	634	757
5	10-0-4	—	—	—	605	338	472
6	10-6-4	20	80	—	1,046	652	849
7	10-6-4	10	90	—	1,010	663	837
8	10-6-4	0	100	—	1,107	679	893
9	10-0-4	—	—	—	694	407	551
10	10-6-4	33-1/3	33-1/3	33-1/3	1,070	647	859
11	10-6-4	—	100[1]	—	1,040	575	807
12	10-6-4	—	75	25[2]	1,016	613	814
13	10-0-4	—	—	—	602	423	512

[1]Twenty-five per cent of the nitrogen on this plot used at planting time and 75 per cent used immediately after thinning.
[2]Ammonium sulfate used at planting time and sodium nitrate used immediately after thinning.

of nitrogen, and 37.5 pounds of potash. Limestone at the rate of 116 pounds per acre was mixed with the fertilizer and used on one-half of each area. This amount of limestone was necessary to neutralize the acidity developed by the Ammo-Phos applications. These tests were conducted during 1930 and 1931. The value of gypsum with dolomite as amendments to the Ammo-Phos materials was studied only during 1931. However, the large number of tests reported and other tests now in progress indicate that the sulfate is an important constituent of a fertilizer for cotton.

In most cases the initial fertilizer application was made by hand and mixed with the soil from 5 to 10 days before planting the cotton. For the side application the fertilizer was placed in a shallow furrow near the plants and was covered immediately. This application was made, in most cases, after the cotton was thinned and before the first cultivation. The fertilizer treatments and results are shown in Tables 6 and 7.

Results on Coastal Plain Soils.—In 56 tests conducted in 1930 and 1931, the low-grade fertilizer mixture either with or without limestone produced more cotton than the high-grade materials with or without limestone (Table 6). Without limestone, the Ammo-Phos materials applied before planting produced 108 pounds of seed cotton per acre less than the low-grade fertilizer. On the average, when no limestone was used, cotton side dressed with Ammo-Phos B produced 37 pounds per acre more than when both of the Ammo-Phos materials were applied before planting. This was probably due to poorer stands of cotton obtained from the latter treatment. The Ammo-Phos materials with limestone produced slightly more cotton than the same fertilizers without limestone, whereas the low-grade fertilizer with limestone produced less cotton than without it. On these soils in 1931, fifty pounds of gypsum per acre increased the average yield in 56 tests by 48 pounds of seed cotton per acre (Table 7).

Additional experiments at this station indicate that a small amount of gypsum on sandy soils may mean the difference between a successful crop of cotton and a failure when di-ammonium phosphate is used in making up the fertilizer. This is illustrated in Figure 1. Gypsum gave similar results with mono-ammonium phosphate. On one of the branch stations in Alabama, an application of 25 pounds of potassium sulfate per acre produced a very strikingly better growth of cotton than where all of the potash was supplied as a chloride. This may be seen by a comparison of Figures 2 and 3. The results with corn are in strong contrast with these cotton results. Even on thin sandy land, corn has responded satisfactorily to applications of ammonium phosphates without the applications of such supplementary materials as gypsum or other sulfate compounds.

TABLE 6.—The Average Yield, pounds per acre, and the Relative Yield of Seed Cotton on Coastal Plain, Appalachian Plateau, and Tennessee Valley Soils from Low- and High-Analysis Fertilizers, 1930-1931.

Plot No.	Fertilizer treatment (pounds per acre)		Coastal Plain—56 tests Yield		Appalachian Plateau – 5 tests Yield		Tennessee Valley—18 tests Yield		Yield	
	Before planting	Side dressing	Average	Relative	Average	Relative	Average	Relative	Average	Relative
			lbs.		lbs.		lbs.		lbs.	
1	400 Superphosphate 36 Ammonium sulfate 75 Muriate of potash	137 Sodium nitrate	1,124[1]	100	1,226[1]	100	992[1]	100	1,114	100
2	85 Ammo-Phos A 125 Ammo-Phos B 75 Muriate of potash	None	1,016	90	1,129	92	945	95	1,030	92
3	85 Ammo-Phos A 75 Muriate of potash	125 Ammo-Phos B	1,053	94	1,109	90	932	94	1,031	92
5	400 Superphosphate 36 Ammonium sulfate 75 Muriate of potash 116 Limestone	137 Sodium nitrate	1,105[1]	98	1,148[1]	94	992[1]	100	1,081	97
6	85 Ammo-Phos A 125 Ammo-Phos B 75 Muriate of potash 116 Limestone	None	1,054	94	1,143	93	990	100	1,062	95
7	85 Ammo-Phos A 75 Muriate of potash 116 Limestone	125 Ammo-Phos B	1,075	95	1,047	85	963	97	1,028	92

[1]Average of duplicate plots.

TABLE 7.—Yield of Seed Cotton, pounds per acre, from a High-Analysis Fertilizer with and without Gypsum, 1931.

Plot No.	Fertilizer treatment[1] (pounds per acre) Before planting	Coastal Plain 26 tests	Appalachian Plateau 5 tests	Tennessee Valley 9 tests	Average 40 tests
		lbs.	lbs.	lbs.	lbs.
9	85 Ammo-Phos A 75 Muriate of potash 116 Dolomite 50 Gypsum	1,112	1,304	1,231	1,215
10	85 Ammo-Phos A 75 Muriate of potash 116 Dolomite	1,064	1,204	1,227	1,165

[1]The cotton on each plot was side dressed with Ammo-Phos B at the rate of 125 pounds per acre.

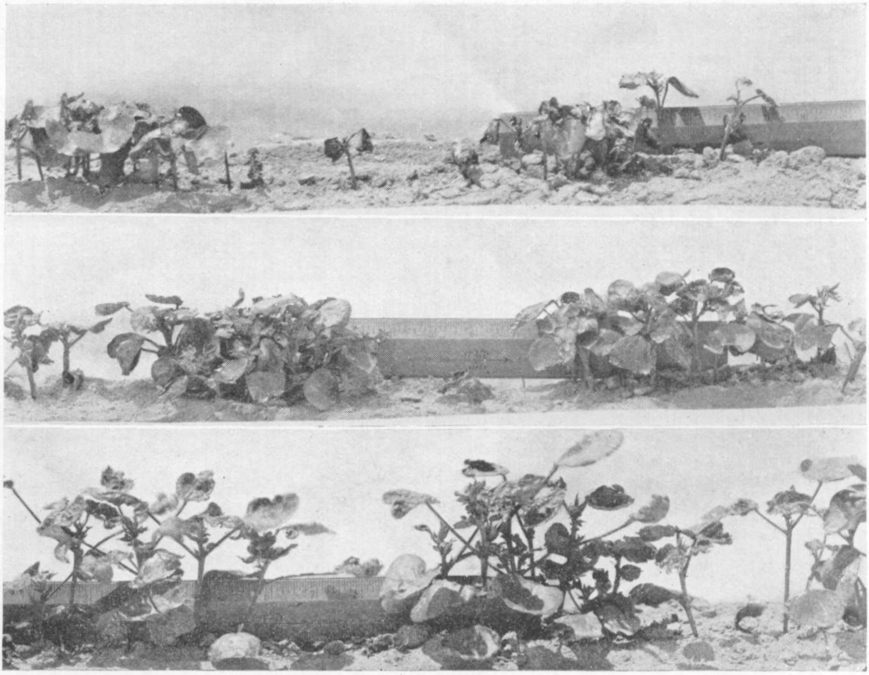

FIGURE 1.—Cotton seedlings on Norfolk sandy loam fertilized with equivalent amounts of di-ammonium phosphate, urea, and muriate of potash. Top, no amendments; center, limestone; bottom, gypsum.

Results on Appalachian Plateau Soils.—The results in Table 6 show that the low-grade mixture, without limestone, produced 97 pounds of seed cotton per acre more than the Ammo-Phos materials when applied before planting and 117 pounds more than the same mixture applied in two applications. With the low-grade material, limestone decreased the yield 78 pounds of seed cotton per acre, whereas with the high-grade materials, some of which were applied as a side dressing, it decreased the yield 62 pounds. The average of the five tests conducted on these soils during 1931 shows that gypsum increased the yields by 100 pounds of seed cotton per acre (Table 7).

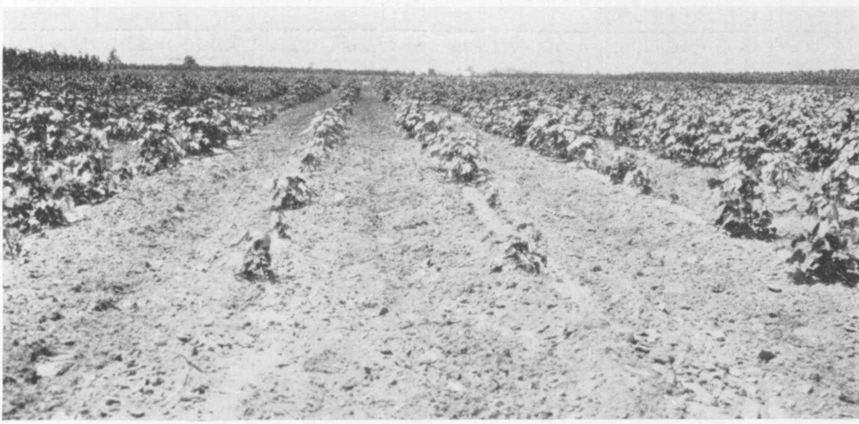

FIGURE 2.—Cotton on Norfolk sandy loam which received 113.4, 36.3, 48, and 138.6 pounds per acre of di-ammonium phosphate, ammonium nitrate, muriate of potash, and limestone, respectively.

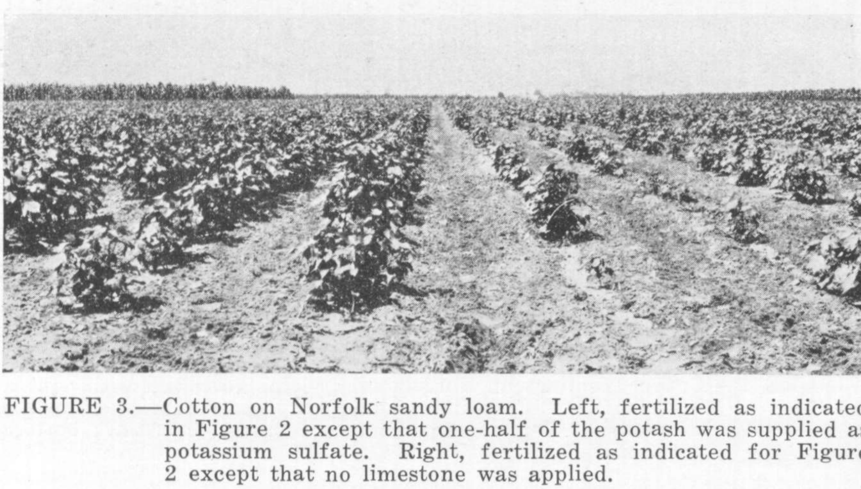

FIGURE 3.—Cotton on Norfolk sandy loam. Left, fertilized as indicated in Figure 2 except that one-half of the potash was supplied as potassium sulfate. Right, fertilized as indicated for Figure 2 except that no limestone was applied.

The results with high-analysis fertilizers are further substantiated by preliminary results from the Sand Mountain Station. These show that di-ammonium phosphate is less efficient than superphosphate supplemented by nitrogen for cotton on the Appalachian Plateau soils. Figures 4 and 5 show the efficiency of these materials in a striking manner.

FIGURE 4.—Cotton on Hartselle fine sandy loam fertilized with 60, 36, and 24 pounds per acre of phosphoric acid, nitrogen, and potash, respectively. The fertilizers were superphosphate, calcium nitrate, and muriate of potash.

FIGURE 5.—Cotton on Hartselle fine sandy loam fertilized with 90, 36 and 24 pounds per acre of phosphoric acid, nitrogen, and potash, respectively. The fertilizers were di-ammonium phosphate and muriate of potash.

Results on Tennessee Valley Soils.—The average result of 18 tests shows that the high-grade fertilizer, without limestone, was approximately 95 per cent as efficient as the low-grade material. High-analysis fertilizers were more efficient on these soils than on the Coastal Plain or Appalachian Mountain soils. With these materials, limestone increased slightly the cotton yields. The gypsum used, in nine tests, had practically no effect on the yields. These soils are relatively heavy textured in contrast with those of the Coastal Plain and Appalachian Plateau regions; this probably explains the better yields from the high-analysis mixture.

Experiments of Long Duration

Old Sources of Nitrogen Test

A test was started in 1911 for the purpose of comparing the effectiveness of sodium nitrate, ammonium sulfate, and calicum cyanamid for crop production. The plots used in this study are on Cecil sandy loam. They have been described in detail by Pierre (15). The mineral fertilizer treatment was the same for all plots; nitrogen when used was applied at the rate of 22.5 pounds per acre from the sources mentioned above for each crop grown during the first fifteen years of the test, after which time only the winter crop received nitrogen.

Oats were usually grown as the winter crop. As a summer crop, sorghum was grown until 1916 when injury on the ammonium sulfate plot was quite marked. Corn was grown in 1917. It also showed injury on the same plot. Cotton was grown from 1920 to 1924, inclusive. In 1925, due to continued poor crops of cotton on the ammonium sulfate plot the area was used for testing the tolerance of various summer crops to soil acidity.

The average yields of seven crops of oats grown between 1922 and 1932 and five crops of cotton grown from 1920 to 1924, inclusive, are shown in Table 8. It will be noticed that the average relative yields of oats were 100, 84, and 75 with sodium ni-

TABLE 8.—The Average and Relative Yield, per acre, of Oats and Cotton on Cecil Sandy Loam when Fertilized with Different Sources of Nitrogen.

Plot No.	Source of nitrogen[1]	Oats[2]		Cotton[3]	
		Average 7 years	Relative	Average 5 years	Relative
		bus.		lbs.	
1, 5	Sodium nitrate	24.9	100	819	100
2, 6	Calcium cyanamid	20.9	84	876	107
3, 7	No nitrogen	6.2	25	347	42
4, 8	Ammonium sulfate	18.7	75	445	54

[1]All plots received for each crop 160 and 100 pounds of superphosphate and kainit per acre, respectively. Nitrogen was applied to each crop at the rate of 22.5 pounds per acre on all plots, except 3 and 7.
[2]Seven crops of oats were grown between 1922 and 1932.
[3]Cotton was grown from 1920 to 1924, inclusive.

trate, calcium cyanamid, and ammonium sulfate, respectively. Lower cotton yields were obtained from the beginning on the ammonium sulfate plots than on the sodium nitrate or calcium cyanamid plots, although the plots had been fertilized as indicated for only nine years. The ammonium sulfate plot produced only 98 pounds of seed cotton per acre more than the one which received no nitrogen.

The acidity and other typical results of this test are shown in Table 9. Except in the case of cowpeas, the yields from the plots which had received ammonium sulfate were in every case smaller than those which received either of the other sources of nitrogen or even from the plots to which no nitrogen was applied. Moreover, the accumulative effect of this source of nitrogen, without lime, was injurious to the growth of forage and soil improving crops. These decreases in yields resulted from an extremely acid condition or from a low available calcium content of the plot which received ammonium sulfate. As shown in the table, this plot is approximately ten times as acid as the sodium nitrate plot. Sudan grass, sorghum, and soybeans suffered more seriously than the other crops from the former applications of ammonium sulfate. These crops also gave a greater increased growth due to the residual effect of calcium cyanamid than the other crops grown. Calcium cyanamid contains a large percentage of active lime; the responses of these crops to the residual effect of this fertilizer further emphasize the fact that they are not well adapted to extremely acid soils and are benefited by lime. These data show clearly the results which will inevitably be obtained if ammonium sulfate is used on soils without lime for a long time.

Sodium Nitrate vs. Ammonium Sulfate for Cotton

The results reported in Tables 8 and 9 show that the continued use of ammonium sulfate on unlimed land caused reduced crop yields; this was due to the depletion of soil bases and the development of soil acidity. Therefore, in 1925 another field test was started for the purpose of comparing sodium nitrate and ammonium sulfate on limed and unlimed soil. Cotton was the only crop grown in this test. The fertilizer treatments and the crop yields are shown in Table 10. Ten years before starting the test under consideration, limestone was applied at the rate of 5,300 pounds per acre on the limed series. These data show that ammonium sulfate, when applied at the rate of 300 pounds per acre on the unlimed soil, produced an average annual yield of 217 pounds of seed cotton less than the equivalent amount of nitrogen from sodium nitrate during the seven-year period. As shown in Table 10, the plot which received this application of ammonium sulfate is more than ten times as acid and contains approximately one-third as much replaceable cal-

TABLE 9.—The Soil Reaction and Average Yield of Hay Crops on Cecil Sandy Loam as Influenced by the Residual Effects of the Nitrogenous Fertilizers Indicated.

Plot No.	Applied to fall crops	pH 1927	Average 3 years (1926-1928)—Pounds of hay per acre						
			Soybean	Cowpea	Sorghum	Entire corn plant	Sudan	Total	
								Yield	Relative
2	Calcium cyanamid	5.85	1,832	1,097	5,389	3,032	2,640	13,990	143
3	No nitrogen	5.45	959	783	2,259	1,437	879	6,317	65
4	Ammonium sulfate	4.55	556	988	838	1,015	200	3,597	37
5	Sodium nitrate	5.50	1,402	1,163	3,693	1,894	1,608	9,760	100

TABLE 10.—The Reaction and Exchangeable Calcium of the Soil and Yield of Seed Cotton, pounds per acre, with Different Sources of Nitrogen on a Cecil Sandy Loam.

Plot No.	Treatment[1] (pounds per acre)	pH 1932	Exchange able Ca[2] 1932	1925	1926	1927	1928	1929	1930	1931	7-year average		
											Yield	Relative	Increase for lime
	Limed[3]						Pounds per acre						
1	400 Sodium nitrate	5.47	2.94	825	1,375	1,159	1,333	1,137	1,020[4]	1,129	1,139	109	32
2	300 Ammonium sulfate	4.51	1.17	796	1,445	1,232	1,408	1,181	1,221	1,294	1,225	118	335
3	No nitrogen	5.34	2.44	766	992	710	620	781	799	669	762	73	50
4	200 Sodium nitrate	5.82	2.67	792	1,333	1,116	1,036	1,100	1,143	1,140	1,094	105	54
5	150 Ammonium sulfate	5.11	1.95	783	1,329	1,126	946	1,080	1,259	1,134	1,093	105	165
	Unlimed						Pounds per acre						
6	400 Sodium nitrate	5.36	2.05	671	1,214	1,130	1,118	1,173	1,229	1,217	1,107	106	—
7	300 Ammonium sulfate	4.22	0.60	669	957	824	854	1,014	805	1,107	890	86	—
8	No nitrogen	5.04	1.56	658	834	594	543	671	950	733	712	68	—
9	200 Sodium nitrate	5.30	1.84	713	1,157	1,005	825	1,100	1,240	1,241	1,040	100	—
10	150 Ammonium sulfate	4.77	1.05	708	1,014	807	862	904	1,062	1,137	928	89	—

[1]All plots received 600 and 100 pounds of superphosphate and muriate of potash per acre, respectively.
[2]M. E. per 100 grams of soil.
[3]Limestone was applied in 1914 at the rate of 5,300 pounds per acre.
[4]Plot No. 1 was damaged by erosion in 1930.

cium as the adjacent sodium nitrate plot. Figure 6 shows the effect of these sources of nitrogen on the growth of cotton in 1932. This is further emphasized by comparing the yields from the two sources of nitrogen during the first three and last four years of the test. Sodium nitrate produced an average of 188 and 239 pounds of seed cotton per acre more than ammonium sulfate on the unlimed plots during the first three and the last four years, respectively. The difference in yields on these two plots should increase with a longer period of time.

FIGURE 6.—Cotton on unlimed Cecil sandy loam which received annually 61.5 pounds of nitrogen per acre for eight years. Center, guard row—no nitrogen; left, ammonium sulfate (four rows); right, sodium nitrate.

As shown in the table, the difference in cotton yields was 112 pounds per acre in favor of sodium nitrate when the smaller application of nitrogen was used on the unlimed plots. This difference was approximately the same during the first three years as during the last four years. It may be further pointed out that ammonium sulfate produced less cotton than sodium nitrate by approximately 11 and 20 per cent when applied at the rates of 150 and 300 pounds per acre, respectively.

On plots which were limed, 300 pounds of ammonium sulfate made an average of 84 pounds of seed cotton per acre more than an equivalent amount of nitrogen from sodium nitrate. This difference, however, may be attributed to erosion in 1930 on one-half of the sodium nitrate plot. It is interesting to note that the limed ammonium sulfate plot produced an average of 335 pounds of seed cotton per acre more than the unlimed plot, although the differences in pH and replaceable calcium are only 0.3 and 0.57 m.e., respectively. In the case of the smaller application of nitrogen (30 pounds per acre) the average yields from sodium nitrate and ammonium sulfate are practically identical even though no lime had been applied since 1914. Regardless of the source of nitrogen, lime increased the yields but the increase was much greater where ammonium sulfate was used. It may be noted that 150 pounds of ammonium sulfate on the limed plot produced an average of 53 pounds of seed cotton per acre more than 200 pounds of sodium nitrate on the unlimed plot.

This test shows that ammonium sulfate without lime produced materially less cotton than sodium nitrate, although it was just as efficient as sodium nitrate on limed soil. The cost of the ammonium sulfate and the annual cost of the limestone were less than the cost of an equivalent amount of nitrogen from sodium nitrate.

A Comparison of Different Sources of Nitrogen for Cotton

In 1926, field tests were started on a Norfolk sandy loam and on a Cecil clay loam to study: first, the influence of various nitrogenous fertilizers on cotton yields on unlimed and limed land during a period of years, and second, the influence of these nitrogenous fertilizers on the soils, with particular reference to the amount of acidity developed and changes in the replaceable base content. One-half of each area was limed in the spring of 1928 by the addition of enough limestone to bring the reaction of the soil to pH 6.5 plus an amount sufficient to neutralize the acid which would be developed by the nitrogenous fertilizers used for a period of four years. The amount of finely ground limestone added to each plot is shown in Table 11; this was determined by the method described by Pierre and Worley (16). At the end of each four-year period, sufficient limestone is to be added to neutralize the acidity developed by the nitrogenous fertilizer for the ensuing four years.

Nitrogen was applied annually to all plots at the rate of 45 pounds per acre, with the exception of a single plot in each test which received no nitrogen. The importance of nitrogen for cotton is shown in Figure 7. All of the plots received annually 96 pounds of phosphoric acid per acre except Plot 10 which received 195 pounds from Ammo-Phos A. Muriate of potash was applied to all plots at the rate of 100 pounds per acre. The phosphorus, potassium, and one-half of the nitrogen were applied only a few days before planting the cotton except for the plots which received Ammo-Phos A and calcium cyanamid; on these two plots, except in 1926 and 1927, all of the nitrogenous fertil-

TABLE 11.—The Amount of Limestone ($CaCO_3$ equivalent—92 per cent) Applied for the Limed Series of the Source of Nitrogen Test on Norfolk Sandy Loam and on Cecil Clay Loam.

Plot No.	Source of nitrogen[1]	Limestone (pounds per acre)	
		Norfolk sandy loam	Cecil clay loam
1	Sodium nitrate	1,100	1,630
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	1,100	1,630
3	Ammonium sulfate	2,270	2,800
4	Leunasalpeter	1,980	2,510
5	Sodium nitrate	1,100	1,630
6	None	1,100	1,630
7	Calcium cyanamid	1,100	1,630
8	Ammonium sulfate (Basic slag)	1,100	1,630
9	Sodium nitrate	1,100	1,630
10	Ammo-Phos A	2,270	2,800
11	Urea	1,690	2,220
12	Sodium nitrate	1,100	1,630
13	Sodium nitrate	1,100	——
14	Calcium nitrate	1,100	——
15	Cottonseed meal	1,100	——
16	Sodium nitrate	1,100	——

[1]Nitrogen applied annually at the rate of 45 pounds per acre.

FIGURE 7.—Cotton on Norfolk sandy loam. Both plots fertilized equally with phosphate and potash. Left, no nitrogen; right, sodium nitrate.

izer was added from 10 to 14 days before planting. When nitrogen was used as a side dressing, it was applied immediately after the cotton was thinned.

Results on Norfolk Sandy Loam.—The cotton yields for the unlimed area are shown in Table 12. These data show that sodium nitrate, calcium nitrate, and the mixture of sodium nitrate and ammonium sulfate produced more cotton than any of the other materials used during the period; their relative efficiency was 100, 102, and 99, respectively. Neither of the nitrates mentioned above increased soil acidity and the mixture of sodium nitrate and ammonium sulfate increased it only slightly. The sodium nitrate plots produced 55 pounds of seed cotton per acre more than urea or the mixture of ammonium sulfate and basic slag. During the five-year period, the plot which received calcium cyanamid made an average of only 85 per cent as much cotton as the sodium nitrate plots. This is due to the low yield from the cyanamid plot in 1927, at which time one-half of the cyanamid was used as a side-dressing material. After 1927 all the cyanamid was applied from 10 to 14 days before planting and its efficiency increased to 96 per cent as compared with the yields from sodium nitrate. The yields on Plots 7 and 11 were vitiated in 1926 because the side applications of nitrogenous fertilizer were interchanged.

The ammonium sulfate and Ammo-Phos A plots made an average of 140 and 160 pounds of seed cotton per acre, respectively, less than the sodium nitrate plots. These are physiologically acid fertilizers, and on this unlimed acid soil they did not produce yields as large as the less acid-forming materials. Ammo-Phos A was less efficacious than any of the other sources of nitrogen used in the test, considering the six-year period. It is worth noting that the Ammo-Phos A plot, which received twice as much phosphoric acid as the other plots, produced unusually poor yields some years and good yields other years as compared with the sodium nitrate plots. For example, in 1929 and 1930 it made 427 and 528 pounds per acre less than sodium nitrate, whereas in 1931 it made only 75 pounds less than sodium nitrate. The final stand of cotton on the unlimed portion of Plot 10 for each of these years was very poor as compared with the other plots even though a perfect stand was present at the time of thinning. Many of the plants died after the thinning on the unlimed area, although the poor stand may not fully account for the smaller yields made by the Ammo-Phos A; in 1930 this plot had a 50 per cent stand and made 43 per cent as much cotton as sodium nitrate, while in 1931 there was only a 66 per cent stand and it made 95 per cent as much as sodium nitrate. In Figures 8 and 9 may be seen the effect of Ammo-Phos A on unlimed and lime Norfolk soil, respectively. Available evidence indicates that the efficiency of Ammo-Phos A is determined to a great extent by the climatic conditions during the early growing period. For example, the early growing season of 1930 was comparatively cool and the fertilizer in question was ineffective, whereas the early growing season of 1931 was warm, under which condition the increased yield from Ammo-Phos A was much more substantial. Similar results have been obtained in other tests conducted in several sections of Alabama.

A comparison of cotton yields from the several sources of nitrogen used in this test on unlimed and limed plots is shown in Table 12. It will be seen that irrespective of the fertilizer treatment limestone increased the yields from this soil during the four-year period. In most cases the plots which received the most physiologically acid fertilizers gave the greatest increase from the use of limestone. For example, the increases from liming were 285, 248, and 169 pounds of seed cotton per acre, respectively, when the Ammo-Phos A, ammonium sulfate, and urea were used; none of the other increases were more than 84 pounds. The average yield from the unlimed Ammo-Phos A plot was the smallest obtained from any plot in the series which received a nitrogenous fertilizer, its yield being only 79 per cent of the yield from the sodium nitrate plot, whereas on the limed series it produced slightly more cotton than sodium nitrate. In fact, all of the acid-forming fertilizers made more cotton than sodium nitrate where lime was applied, except Leunasalpeter which was 97 per cent as efficient as the sodium nitrate.

The acidic fertilizers should continue to produce crops satisfactorily on the lime plots because limestone will be supplied in sufficient quantities to neutralize the acids developed therefrom. It will be necessary, however, to add more than the theoretical amount of limestone to each plot because of the removal of calcium by the plants and by leaching. As mentioned earlier, the theoretical amount of limestone was added in 1928 to give a reaction of pH 6.5 plus enough to neutralize the acidity from the particular fertilizer used on the plot for a period of four years. It will be noticed in Table 13 (page 36) that the limestone did not maintain the reaction at pH 6.5. The soil samples whose pH values are given in the table were obtained from the cotton rows and not from the middles. That is, the samples were drawn from the place where the fertilizer was applied. These samples were more acid than those drawn from the middles, notwithstanding the fact that the land was turned each year. However, in all cases the reaction of the soil was more acid than pH 6.5 in the middles.

Some of the probable causes for the low yields from the acidic fertilizers on the unlimed plots are indicated in Table 13. For example, all of the plots are extremely low in replaceable calcium, but the ammonium sulfate and Ammo-Phos A plots contain approximately one-third as much as the sodium nitrate plots. On the other hand, the ammonium sulfate and Ammo-

TABLE 12.—Yield of Seed Cotton from Various Sources of Nitrogen on Unlimed and Limed Norfolk Sandy Loam.

Plot No.	Source of nitrogen	Pounds per acre—Unlimed									
		1926	1927	1928	1929	1930	1931	Six-years		Last four-years	
								Average	Relative	Average	Relative
1	Sodium nitrate	1,122	1,180	884	944	978	1,472	1,096	95	1,069	97
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	1,272	1,062	1,080	968	1,033	1,456	1,145	99	1,134	103
3	Ammonium sulfate	1,262	787	1,004	920	731	1,360	1,011	88	1,004	91
4	Leunasalpeter	1,480	935	716	1,036	853	1,484	1,084	94	1,022	93
5	Sodium nitrate	1,410	1,158	796	960	829	1,632	1,131	98	1,054	96
6	None	732	323	256	320	387	672	448	39	409	37
7	Calcium cyanamid	——	563	740	996	928	1,576	961[1]	85[1]	1,060	96
8	Ammonium sulfate (Basic slag)	1,076	1,101	1,032	988	910	1,472	1,096	95	1,100	100
9	Sodium nitrate	1,370	1,303	860	1,024	928	1,544	1,171	102	1,089	99
10	Ammo-Phos A	1,436	1,048	972	588	402	1,508	991	86	867	79
11	Urea	——	1,154	936	1,048	753	1,588	1,096[1]	97[1]	1,081	98
12	Sodium nitrate	1,482	1,394	536	1,028	792	1,640	1,145	99	999	91
13	Sodium nitrate	——	1,117	1,128	1,048	1,136	1,544	1,195[1]	106[1]	1,214	110
14	Calcium nitrate	——	993	1,016	1,108	1,018	1,620	1,151[1]	102[1]	1,190	108
15	Cottonseed meal	——	879	972	1,028	803	1,384	1,013[1]	90[1]	1,047	95
16	Sodium nitrate	——	1,161	1,020	1,088	919	1,664	1,170[1]	104[1]	1,173	107
Average sodium nitrate		1,346	1,218	871	1,015	930	1,583	1,151	100	1,100	100

[1]Five-year average.

TABLE 12.—Yield of Seed Cotton from Various Sources of Nitrogen on Unlimed and Limed Norfolk Sandy Loam—(Cont.)

Plot No.	Source of nitrogen	Pounds per acre—Limed						
		1928	1929	1930	1931	Four-years		Increase due to limestone
						Average	Relative	
1	Sodium nitrate	1,356	1,040	966	1,392	1,188	105	119
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	1,168	1,056	1,048	1,584	1,214	107	80
3	Ammonium sulfate	1,200	1,068	1,119	1,620	1,252	110	248
4	Leunasalpeter	888	1,064	832	1,628	1,103	97	81
5	Sodium nitrate	924	928	759	1,740	1,088	96	34
6	None	384	432	452	704	493	44	84
7	Calcium cyanamid	928	1,000	840	1,544	1,078	95	18
8	Ammonium sulfate (Basic slag)	1,204	1,016	851	1,544	1,154	102	54
9	Sodium nitrate	1,052	1,012	854	1,524	1,110	98	21
10	Ammo-Phos A	1,236	924	877	1,572	1,152	102	285
11	Urea	1,348	1,052	1,020	1,580	1,250	110	169
12	Sodium nitrate	880	976	756	1,528	1,035	91	36
13	Sodium nitrate	1,344	996	925	1,484	1,187	105	–27
14	Calcium nitrate	1,240	1,072	1,141	1,644	1,274	112	84
15	Cottonseed meal	940	1,024	936	1,488	1,097	97	50
16	Sodium nitrate	1,128	1,104	859	1,672	1,191	105	18
Average sodium nitrate		1,114	1,009	853	1,557	1,133	100	33

FIGURE 8.—Cotton on unlimed Norfolk sandy loam fertilized annually with 409 and 100 pounds per acre of Ammo-Phos A and muriate of potash, respectively, since 1926. Photographed July 6, 1932.

Phos A plots contain approximately three-fourths as much replaceable calcium as the sodium nitrate plots where lime was used. It will be remembered that the yields were higher on these plots than the yields on the unlimed plots. As would be expected, the amount of replaceable hydrogen decreased as the replaceable calcium increased from the lime application. Little or no significance is attached to the replaceable magnesium and potassium results reported.

Results on Cecil Clay Loam.—The cotton yields from the unlimed plots are given in Table 14. It will be observed that sodium nitrate, the mixture of ammonium sulfate and sodium nitrate, ammonium sulfate, and Leunasalpeter gave relative yields of 100, 103, 100, and 108, respectively, for the six-year period. These figures indicate that Leunasalpeter and ammonium sulfate, both physiologically acid fertilizers, were relatively more efficient on the Cecil clay loam than on the Norfolk sandy loam. The average yield of the sodium nitrate plots was 282 pounds of seed cotton per acre more than that of the plot which received calcium

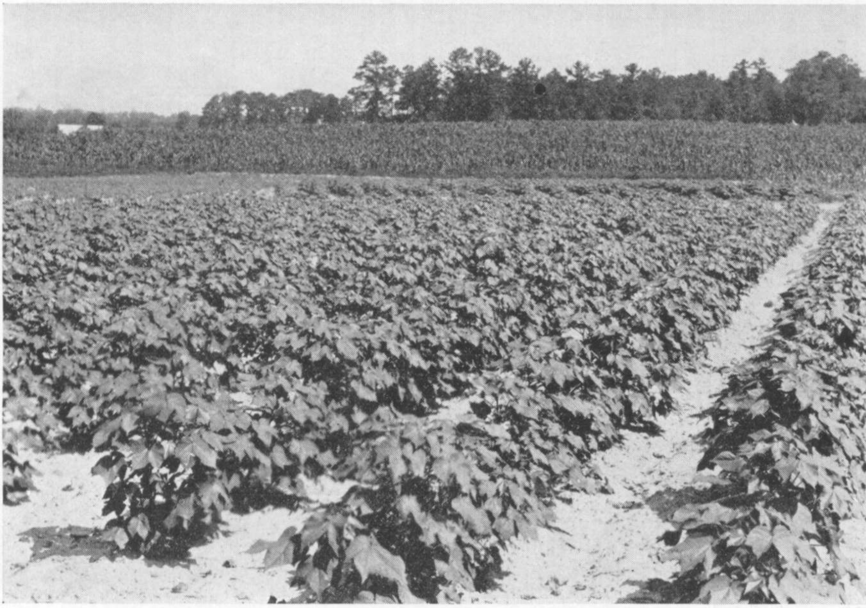

FIGURE 9.—Cotton on limed Norfolk sandy loam fertilized annually with 409 and 100 pounds per acre of Ammo-Phos A and muriate of potash, respectively, since 1926. Photographed July 6, 1932.

cyanamid and was 272 pounds more than the plot which received Ammo-Phos A. These data show that calcium cyanamid and Ammo-Phos A were considerably less efficient on the heavy soil than on the light Norfolk soil when compared with the yields from the sodium nitrate plots; these results are contrary to those expected. Due to erosion, the limed plots are not sufficiently uniform to be considered.

On this Cecil soil all of the acid-forming fertilizers except Ammo-Phos A gave yields which compare favorably with those from sodium nitrate. As shown in Table 15 these materials have not as yet reduced the replaceable calcium in this soil to a critically low point for the production of a good crop. For example, the plot which received ammonium sulfate contained 20 m.e. of calcium per 1000 grams of soil, or approximately two-thirds as much as the sodium nitrate plots; whereas in the case of the Norfolk sandy loam (Table 13) the ammonium sulfate plot had less than one-third as much replaceable calcium as the sodium nitrate plots. These acidic fertilizers should continue for a few years to give satisfactory yields on the Cecil soil because of the relatively high replaceable base content and a high buffer capacity of the soil. However, at some future time the plots which receive acid-forming fertilizers will need an application of lime if a decline in yield is to be prevented.

TABLE 13.—The Reaction and Amount of Exchangeable Cations of Unlimed and Limed Norfolk Sandy Loam after Six Annual Applications of Different Sources of Nitrogen.

Plot No.	Source of nitrogen	Unlimed						Limed[2]					
		pH 1932	Exchangeable[1]					pH 1932	Exchangeable[1]				
			H	Ca	Mg	K	Total bases		H	Ca	Mg	K	Total bases
1	Sodium nitrate	5.8	15.8	10.2	0.36	1.5	12.1	5.8	11.2	16.5	0.39	1.20	18.1
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	5.0	19.4	6.7	0.35	1.3	8.3	5.8	14.2	14.6	0.43	1.03	16.1
3	Ammonium sulfate	4.6	19.5	2.9	0.27	0.6	3.8	5.2	16.5	11.7	0.39	0.86	12.9
4	Leunasalpeter	4.7	18.8	6.3	0.24	1.1	7.6	5.6	13.9	12.5	0.36	1.03	13.9
5	Sodium nitrate	5.6	18.0	9.1	0.27	1.5	10.9	6.1	10.4	16.8	0.31	1.16	18.3
6	No nitrogen	5.3	16.5	9.4	0.24	1.2	10.8	5.8	9.7	15.8	0.30	1.46	17.5
7	Calcium cyanamid	5.9	14.5	14.0	0.24	0.4	14.6	6.3	5.8	21.7	0.23	0.98	22.9
8	Ammonium sulfate (Basic slag)	6.1	8.2	23.2	0.24	0.5	23.9	6.2	8.1	23.8	0.27	1.03	25.1
9	Sodium nitrate	5.4	17.7	10.9	0.25	0.5	11.6	5.9	13.2	17.8	0.20	1.46	19.5
10	Ammo-Phos A	4.5	24.8	3.2	0.27	0.9	4.4	5.1	21.0	12.0	0.15	2.14	14.3
11	Urea	5.2	19.0	9.1	0.25	0.4	9.7	5.5	14.0	15.6	0.05	1.20	16.8
12	Sodium nitrate	5.3	15.6	9.7	0.25	1.1	11.0	5.8	12.6	16.3	0.15	1.50	17.9
13	Sodium nitrate	5.2	18.6	12.7	0.16	1.5	14.4	5.8	12.7	17.5	0.09	1.37	18.9
14	Calcium nitrate	5.2	18.2	13.2	0.21	1.1	14.5	5.8	16.6	16.3	0.07	1.16	17.5
15	Cottonseed meal	5.2	19.8	12.4	0.16	1.1	13.7	5.3	18.0	13.8	0.08	1.11	15.0
16	Sodium nitrate	5.6	19.2	12.9	0.12	1.3	14.3	5.9	14.3	15.5	0.05	1.29	16.8
Average sodium nitrate		5.5	17.5	10.9	0.23	1.2	12.3	5.9	12.4	16.7	0.19	1.33	18.2

[1]M. E. per 1,000 grams of soil, 1932.
[2]Limed in Spring of 1928.

TABLE 14.—The Yield of Seed Cotton, pounds per acre, and the Relative Yield from Different Sources of Nitrogen on Unlimed Cecil Clay Loam.

Plot No.	Source of nitrogen	1926	1927	1928	1929	1930	1931	Six-years	
								Average	Relative yield
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	Sodium nitrate	1,440	982	1,440	970	1,380	1,409	1,270	102
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	1,335	1,069	1,530	834	1,402	1,486	1,276	103
3	Ammonium sulfate	1,388	998	1,478	998	1,222	1,384	1,245	100
4	Leunasalpeter	1,523	930	1,433	1,046	1,485	1,602	1,336	108
5	Sodium nitrate	1,515	1,013	1,410	1,203	1,290	1,555	1,331	107
6	No nitrogen	750	311	510	393	690	664	553	44
7	Calcium cyanamid	1,148	645	945	1,042	937	1,045	960	77
8	Ammonium sulfate (Basic slag)	1,125	863	1,245	890	840	1,075	1,006	81
9	Sodium nitrate	1,335	975	1,435	1,040	900	1,211	1,149	93
10	Ammo-Phos A	1,275	769	885	970	967	953	970	78
11	Urea	1,140	806	1,283	1,019	1,087	1,503	1,140	92
12	Sodium nitrate	1,335	923	1,305	1,077	1,162	1,502	1,217	98
Average sodium nitrate		1,406	973	1,397	1,072	1,183	1,419	1,242	100

TABLE 15.—Soil Reaction and Exchangeable Cations of Unlimed Cecil Clay after Six Annual Applications of Different Sources of Nitrogen.

Plot No.	Source of nitrogen	pH 1932	Exchangeable[1]				
			H	Ca	Mg	K	Total bases
1	Sodium nitrate	6.5	9.4	31.0	1.0	4.3	36.3
2	Sodium nitrate 3/5 Ammonium sulfate 2/5	5.6	18.0	31.5	1.7	3.6	36.8
3	Ammonium sulfate	4.8	33.0	20.0	4.2	3.1	27.3
4	Leunasalpeter	4.9	25.2	30.7	1.9	3.3	35.9
5	Sodium nitrate	6.5	8.6	34.2	1.3	4.5	40.0
6	No nitrogen	5.9	13.0	33.1	0.9	3.4	37.4
7	Calcium cyanamid	6.8	7.6	45.0	0.5	3.3	48.8
8	Ammonium sulfate (Basic slag)	6.6	4.5	56.2	3.3	2.2	61.7
9	Sodium nitrate	6.3	3.2	33.5	0.4	3.9	37.8
10	Ammo-Phos A	5.1	33.6	20.3	5.9	5.1	31.3
11	Urea	5.6	22.6	30.4	0.8	3.3	34.5
12	Sodium nitrate	6.1	11.0	37.2	1.1	3.4	41.7
Average sodium nitrate		6.3	8.1	34.0	0.9	4.0	38.9

[1]M.E. per 1,000 grams of soil, 1932.

FACTORS THAT DETERMINE THE RELATIVE VALUE OF DIFFERENT NITROGENOUS FERTILIZERS

Numerous factors are involved in determining the relative value of various nitrogenous fertilizers. Important ones in determining their value are leaching of ammonium- and nitrate-nitrogen; absorption of different forms of nitrogen by plants; and the influence of the various nitrogenous fertilizers on soil acidity, on the availability of phosphorus and potash, and on the physical properties of the soil. Each of these is briefly discussed.

The Leaching of Ammonium- and Nitrate-Nitrogen

In many sections of the Southeast, farmers apply fertilizer materials several weeks before planting cotton. This practice is necessary if the land is to be "bedded" after applying the fertilizer because of the considerable time required to prepare the land in this manner. Consequently, much cotton fertilizer is applied to the soil from two to four weeks before the plants are large enough to absorb the nutritive elements supplied. Furthermore, many farmers apply fertilizer to the soil and then wait for rains to settle the beds before planting; this usually gives a better stand than planting in a loose soil. With this practice in common use and in the case of heavy rains, the relative loss of nitrogen added in different forms becomes of considerable importance. It has been generally recognized that excessive rainfall leaches nitrate-nitrogen more readily than ammonium-nitrogen.

This study was therefore started to determine the extent to which nitrate- and ammonium- nitrogen are leached from a Norfolk sandy loam and a Cecil clay by various amounts of water.

A six-inch column of Norfolk sandy loam soil was packed very firmly into each of seventy-two percolators. Sodium nitrate or ammonium sulfate was added on the surface of the soil and then water was placed on top of the column of soil in varying amounts. The Cecil clay was treated in a similar manner. The amounts of nitrogen and water applied and the percentages of nitrogen which leached through the soils are given in Table 16. Six pounds of nitrogen per acre were used in one case because this approximates the amount used before planting by many farmers; and in the second case, fifteen pounds were used because many farmers apply approximately this amount before planting or as a side dressing. The results obtained show that nitrate-nitrogen leached to a greater extent than ammonium-nitrogen irrespective of the amount of nitrogen added or the amount of water used in leaching. The original moisture content of the Norfolk soil was 7 per cent and that of the Cecil was 10 per cent; consequently, no water passed through the columns of soil when a one-inch application was made. As a result of the two-inch application of water to the Norfolk sandy loam, a very large proportion of the nitrogen added as sodium nitrate leached through the column. On the other hand, this amount of water caused a loss of only 1.5, 3.6, and 23 per cent of the nitrogen added as ammonium sulfate at the rates of 6, 15, and 75 pounds of nitrogen per acre, respectively. With a four-inch application of water and 15 pounds of nitrogen per acre, about three-fourths of the nitrate-nitrogen but only one-ninth of the ammonium-nitrogen were leached from the columns of the Norfolk sandy loam. Under the same conditions, about 50 per cent of the nitrate- and 2.4 per cent of the ammonium-nitrogen were lost from the columns of Cecil clay. The results reported are not in every case consistent, but they show clearly that a relatively large proportion of the nitrogen added was leached from the soil columns by a rather small amount of water and that the nitrate-nitrogen was lost to a much greater extent than the ammonium-nitrogen. The ammonium-nitrogen was probably held in the replaceable-base complex which prevented its loss by leaching to a considerable extent. Consequently, under field conditions, the amount of ammonium-nitrogen lost by leaching decreases as the replaceable-base complex of soils increases.

Other studies have shown that four inches of water leached nitrate-nitrogen to a considerable depth, 30 inches or more. It is then necessary for the plant roots to grow into the soil zones into which the nitrogen has been leached if they are to absorb this nitrogen. The weather records for the southeastern states reveal many instances of heavy rainfall (more than 2 inches)

TABLE 16.—The Percentages of NO_3- and NH_4-Nitrogen which Leached Through Six-Inch Columns of Norfolk Sandy Loam and Cecil Clay by the Applications of Different Amounts of Water.

Water added inches	Norfolk Sandy Loam[1]						Cecil Clay[2]					
	Sodium nitrate (pounds N per acre)			Ammonium sulfate (pounds N per acre)			Sodium nitrate (pounds N per acre)			Ammonium sulfate (pounds N per acre)		
	6	15	75	6	15	75	6	15	75	6	15	75
	Percentage of Nitrogen Leached											
1	0	0	0	0	0	0	0	0	0	0	0	0
2	41.0	44.0	39.0	1.5	3.6	23.0	37.8	14.0	6.9	3.0	1.2	0.2
3	68.2	70.5	64.6	3.0	9.1	33.8	39.4	33.3	29.1	4.5	2.4	0.7
4	71.2	78.2	68.5	6.0	11.5	37.0	62.4	49.8	48.3	6.1	2.4	1.5
5	89.4	77.0	78.8	3.7	——	37.1	74.5	57.0	60.5	—	3.6	2.4
6	93.9	88.0	76.0	4.9	11.5	40.5	95.5	57.8	72.5	4.5	8.1	5.5

[1]The original moisture content was 7 per cent.
[2]The original moisture content was 10 per cent.

after the fertilizer application and before the cotton plants have absorbed much of the nitrogen. In such cases, nitrate-nitrogen is lost to crops to a greater extent than ammonium-nitrogen.

Absorption of Ammonium- and Nitrate-Nitrogen by Plants

Although more work has been done on nitrogen fertilization than on any other phase of soil fertility, little information is available concerning the absorption of the various forms of nitrogen by plants. It has been noticed that plants fertilized with amomnium- and nitrate-nitrogen make a more rapid growth in their early stages than those which received only nitrate-nitrogen. Hutchison and Miller (7) gave a review of the early work concerning the absorption of ammonium- and nitrate-nitrogen and concluded that most plants may utilize either form of nitrogen. Some plants grew better throughout their growth period when nitrogen was supplied as nitrate. The best growth was generally obtained, however, when both forms of nitrogen were present. Jones and Skinner (9) found that soybeans and corn absorbed more ammonium- than nitrate-nitrogen in their early stages of growth. Tiedjens and Robbins (22) recently showed that tomato, peach, and apple seedlings absorbed both ammonium- and nitrate-nitrogen, although the controlling factor in nitrogen assimilation was the reaction of the culture medium.

The absorption of the ammonium- and nitrate-nitrogen by cotton seedlings was studied at this station (12). The seedlings were grown in solution, sand, and soil cultures. The effect of the age of the seedlings, reaction of the culture solution, and the length of the absorption period on the relative amounts of ammonium- and nitrate-nitrogen removed from the culture solutions were studied. The results of this investigation may be briefly summarized as follows:

(1) Ammonium-nitrogen was absorbed in larger amounts than nitrate-nitrogen by the young seedlings until they were from three to five weeks old. After this age more nitrate-nitrogen was absorbed.

(2) The data show that both ammonium- and nitrate-nitrogen were absorbed in large amounts when the plants were 4 to 8 weeks old.

(3) Both growth and fruiting of plants were better when both forms of nitrogen were present.

(4) Ammonium-nitrogen absorption increased as the acidity of the culture solution decreased. The absorption of nitrate-nitrogen was only slightly affected by the reaction of the solution used.

(5) The highest total nitrogen absorption usually occurred at pH 6.0.

(6) Total nitrogen absorption was greatest when both forms of nitrogen were present.

(7) The growth and fruiting of cotton plants in field plots agreed well with that of plants in the culture solutions.

In order to test the applicability of the above findings to field conditions a comparison of sodium nitrate and a combination of ammonium sulfate and sodium nitrate was made during 1929 and 1930. The fertilizer treatments for the plots were identical except that before planting in one case sodium nitrate was used as the source of nitrogen and in the other case ammonium sulfate. All plots were side dressed with the same quantity of sodium nitrate. In 59 tests on various soil types, the ammonium sulfate-sodium nitrate combination produced an average of 31 pounds of seed cotton per acre more than the sodium nitrate.

Development of Soil Acidity

In the past, nitrogenous fertilizers have been sold largely on the basis of their nitrogen content. Studies have shown, however, that the value of a fertilizer may be influenced to a very great extent by its residual effects on the soil; this is especially true when the residual effects over a period of years are considered. The effect of physiologically acid fertilizers on the soil and the results which might be expected from the use of such fertilizers on calcium deficient soils have been pointed out (17). Most of the soils of the southeastern states are acid and they have a very low calcium content.

Cause of Acidity

Many theories have been advanced concerning the cause of the development of acidity from certain nitrogenous fertilizers. They have been briefly summarized by Pierre (17). The most plausible explanation of the development of soil acidity by acid-forming fertilizers is that the cation of the added salt undergoes a base exchange reaction with the absorbing complex. This complex is usually represented by the formula CaX, in which Ca represents the various exchangeable cations which are combined with the anions, X, in exchangeable form. For convenience, it may be assumed that the X can only combine with one Ca. If ammonium sulfate, for instance, is added to a soil the following reactions may take place:

$$(NH_4)_2SO_4 + CaX \rightarrow CaSO_4 + (NH_4)_2X \qquad \text{(I)}$$

$$(NH_4)_2X + O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O \qquad \text{(II)}$$

$$2HNO_3 + CaX \rightarrow Ca(NO_3)_2 + H_2X \qquad \text{(III)}$$

The soil acidity is not increased immediately by ammonium sulfate applications as shown in Equation I. Moreover, it makes little difference as far as soil acidity is concerned whether or not the $CaSO_4$ is leached out of the soil, because the calcium it contains has been replaced in the exchangeable complex by ammonium. No acidity is developed until nitrification has taken place, as represented in Equation II. As a result of this process, two molecules of nitric acid and one molecule of dibasic acid are formed. The nitric acid may react with another molecule of CaX forming $Ca(NO_3)_2$ and H_2X, as shown by Equation III. The $Ca(NO_3)_2$ may be absorbed by plants or leached from the soil. Thus, ammonium sulfate increases soil acidity due to the formation of dibasic acids, one molecule of the former producing two molecules of the latter. The acidity developed from other nitrogenous materials, such as Leunasalpeter, urea, ammonium nitrate, and ammonium phosphate may be explained by equations similar to those shown above.

Amount of Acidity

It was found that the relative increases in exchangeable hydrogen from the various acid-forming fertilizers were in close agreement with the relative increases in the H-ion concentration (17). These values were also in close agreement with the theoretical amounts of acidity that should be developed. The relative values are as follows:

	Ammonium sulfate	Ammonium phosphate	Leunasalpeter	Urea	Ammonium nitrate
Experimental	100	100-104	68-75	42-50	42-55
Theoretical	100	100	75	50	50

The acid-forming nitrogenous fertilizers will increase the acidity of all soils to a harmful degree if applied in liberal amounts and for a sufficient period of time. The extent to which these materials will increase the acidity, however, will vary with different soils, depending on their respective buffer capacities. In general, the greater the colloidal and exchangeable-base contents of a soil, the greater is its buffer capacity toward acid, since the addition of an acid or acid-forming fertilizer to a soil results in hydrogen's replacing the bases in the exchange complex. After thus removing a large portion of the exchangeable bases, the soil becomes so acid or so deficient in calcium that plant growth may be injured. Consequently, the greater the buffer capacity of a soil or the higher the percentage base saturation, the greater the quantity of acid-forming fertilizer which may be added before the soil develops a sufficiently high hydrogen-ion concentration or calcium deficiency to be injurious to plant growth. Therefore, soils would be expected to vary greatly as to the amount of ammonium sulfate required to produce a definite change in soil acidity. On a clay soil well supplied with replaceable-bases, many normal applications of ammonium sulfate may be required to increase the soil acidity to such an extent as to be injurious to plant growth. On the other hand, a few applications of this fertilizer may injure some soils, particularly light textured soils, to such an extent that plants will make a very unsatisfactory growth on them.

The effect of different nitrogenous fertilizers on soil reaction has been shown from greenhouse studies at this station (17). These studies show that consideration should be given to the effect of the various materials on the H-ion concentration of the soil and on the amount of replaceable hydrogen resulting from their use. The former is of greater importance in determining how soon injury to crops will result, and the latter gives information on how much lime will have to be added to bring a soil fertilized with an acid-forming fertilizer back to its original reaction.

Short-Time Field Tests.—Data have been presented (Tables 13 and 15) which show the effect of various nitrogenous fertilizers on soil acidity. During the past six years, ammonium sulfate at the rate of 220 pounds per acre on Cecil clay loam has increased the H-ion concentration by 1.1 of a pH and the replaceable hydrogen by approximately 150 per cent. During the same period on a Norfolk sandy loam, this amount of ammonium sulfate increased the H-ion concentration of the surface soil by approximately 0.7 of a pH and the replaceable hydrogen by 30 per cent (Table 13). During the past seven years an annual application of 300 pounds of ammonium sulfate increased the H-ion concentration by approximately 0.8 of a pH, while a 150 pound application increased the H-ion concentration by approximately 0.25 of a pH. These results are shown in Table 10. From the standpoint of residual acidity, the above mentioned tests may be considered as "short-time" tests.

Long-Time Field Tests.—Numerous tests have been conducted over a long period of years which show that soils may become extremely acid from the continued use of ammonium sulfate. Reference can be made here to only a few of these tests. Table 9 shows that, on a Cecil sandy loam, thirty 105 pound applications of ammonium sulfate per acre for twenty years have increased the acidity in the surface soil ten-fold. It has been shown (5) that certain New Jersey plots which have received for twenty years an annual application of ammonium sulfate, equivalent to 320 pounds of sodium nitrate per acre, increased acidity from pH 4.85, the reaction of the check plot, to pH 4.25. All other sources of nitrogen added, except dried blood, decreased the acidity; these were sodium nitrate, calcium nitrate, and calcium cyanamid. Similar results were also reported (5) for samples of Merrimac silt loam from the sources of nitrogen experiment conducted since 1893 at the Rhode Island Experiment Station. Likewise, a number of experiment stations which have tests of long duration comparing various sources of nitrogen have shown similar results.

Penetration of Acidity

Practically all of the work dealing with the changes in soil reaction from the use of nitrogenous fertilizers has been concerned with only the surface soil. The probability that some of the acid developed may penetrate into the sub-surface layers of soil has been overlooked to a considerable extent. This penetration is more likely to take place after most of the replaceable bases, particularly calcium, have been largely replaced by hydrogen in the surface soil. It has been shown that the acidity developed from ammonium sulfate penetrated into the subsoil to a considerable extent (15). These results are shown in Table 17. It may be seen from the table that the acidity developed from the ammonium sulfate has penetrated the Cecil sandy loam to a depth of 12 and 8 inches in the Auburn and Athens plots, respectively. As the ammonium sulfate applications continue, it is reasonable to expect that the penetration of acid will advance to greater depths.

TABLE 17.—Acidity at Different Soil Depths from Ammonium Sulfate Applications.[1]

Depth in inches	Source of nitrogen plots at Auburn, Alabama		Fertilizer test plots at Athens, Georgia	
	Check plot	$(NH_4)_2SO_4$ plot[2]	Check plot	$(NH_4)_2SO_4$ plot[3]
	pH	pH	pH	pH
0-4	5.40	4.55	5.00	4.60
4-8	5.40	4.55	5.00	4.60
8-12	5.00	4.55	5.05	5.05
12-16	4.95	4.85	5.35	5.35
16-20	4.85	4.80	—	—

[1]Data from Pierre (15).
[2]3,150 pounds of $(NH_4)_2SO_4$ applied over a 15-year period; Cecil sandy loam.
[3]1,540 pounds of $(NH_4)_2SO_4$ applied over a 12-year period; Cecil sandy loam.

Availability of Phosphorus and Potassium

The concentration and nature of the replaceable bases and soil acidity may be considered as important factors in determining the availability of phosphorus and potassium in the soil. This has been shown by the work of Burd and Martin (3, 4), Spurway (19, 20, 21), McGeorge (10), and others. Any soil treatment which affects the replaceable-base complex may be expected to influence the availability of these plant nutrients. It has been shown that the nitrogen fertilizers influence the acidity and the replaceable base content of soils. They, therefore, should affect the availability of phosphorus and potassium in soils.

Fudge (5) studied the influence of various nitrogenous fertilizers on the availability of phosphate and potassium in greenhouse cultures and in soil samples from plots of the long-continued sources of nitrogen experiments of the Alabama, New Jersey, Rhode Island, Pennsylvania, and North Carolina Experiment Stations. The availability of these nutrients was studied by determining their solubility as indicated by the concentration of displaced solutions and 1:5 extracts, using water, 0.04 N carbonic acid, and 0.2 N nitric acid as extractants. Their availability was also studied by means of the Neubauer and Schneider method (13).

The results of this work may be briefly summarized as follows:

(1) Various nitrogenous fertilizers affected the availability of phosphate and potassium differently; their effect depended upon the influence of these fertilizers on the reaction of the soil and on the introduction of various cations carried by the fertilizers.

(2) Acid-forming fertilizers caused a decrease in phosphate availability and an increase in the amount of water-soluble potassium, whereas physiologically basic fertilizers caused an increase in phosphate availability and a decrease in the amount of water-soluble potassium.

Physical Properties of the Soil[1]

It has been shown, in the foregoing paragraphs, that various nitrogenous fertilizers affect the reaction and the nature of the replaceable cations of soils. The secondary products resulting from the use of these fertilizers deserve consideration. After the absorption of the nitrogen by plants, the nature of the product remaining in the soil depends upon the original composition of the fertilizer, changes that take place during the time that the fertilizer is in contact with the soil, and the capacity of the soil to absorb any of the fertilizer constituents. It is apparent that the basic or cationic elements of a fertilizer remain in the soil unless they are leached or absorbed by plants.

Many workers have shown that the physical properties of a soil are influenced by the absorbed cations in the soil complex. Joffe and McLean (8) state that the nature of the cation saturating the soil complex determines the mobility of the compounds in the soil solution and controls to some extent the soil structure and permeability. The work of Pate (14) and Anderson (1)

[1]This study was made by Mr. L. G. Brackeen, formerly a graduate student of the Department of Agronomy and Soils and now with the Alabama State Department of Agriculture.

shows that the heat of wetting and amount of water absorbed are greater when the soil is saturated with divalent cations, whereas swelling, moisture equivalent, and migration velocity are greater when the soil is saturated with monovalent cations, except in the case of the H-ion. Gedroiz (6) found that the H-ions caused a greater flocculation of soil colloids than other monovalent cations and approached that of the divalent cations.

Soils saturated with a given cation have been used by most investigators when studying the effects of the different cations on their physical properties. Under field conditions, a given nitrogenous fertilizer will not be used on the same soil for a sufficient period of time nor in sufficient quantities to completely saturate the soil with the resulting cation. However, it is claimed that the residual cation may accumulate in the exchange complex in sufficient concentrations to appreciably affect the physical properties of the soil. A study was made to determine the influence of some of the nitrogenous fertilizers on the flocculation of soils. Flocculation may be considered as an index to other physical porperties.

Eleven Alabama soils, which varied from sands to clays in texture, were weighed into pots and fertilized with superphosphate and muriate of potash for the first three crops at the rate of 1,000 and 100 pounds per acre, respectively. Oats and Sudan grass, two crops of each, were grown on these soils. Nitrogen was applied, as top dressings, at the rate of 150 pounds per acre for each crop to all cultures except the checks from the sources shown in Table 18.

TABLE 18.—The Amount of Soil in Suspension after Mechanical Dispersion, as Influenced by Different Sources of Nitrogen.[1]

Source of nitrogen	Grams in suspension at intervals indicated (minutes)					
	1	3	5	7	10	15
Check	32.7	27.9	23.8	20.5	17.2	14.2
Sodium nitrate	32.0	27.1	23.9	21.5	19.2	16.6
Calcium nitrate	31.6	26.2	22.7	19.8	17.1	14.4
Ammonium sulfate	29.8	24.6	20.3	15.9	10.4	6.5
Ammonium sulfate and lime	21.8	26.3	22.7	19.1	14.8	10.5

[1]The average results on eleven soils which varied in texture from sands to clays.

In order to study the flocculation of the soils, the method of Bouyoucos (2) without a dispersing agent was used. Hydrometer readings of the suspensions were made in duplicate for each fertilizer treatment of the eleven soils at intervals of 1, 3, 5, 10, and 15 minutes. As the general trends of the fertilizer affects were similar for all the soil types, the results and a discussion of the individual soils are unnecessary. The average results of the eleven soils obtained at the stated intervals of time are shown in Table 18. It may be seen that sodium nitrate deflocculated the soil, and this is particularly noticeable at the intervals of 7, 10, and 15 minutes. This effect was probably minimized due to the method of sampling the soil. In obtaining the data on which Table 18 is based, a composite sample from each treatment was used, although the nitrogenous fertilizers were applied on the surface of the soil. It is here that one would expect the greatest influence on the physical and chemical properties. The sodium nitrate pots were covered with a thick crust. It was observed during the pulverization of the heavier soils which were fertilized with sodium nitrate that they were much harder to pulverize than those which received the other sources of nitrogen. Even with this heavy application of sodium nitrate, these soils were only about one-third saturated with sodium.

Calcium nitrate had very little effect on the flocculation of these soils. This indicates that the replaceable base content was not appreciably changed or that the base absorbed was the same as that of the original soil. Chemcial data on these soils showed that the replaceable calcium was increased by approximately 20 per cent as a result of the calcium nitrate additions and that calcium was the predominating cation in the original soil.

Ammonium sulfate fertilization caused a very marked and consistent flocculation of these soils. This was due either to the partial replacement of the normal soil cations, chiefly calcium, by hydrogen ions or to the combined action of the calcium and hydrogen ions. The ammonium sulfate pots ranged from 1.0 to 1.5 pH more acid than the checks. According to Gedroiz (6), a soil saturated with hydrogen ions is more flocculated than the same soil saturated with the monovalent cations and less flocculated than when it is saturated with divalent cations. He also states that the precipitating power of any cation is very greatly increased in the presence of even a small quantity of hydrogen ions.

The flocculation of the soils which received ammonium sulfate and lime was consistently greater than that of the soils which received no nitrogen but was less than that of those which received only ammonium sulfate. The lime neutralized the acidity developed by the ammonium sulfate; therefore, the calcium ion probably played the important role in flocculation.

The effect of various nitrogenous fertilizers applied under field conditions on the flocculation of a Norfolk sandy loam was studied. These plots received annually, for four years, superphosphate and muriate of potash at the rates of 600 and 100 pounds per acre, respectively. To each plot, except the check, was applied annually 45 pounds of nitrogen per acre. The results of the flocculation studies are given in Table 19. It may be observed that this was a sandy soil and after a settling period of one minute not more than 14 grams of soil were in suspension irrespective of the fertilizer treatment. The small differences recorded are apparently due to soil variations and not to the fertilizer treatments. If the fertilizer treatments had been the principal factors which influenced the rate of settling, the effect of calcium cyanamid and calcium nitrate applications would have been in the same direction. Likewise, the trend of the applications of ammonium sulfate, Leunasalpeter, and urea would have been similar, due to the increases in the hydrogen-ion concentration.

TABLE 19.—The Amount of Soil in Suspension, after Mechanical Dispersion, as Influenced by Different Sources of Nitrogen on a Norfolk Sandy Loam under Field Conditions.

Source of nitrogen	Grams in suspension at intervals indicated (minutes)						
	1	3	5	7	10	15	30
Ammonium sulfate	13.0	9.0	8.0	6.0	5.0	4.5	3.0
Leunasalpeter	14.0	10.0	7.0	6.0	5.5	4.0	1.5
Sodium nitrate	14.0	10.0	8.0	6.5	6.0	5.0	4.0
None	13.0	9.0	7.5	6.5	5.5	4.0	3.0
Calcium cyanamid	13.0	9.0	8.0	7.0	6.0	5.0	3.5
Urea	14.0	10.0	9.0	8.5	8.0	6.5	5.0
Calcium nitrate	14.0	10.5	9.5	8.5	7.5	7.0	5.5

The replacement of calcium- and hydrogen-ions by sodium-ions in the case of sodium nitrate fertilization was fairly rapid; however, the physical condition of this soil was not markedly influenced by the nature of the cation on the exchange complex because of the extremely low colloidal content of this soil. In other words, normal applications of sodium nitrate did not influence under field conditions the physical properties of a sandy soil to an appreciable degree. Furthermore, sodium nitrate at the rate of 150 pounds per acre annually for the past 21 years on a sandy loam soil has caused no apparent changes in the physical properties of the soil. Miller of the Missouri Agricultural Experiment Station (11) reports that an application of 495 pounds of sodium nitrate annually for the past forty-three years has caused no apparent injury to the physical properties of a Putnam silt loam soil.

From a practical standpoint, nitrogenous fertilizers did not influence the physical properties of the soils studied to an appreciable extent. Under field conditions and on average soils of the Southeast, normal applications of sodium nitrate should not cause a perceptible change in the physical condition of the soil.

METHODS OF CORRECTING THE ACIDITY DEVELOPED FROM PHYSIOLOGICALLY ACID FERTILIZERS

It has been shown that in addition to ammonium sulfate several of the new nitrogenous fertilizers cause soil acidity. One of the well recognized factors in soil fertility is the reaction or acidity of the soil. If acid-forming nitrogenous fertilizers are used on the same soil for a considerable period of time, it is a well established fact that acidity will develop to an extent which will be injurious to crop production unless the acidity is corrected in some manner. In fact, the soil will not produce a satisfactory crop after a period of years. This period will depend on the kind of soil, the amount of acid-forming material applied, the climatic conditions, and the kinds of crops grown. Some crops grow satisfactorily on very acid soils but most of the economic crops grow best on soils that are only slightly acid. The influence of soil acidity on crop production is considered to be due primarily to a deficiency of bases rather than to a direct injurious effect of the acidity. Soils having a reaction of from pH 6.0 to 7.0 are considered slightly acid. Those with a reaction of from pH 5.0 to 6.0 are strong to medium in acidity. When the reaction is below pH 5.0, the soil is considered very acid and natural soils are seldom found having a reaction below pH 4.4.

Since the acid-forming fertilizers are being used in greater amounts, it is important that the acid condition developed therefrom be corrected before injurious effects occur. This is of paramount importance in the southeastern states where the soils are already acid and are extremely low in calcium and other bases. In considering methods for neutralizing the acidity produced by acid-forming fertilizers, three have been studied (18): combinations of physiologically basic and acid-forming fertilizers, the use of basic slag, and the use of calcium carbonate. These methods are discussed below.

Combinations of Physiologically Basic and Physiologically Acidic Nitrogenous Fertilizers

It has been shown that sodium nitrate, calcium nitrate, and calcium cyanamid decrease the acidity of the soil, whereas ammonium sulfate, ammonium phosphate, Leunasalpeter, urea, and ammonium nitrate cause an increase in soil acidity. The extent to which these materials increase or decrease the exchangeable hydrogen of a Cecil clay loam was studied (17). From those data Pierre (18) calculated the proportions of various acid-forming and physiologically basic fertilizers which when used in combination should not change the reaction of the soil. The results are presented in Table 20. It may be observed that, according to the exchangeable hydrogen data, a combination in which 70 per cent of the nitrogen is in the form of sodium

TABLE 20.—Proportions of Various Physiologically Basic and Acid-Forming Nitrogenous Fertilizers Required to Maintain a Soil at its Original Reaction.[1]

Combination	Physiologically basic fertilizers		Acid-forming fertilizers	
	Kind	Amount	Kind	Amount
		percent		percent
1	Sodium nitrate	70	Ammonium sulfate	30
2	Sodium nitrate	54	Urea	46
3	Sodium nitrate	64	Leunasalpeter	36
4	Calcium cyanamid	65	Ammonium sulfate	35
5	Calcium cyanamid	52	Urea	48
6	Calcium cyanamid	58	Leunasalpeter	42

[1]Data from Pierre (18).

nitrate and 30 per cent in the form of ammonium sulfate can be used without affecting the reaction of the soil. If urea or Leunasalpeter is used only 54 and 64 per cent of the nitrogen, respectively, needs to be in the form of sodium nitrate. Since calcium nitrate has about the same action as sodium nitrate, it could be substituted for the latter. Similarly, in all these combinations ammonium nitrate could be substituted for urea and ammonium phosphate for ammonium sulfate in the same relative amounts. The use of calcium cyanamid results in a greater decrease in soil acidity than the use of sodium nitrate; it can, therefore, be used in combination with the various acid-forming fertilizers in slightly lower proportions than can sodium or calcium nitrate.

In order to test the validity of the calculated values for sodium nitrate-ammonium sulfate combination given above, the following experiment was conducted (18). Various combinations of sodium nitrate and ammonium sulfate were added to a Cecil clay loam and Norfolk sandy loam in greenhouse pots; these soils were cropped. After the removal of the second and fourth crops, samples were obtained from the pots for acidity studies. In the case of the Cecil clay loam the results show that the combination in which 80 per cent of the nitrogen was added as sodium nitrate and 20 per cent as ammonium sulfate decreased the H-ion concentration and exchangeable hydrogen of the soil. When the proportion of nitrogen was changed to 60 and 40 per cent as sodium nitrate and ammonium sulfate, respectively, the H-ion concentration and exchangeable hydrogen of the soil were increased. Thus, it is evident from these data that approximately 70 to 75 per cent of the nitrogen of a sodium nitrate-ammonium sulfate combination should be added as sodium nitrate if the acidity of soil is not changed. Similar results were obtained with the Norfolk sandy loam. The calculated ratios given in Table 20 for the various other combinations of physiologically basic and acid-forming fertilizers are approximately correct.

It is not necessary nor desirable that the nitrogen combinations mentioned in the preceding paragraphs be mixed before applying them to the soil. For example, calcium cyanamid should not be mixed with ammonium sulfate and only limited amounts of it should be used in mixtures containing superphosphate. In such cases, this difficulty may be overcome by applying one of the nitrogenous materials before planting the crop and the other as a "side dressing".

From a practical standpoint, it is apparent that the cost per unit of nitrogen in the physiologically basic fertilizers cannot be very much higher than that in the acid-forming fertilizers if the method of correcting the acidity indicated above is to be recommended. Ordinarily the use of limestone to counteract the acid condition will be much cheaper. This method will be discussed later.

The Use of Basic Slag

Basic slag is a source of phosphorus known to decrease soil acidity. Under field conditions a phosphatic fertilizer is frequently used along with a nitrogenous fertilizer. It is obvious that if ammonium sulfate or another acidic nitrogenous fertilizer is used on land which has received a sufficient quantity of basic slag the soil could be maintained at its original reaction. The value of basic slag in correcting the acidity developed by the use of ammonium sulfate was studied in detail (18). A brief account of this work is reported below.

A Cecil clay loam and a Norfolk sandy loam soil were fertilized with various proportions of ammonium sulfate and basic slag. The basic slag used was a 100-mesh material which contained 18 per cent of phosphoric acid. Determinations of H-ion concentration and exchangeable hydrogen were made as in previous experiments. Two pounds of basic slag per pound of ammonium sulfate were required to maintain both of the soils at their original reaction. The original H-ion concentration and exchangeable hydrogen of the Cecil soil were pH 6.03 and 3.75 m.e. per 100 grams, respectively; after the addition of one part of ammonium sulfate and two parts of basic slag, this soil had a pH value of 6.05 and 3.70 m.e. of hydrogen per 100 grams of soil. The H-ion concentration of the Norfolk soil was not changed by the above treatment. This represents a ratio in which the phosphoric acid present in basic slag is lower in proportion to the nitrogen used than is usually applied in fertilizer practice on many soils. At present, most of the basic slag on the market contains approximately 9 per cent of phosphoric acid; therefore, if a sufficient quantity is used to supply the phosphoric acid for crops, this amount would be more than sufficient to correct the acid which would be developed by a normal application of any acid-forming fertilizer now on the market.

For crops in which basic slag is equal to superphosphate as a source of phosphorus, it may be used on the same soil to correct the acidity developed by acidic nitrogenous fertilizers. Its inefficiency as a source of phosphorus for cotton has been discussed. Basic slag applied for fall crops will tend to neutralize the acidity which may be present or which may develop later. This material is about 60 per cent as efficient as pure calcium carbonate in neutralizing the acid in the soil.

The Use of Limestone

Amount Required

If the total potential acidity is developed by one pound of ammonium sulfate, it should take, theoretically, 1.5 pounds of calcium carbonate to neutralize this acidity. A review of several investigations regarding the amounts of lime required to correct the acidity developed from a given amount of ammonium sulfate has been reported (18). These amounts varied from 1.2 to 1.67 pounds of calcium carbonate per pound of ammonium sulfate. In order to study this question more carefully and under better controlled conditions, Pierre (18) conducted at this station the investigation herein described.

Ammonium sulfate was used as the source of nitrogen. Lime, in the form of precipitated calcium carbonate, was added in various amounts to different pots of Cecil clay loam and Norfolk sandy loam. The treatments and results are presented in Table 21. It may be noticed that with both soils about 1.2 pounds of calcium carbonate were necessary per pound of ammonium sulfate to maintain the soil at its original pH value. The determinations of exchangeable hydrogen show the same result, as may be seen in columns three and four of the table. Similar

TABLE 21.—The H-ion Concentration and Exchangeable Hydrogen of Soils to which have been added Ammonium Sulfate and Various Amounts of Calcium Carbonate.[1]

Ratio between amounts of $(NH_4)_2SO_4$ and $CaCO_3$ applied	Cecil clay loam			Norfolk sandy loam
	H-ion concentration	Exchangeable hydrogen	Lime necessary to neutralize acidity due to 1 pound of $(NH_4)_2SO_4$[2]	H-ion concentration
	pH	mgm. equiv.	lbs.	pH
No treatment	6.03	3.75	—	5.35
1 to 0.0	4.80	6.45	—	4.43
1 to 0.5	5.15	5.35	1.2	5.03
1 to 1.0	5.83	4.20	1.2	5.23
1 to 1.5	6.40	2.65	1.1	5.50
1 to 2.0	6.90	1.40	1.1	6.00

[1]Data from Pierre (18).
[2]Calculated from data in preceding column.

experiments were conducted on five other soils which likewise gave values between 1.2 and 1.3 pounds. Later, White (23) studied soil samples from the Jordan Fertility Plots and reported that approximately 0.757 pounds of calcium carbonate were required to neutralize the acidity developed from one pound of ammonium sulfate. In his work, White considered only the surface soil to a depth of seven inches. There is no valid reason to believe that the acidity, from the ammonium sulfate applications on the Jordan Fertility Plots, has not penetrated the soil to a greater depth than seven inches. This may account for the discrepancy between the results of Pierre and those of White.

In order to determine the amounts of lime necessary to correct the acidity developed by the other acid-forming fertilizers, experiments were conducted using Cecil clay loam soil (18). Duplicate pots of this soil had been fertilized with equivalent amounts of the various acid-forming nitrogenous fertilizers. After the removal of the fourth crop, the soils from the duplicate pots were thoroughly mixed. Four separate 2,500 gram samples of the soil from each treatment were then placed in one-gallon pots. In each case one of the one-gallon pots was left unlimed, whereas the others were limed at various rates with precipitated calcium carbonate. The pots were watered with rain water from time to time and allowed to remain in the greenhouse uncropped. After four months the soil from each pot was thoroughly mixed and sampled for pH determinations. The amounts of lime added to each series were plotted against the pH values obtained and the amounts of lime necessary to bring the soil of each series back to its original H-ion concentration were interpolated. The relative amounts of lime necessary to bring the soils of each series back to their original reaction were then calculated. It was found that if the value for ammonium sulfate is taken as 100 the relative values for ammonium phosphate, Leunasalpeter, urea, and ammonium nitrate were 83, 77, 51, and 47, respectively. Thus, whereas one pound of ammonium sulfate required 1.2 pounds of calcium carbonate to neutralize its acidity, the same amount of nitrogen from the other acid-forming nitrogenous fertilizers required approximately the following amounts: ammonium phosphate, 1.0 pound; Leunasalpeter, 0.9 pound; ammonium nitrate and urea, 0.6 pound. If dolomitic limestone should be used, approximately 92 per cent of the amounts given above would be required.

Time and Method of Application

It is apparent that lime should be applied before the acidity has developed to an injurious extent. The method of application will depend to some degree on the form of lime which is to be used. Under ordinary conditions limestone (calcium carbonate) or dolomite (calcium and magnesium carbonates) will be used because of the relative costs as compared to other forms of lime. Either of these limestones may be mixed with the fertilizer by the dealer or the farmer or preferably broadcast on the land without mixing. If limestone is mixed with the fertilizer at the mixing plant it is evident that this method will be more expensive. In addtion to the dealer's cost and profit on the limestone, a charge must be made for the mixing process and the freight charges will be higher on the limestone when it is mixed with the fertilizer materials. Furthermore, this procedure will greatly reduce the analysis of the fertilizer mixture if sufficient limestone is included to neutralize the potential acidity from the average acid-forming fertilizer. The disadvantages of this method are obvious, although it is more desirable than the use of the acid-forming materials without limestone applications.

It may be more feasible for the farmer to purchase the acid-forming nitrogenous fertilizers and limestone separately and mix them on the farm. In this way the limestone will be cheaper than when mixed with the fertilizer at the factory. In either case, it will be necessary to apply limestone every year if an acidic fertilizer and the theoretical amount of limestone are used.

Sufficient limestone may be used in one application to neutralize the acidity which will be developed over a period of five to ten years. In this case it should be broadcast and thoroughly mixed with the soil. This method of application is probably the most practical one even though more limestone may be required due to excessive leaching of the calcium. However, the annual cost of limestone is low and a moderate application will take care of the acidity developed from the acidic fertilizers for several years. For example, 2.65 tons of limestone per acre were applied to a Cecil sandy loam, at Auburn, fourteen years ago and excellent benefits are being obtained at present.

DISCUSSION

It is evident from the studies presented that different nitrogenous fertilizers vary as to their efficiency for crop production. The relative values of these materials when used for a short time may be quite different from their values when used over a longer period. Physiologically acid nitrogenous fertilizers on unlimed acid soils may be quite satisfactory if used for a short time, but they may be very inefficient on these soils if used for a longer time. It was found that under field conditions several of these materials on limed soils were just as efficient as the non-acid-forming fertilizers. Other things being equal, the efficiency of the acidic materials without lime will decrease with time and if used for a sufficient length of time they will cause practically a barren soil. It is absolutely essential from an economical standpoint to supply the necessary limestone before the decline in yields begins.

Many factors are involved in determining the relative values of different sources of nitrogenous fertilizers. So many variables affect their efficiency that it is impossible to give a product a rating that will apply under all conditions. The influence of the various nitrogenous fertilizers on soil acidity is one of the most important factors to be considered in the South; the reduced yields from the continuous use of acid-forming fertilizers are caused by an increase in soil acidity and a decrease in exchangeable bases, particularly calcium. The buffer capacity of the soil which is determined by the colloidal and exchangeable base contents and the amount of fertilizer applied will determine the rate at which the acidity is increased. Most of the soils growing cotton in the southeastern states are sandy and poorly buffered. Only a few years of fertilization with acid-forming fertilizers, without the use of lime, will result in serious injury to plant growth. Any fertilizer containing ammonium-nitrogen or those like urea which form ammonium compounds upon decomposition are acid-forming fertilizers. An application of limestone is the most practical method of correcting the acid condition of the soil and supplying calcium. In comparing the cost of various acid-forming and non-acid-forming fertilizers, the cost of the limestone required as a supplement to the acid-forming materials should be considered.

At present, liming is not a common farm practice in the southeastern states. For example, in 1929 Alabama used 32,534 tons of nitrogen and approximately 8,000 tons of limestone. If all of this nitrogen had been in the form of ammonium sulfate, 195,204 tons of limestone would have been required to correct the acidity. This does not take into consideration the enormous amount of limestone required to replace that which is lost through leaching or crop removal. More lime must be used if the acidic fertilizers are to produce satisfactory crops in the future. These fertilizers will undoubtedly be largely used because of their lower price as compared to that of the standard non-acidic nitrogenous fertilizers.

SUMMARY

This bulletin records the results of studies obtained on the relative value of different sources of nitrogen, factors that determine the relative value of different nitrogenous fertilizers, and methods of correcting the acidity developed in soils from the use of physiologically acid fertilizers. The results may be briefly summarized as follows:

(1) Sodium nitrate produced more cotton for a five-year period than any other source of nitrogen used on Clarkesville, Decatur, Holston, Oktibbeha, and Norfolk soils, whereas ammonium sulfate was about as effective on Hartselle, Cecil, and Greenville soils.

(2) The average relative efficiency of the different sources of nitrogen studied including the 222 tests on the soils mentioned above was as follows: sodium nitrate, 100; ammonium sulfate, 89; urea, 86; a combination of Ammo-Phos A and sodium nitrate, 82; Leunasalpeter, 82; and cottonseed meal, 57.

(3) In 222 tests, during a five-year period, ammonium sulfate produced an average of 36 pounds of seed cotton per acre less than sodium nitrate when superphosphate was used; when basic slag was used as the source of phosphorus with the ammonium sulfate the increase was 98 pounds less than the sodium nitrate-superphosphate combination.

(4) The continued use of acid-forming nitrogenous fertilizers on unlimed land caused a reduced crop yield due to the development of soil acidity and a reduction in the amount of soil bases.

(5) The acidic nitrogenous fertilizers without lime were less efficient for cotton on Norfolk sandy loam than sodium nitrate, whereas on a Cecil clay loam all of the acid-forming fertilizers except Ammo-Phos A were about as efficient as sodium nitrate.

(6) All of the acid-forming fertilizers, except Leunasalpeter, on limed Norfolk sandy loam produced more cotton than sodium nitrate produced.

(7) In sandy soils, the acidic fertilizers decreased the amount of exchangeable calcium and increased the amount of exchangeable hydrogen to an extent which was injurious to plant growth.

(8) The extent to which acid-forming fertilizers will increase soil acidity depends upon the kind and nature of the soil and the chemical composition of the fertilizer. The relative values are: ammonium sulfate, 100; ammonium phosphate, 100; Leunasalpeter, 75; urea, 50; and ammonium nitrate, 50.

(9) Acidic nitrogenous fertilizers, when used on the same soil for a considerable period of years, caused a marked decrease in phosphate availability. They caused an increase in water-soluble potassium.

(10) Physiologically basic fertilizers caused an increase in phosphate availability and a reduction in the water-soluble potassium.

(11) Nitrogen applied in sodium nitrate was leached from a sandy and from a clay soil to a much greater extent than nitrogen applied in ammonium sulfate.

(12) Ammonium-nitrogen was absorbed by cotton seedlings more rapidly than nitrate-nitrogen.

(13) Under field conditions, the physical properties of the sandy loam soils were not affected to an appreciable extent by any of the sources of nitrogen.

(14) An increased soil acidity may be prevented by the use of a combination in which about 70 per cent of the nitrogen is in

the form of sodium or calcium nitrate and about 30 per cent in the form of ammonium sulfate or ammonium phosphate. Other combinations may be calculated from the data presented.

(15) Soil acidity developed by acid-forming nitrogenous fertilizers may be corrected by applications of sufficient quantities of basic slag.

(16) This acidity may also be corrected by certain quantities of limestone or dolomite mixed with the fertilizers or applied to the soil in the drill or broadcast.

(17) With the continued use of acid-forming fertilizers, applications of some form of lime will be essential to maintain crop yields.

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APPENDIX

The Chemical Composition of Various Nitrogenous Fertilizers and Their Influence on Soil Reaction.

Materials	Per cent[1]			Acidity or alkalinity[2]	Form of nitrogen
	Nitrogen	Ammonia equivalent	Phosphoric acid		
Ammonium chloride	26	31.5	0	Acid	Ammonium
Ammonium nitrate	35	42.5	0	Acid	½ Ammonium ½ Nitrate
Ammo-Phos A	11	13.3	46	Acid	Ammonium
Ammo-Phos B	16	20.0	20	Acid	Ammonium
Ammonium sulfate	21	25.5	0	Acid	Ammonium
Ammoniated superphosphate	2-4	2.4-4.8	19	Acid	Ammonium
Animal tankage	6	7.3	9-20	Acid	Protein
Calcium nitrate	17	20.6	0	Alkaline	Nitrate
Calnitro	16	19.5	0	Alkaline	½ Ammonium ½ Nitrate
Calurea	34	41.3	0	Acid	1/5 Nitrate 4/5 Amide
Cottonseed meal[3]	6	7.3	2-3	Acid	Protein
Cyanamid	21	25.5	0	Acid	Cyanamide
Di-ammonium phosphate	20	24.3	53	Acid	Ammonium
Dried blood[4]	10	12.1	0.5-1.5	Acid	Protein
Leunasalpeter	26	31.5	0	Acid	¾ Ammonium ¼ Nitrate
Mono-ammonium phosphate	11	13.3	60	Acid	Ammonium
Nitrate of soda-potash	14	17.0	0	Alkaline	Nitrate
Potassium nitrate[5]	12	14.5	0	Alkaline	Nitrate
Sodium nitrate	15	18.2	0	Alkaline	Nitrate
Urea	46	55.8	0	Acid	Amide

[1]Minimum percentages. [2]Effect on soil. The following contain potash—approximate percentages: [3]1.5-2.0, [4]0.6-0.8, [5]44.

ERRATUM

Alabama Agricultural Experiment Station Bulletin 238, page 60, column 5 should read alkaline instead of acid for Cyanamid.