UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1180

Washington, D. C. ▼ January 22, 1924

FIELD EXPERIMENTS WITH ATMOSPHERIC-NITROGEN FERTILIZERS

By

F. E. ALLISON and J. M. BRAHAM, of the Fixed-Nitrogen Research Laboratory, and J. E. McMURTREY, Jr., of the Bureau of Plant Industry

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1180

Washington, D. C. ▼ January 22, 1924

FIELD EXPERIMENTS WITH ATMOSPHERIC-NITROGEN FERTILIZERS.[1]

By F. E. Allison and J. M. Braham, *of the Fixed-Nitrogen Research Laboratory*, and J. E. McMurtrey, jr., *of the Bureau of Plant Industry*.

CONTENTS.

INTRODUCTION.

Nitrogen compounds made from the air are rapidly becoming important in meeting the world's constantly increasing demand for nitrogen fertilizers. A number of European countries are already manufacturing sufficient atmospheric-nitrogen fertilizer to meet the larger part of their requirements. The United States has made a beginning in this direction but still depends almost wholly for her nitrogen upon the natural sodium-nitrate deposits of Chile, the ammonium sulphate obtained from by-product coke ovens, and the various organic sources, such as slaughterhouse wastes, cottonseed meal, and fish scrap. A small quantity of cyanamid,[2] imported from Canada, is also used.

Interest in the production of synthetic nitrogen compounds in the United States was greatly stimulated during the World War in connection with the production of explosives. Nitrogen-fixation activi-

[1] The experimental work described in this bulletin was carried out by the Nitrate Division of the Ordnance Office, United States Department of War, working in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The work during the first year was under the direct supervision of the bureau mentioned. During the two following years the work was conducted by the Fixed-Nitrogen Research Laboratory, which was a part of the Nitrate Division until its transfer to the Department of Agriculture on July 1, 1921. The writers are indebted to Drs. Karl F. Kellerman, W. W. Garner, Oswald Schreiner, and J. J. Skinner, of the Bureau of Plant Industry, for many valuable suggestions in planning this investigation and to members of the staff of the Nitrate Division, particularly Lieut. Cols. J. K. Clement and Hardee Chambliss, for assistance in carrying out these experiments. The Office of Soil-Fertility Investigations, Bureau of Plant Industry, is conducting field experiments with most of the nitrogen materials mentioned in this bulletin. These experiments have been in progress in several States for a number of years, and the results are to appear in a later publication.

[2] Crude calcium cyanamid treated with a small quantity of water and of oil.

52765°—24—Bull. 1180——1

ties during that period were largely limited to the Government, and as a part of the program for providing an adequate supply of explosives the War Department constructed two nitrogen-fixation plants at Muscle Shoals and Sheffield, Ala., in 1917 and 1918. While these plants were constructed for the immediate purpose of furnishing explosives it was expected that they would be utilized for the production of nitrogen fertilizer in peace times. Although not operating, they represent a potential source of about 48,000 tons of fixed nitrogen per annum. This quantity of nitrogen is equivalent to about 240,000 tons of ammonium sulphate or 308,000 tons of sodium nitrate and is approximately equal to 30 per cent of the nitrogen consumed as fertilizer in this country in 1919. These plants were designed to produce ammonium nitrate for high explosives as their final product, with calcium cyanamid, ammonia, and nitric acid as intermediate products.

At the close of the war the problem of utilizing these nitrogen-fixation plants for the production of nitrogen fertilizer arose, and this immediately raised the question of the fertilizing value of the products which might be made there. The direct product of the larger and more important of the two plants is calcium cyanamid, from which ammonia can be readily obtained, and this, in turn, can be oxidized to form nitric acid. This one plant, therefore, provides a source of cyanamid nitrogen, ammonia nitrogen, and nitrate nitrogen, representing all the forms of fixed nitrogen obtainable by the present fixation processes, and hence the problem of its agricultural utilization involves a consideration of the fertilizing value of cyanamid and various ammonium and nitrate compounds. Considerable investigational work, particularly on cyanamid, has been reported by a number of European experiment stations, but with the exception of cyanamid these new materials have been studied very little under American conditions. It was to obtain information concerning their fertilizing value that the field experiments described in this bulletin were made.

The experiments were begun in the spring of 1919 by the Nitrate Division of the Ordnance Office, United States Department of War, in which the Government's fixed-nitrogen activities were then centered, working in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The work was conducted on the reservations at the two nitrate plants, where the necessary land, labor, and equipment were available, and covered a period of three years, at the end of which time it was discontinued. During the first summer the experiments dealt wholly with cyanamid and ammonium nitrate, but the following two years the scope of the work was enlarged to include a number of other synthetic-nitrogen products which appeared to have fertilizer possibilities.

FERTILIZERS USED.

Experiments were made with the following nitrogen materials: Cyanamid, ammonium nitrate, ammonium phosphate, ammoniated superphosphate, ammonium chlorid, a double salt consisting of ammonium nitrate and ammonium sulphate, a mixed salt obtained from ammonium nitrate and potassium chlorid, a mixed salt obtained from ammonium nitrate and potassium sulphate, urea, and Urephos. Sodium nitrate and ammonium sulphate, the present standard inorganic-nitrogen fertilizer materials, were used as reference substances. In connection with the experiments on cyanamid a few tests were made with calcium nitrate alone and in admixture with cyanamid and also tests on calcined phosphate and basic slag as sources of phosphorus.

The composition of the fertilizer materials used, although varying slightly from year to year, is quite accurately expressed in Table 1. Some of the more important features of these materials which have a bearing on their utility as fertilizers, particularly from the standpoint of production, are briefly discussed in the following pages.

TABLE 1.—*Composition of fertilizers used.*

Fertilizer.	Composition (per cent).		
	NH_3.	P_2O_5.	K_2O.
Cyanamid (hydrated and oiled)	22.5		
Ammonium nitrate (grained)	41.2		
Ammonium chlorid	31.0		
Ammonium sulphate	25.3		
Ammonium phosphate (mainly $NH_4H_2PO_4$)	13.9	47.0	
Ammoniated superphosphate	5.4	[1] 13.5	
Urea	55.5		
Urephos	7.0	[2] 4.45	
Calcium nitrate (grained and coated)	14.9		
Sodium nitrate	18.6		
Double salt ($2NH_4NO_3$. $(NH_4)_2SO_4$)	32.5		
Mixed salt (from NH_4NO_3 and KCl)	16.5		30.2
Mixed salt (from $2NH_4NO_3$ and K_2SO_4)	19.0		25.0
Calcined phosphate, sample No. 1		[3] 27.0	
Calcined phosphate, sample No. 2		[4] 11.7	
Basic slag		[1] 16.0	
Acid phosphate		16.0	
Potassium sulphate			50.0

[1] Solubility in 2 per cent citric acid instead of standard ammonium citrate solution.
[2] Total P_2O_5 8.1 per cent. [3] Total P_2O_5 31.0 per cent. [4] Total P_2O_5 28.7 per cent.

Cyanamid is a very important form of fixed nitrogen and is manufactured in large quantities, the estimated capacity of the Muscle Shoals plant, for example, being 245,000 tons per annum. Since it is the direct product of the cyanamid process of nitrogen fixation, it represents a cheaper form of nitrogen than any of its transformation products, such as ammonium salts, and hence it is important to determine its fertilizing value. Owing to its chemical nature it can not safely be used in large quantities in mixed fertilizers containing acid phosphate, and therefore some of the experiments were made using mixtures of it with calcined phosphate and basic slag as well as with acid phosphate. Since cyanamid nitrifies rather slowly, tests were also made in which readily available nitrogen in the form of calcium nitrate was used with it.

Ammonium nitrate is one of the most important synthetic-nitrogen compounds. It can be produced by a number of methods, and although a somewhat more expensive form of nitrogen than cyanamid its manufacture was so highly developed during the war that it is now available in large quantities at a price only slightly above that of ammonium sulphate on the basis of contained nitrogen. It has the advantage over many fertilizer materials in that it contains both ammonia and nitrate nitrogen and does not leave a residue in the soil. It has the disadvantage, however, that it tends to become moist under ordinary conditions of storage and handling to a somewhat greater extent than sodium nitrate. This difficulty has been partially overcome by forming the ammonium nitrate into small grains and coating them with an oil to lessen the absorption of moisture. This treatment is comparatively inexpensive.

Among other methods which have been attempted to overcome this handicap of moisture absorption are the production of double and mixed salts which are less hygroscopic than ammonium nitrate alone, and in the present experiments tests were made with such salts as well as with ammonium nitrate. These materials include a double salt consisting of ammonium nitrate and ammonium sulphate and two mixed salts made by the double decomposition of ammonium nitrate with potassium chlorid or with potassium sulphate. The products obtained from potassium chlorid and ammonium nitrate are ammonium chlorid and potassium nitrate, while with potassium sulphate they are ammonium sulphate and potassium nitrate. The processes of manufacture of these double and mixed salts are comparatively simple and inexpensive. However, the necessity of using higher grade potash salts than are normally available (particularly the chlorid) in order to obtain sufficiently nonhygroscopic mixed salts may constitute a rather serious obstacle to their economical production. They have been prepared only on an experimental scale in this country.

Ammonium phosphate will in all probability become an important fertilizer salt within the next decade. It is especially desirable because of its excellent physical properties and high concentration of plant food, containing as it does both nitrogen and phosphorus. It has been manufactured in this country to a limited extent as a fertilizer material, but its commercially successful production is largely dependent on the development of a process for cheaply producing phosphoric acid. Important advances are now being made in this country in the production of phosphoric acid directly from phosphate rock by thermal or electrothermal processes.

Ammoniated superphosphate is obtained by absorbing ammonia in acid phosphate, thus providing a carrier for ammonia without the use of additional acid. The product is of excellent physical quality but has the disadvantage that a part of the phosphate is reverted to the citrate insoluble form. It has been produced only on an experimental scale in the United States.

Ammonium chlorid has not heretofore been regarded as a fertilizer. There is a possibility, however, that it may soon become available for such purpose as a product of the ammonia-soda process combined with the direct synthetic-ammonia process of nitrogen fixation, and hence the value of this material as a fertilizer is of considerable interest.

Urea possesses unusually desirable properties as a fertilizer. It is a highly concentrated nitrogen compound, readily available, possesses good physical qualities, and when used by the plant leaves no undesirable acidic or basic residue in the soil. While at present the cost of manufacture for fertilizer use is prohibitive it seems probable that this obstacle may soon be overcome.

Urephos is the product obtained by treating cyanamid with an excess of sulphuric acid and neutralizing the latter with ground phosphate rock for the purpose of rendering cyanamid more generally suitable for use in mixed fertilizers. The material, which has been made only on an experimental scale, contains about 5.8 per cent nitrogen, approximately 65 per cent of which is present as urea and ammonium sulphate, 30 per cent as guanylurea sulphate, and 5 per cent in undetermined forms. Nearly one-half of the phosphorus is insoluble in standard ammonium-citrate solution.

Calcined phosphate is the product obtained by heating a mixture of phosphate rock, carbonaceous material, and an alkali salt, such as salt cake or niter cake, in a rotary kiln. A high percentage of the phosphorus can be obtained in ammonium-citrate soluble form in this manner. Unlike acid phosphate, this material can be mixed with cyanamid in any proportion without producing deleterious changes. The new material has not as yet come on the market.

SOILS AND CROPS.

In choosing the areas to be used for experimental purposes the necessity of limiting selections to the two Government reservations at Muscle Shoals, Ala., comprising about 1,000 acres, proved a handicap. This soil is for the most part poor and is rather hilly and irregular. The most suitable areas from the standpoint of topography and also uniformity were naturally the most fertile and less adapted to fertilizer experiments. This irregularity naturally minimized the value of the results to a certain extent, but nevertheless the responses to fertilizer applications were usually sufficiently striking to leave no doubt as to their value. In this connection it is important to emphasize the value of the observations made during growth. The effects of a given treatment on germination and early and late growth were nearly always quite striking regardless of natural fertility and gave a better picture in many instances of the real merits of the material than did the yields.

The total area used for experimental purposes was approximately 10 acres the first year and 20 acres the following two years. All the work was done on areas of about 5 acres each. Three soil types, namely, Clarksville, Colbert, and Decatur loams, were represented. These were not widely different either in chemical or physical nature, all being poor in nitrogen and phosphorus except in the lower areas, which had benefited by leachings from higher levels.

The lay-out of the plats on the various experimental fields is shown in the diagrams (see figs. 1 to 4). The size of the plats varied from one-fortieth to one-twentieth of an acre.

A variety of crops was grown the first year, primarily to determine the responses from treatments of cyanamid and ammonium nitrate. These included several vegetables, tobacco, grasses, small grains, forage crops, cotton, and corn. The experiments of the last two seasons were confined to cotton and corn, the crops which, together with tobacco, receive the bulk of the fertilizer used in the South.

METHODS USED IN EXPERIMENTS.

The fertilizer mixtures used were of such a variable nature that reference must be made to the tables given later to determine the particular combinations tested. In these tables the term fertilizer ratio refers to pounds of N, P_2O_5, and K_2O in the 1919 results and to pounds of NH_3, P_2O_5, and K_2O for the results of 1920 and 1921. All mixtures were prepared the first year at the plats and used within 10 days, but the following two years the preliminary work was done at the Washington laboratory and the mixture shipped to Muscle Shoals. In the latter case from three to eight weeks elapsed from the time of mixing until the time of application.

The methods used in preparing the soil, application of fertilizers, seeding, and cultivation were essentially the same as those followed by the farmers of the community. With the exception of one experiment, where side applications were made, the fertilizers for cotton and corn were applied in the row just prior to seeding. The materials were in close proximity to the seed but never in direct contact. Both corn and cotton were planted in rows 4 feet apart with three rows per plat. The corn was thinned to 30 to 36 inches in the row and the cotton to 15 to 24 inches. Harvesting was done in the usual manner, the cotton being weighed when picked, while the corn was allowed to dry in the shock for four to eight weeks before husking and weighing.

The methods of fertilizing, seeding, and harvesting the winter grains are considered in connection with the discussion of those experiments.

OBSERVATIONS DURING GROWTH.

The effects of the different fertilizer mixtures on plant growth under the various conditions were intimately related to the weather conditions prevailing, particularly the rainfall. A severe drought subsequent to planting sometimes resulted in marked injuries due to the high concentration of soluble salts. A drought at the time of maturity often decreased the grain yields, resulting in a yield of stalks considerably out of proportion to the grain production. The rainfall records of the United States Weather Bureau at Florence, Ala., located at a distance of 3 to 6 miles from the experimental fields, are shown in Table 2.

TABLE 2.—*Rainfall at Florence, Ala., during the 8-year period from 1914 to 1921, inclusive.*

Month.	Rainfall records (inches).			
	Average, 1914 to 1918.	1919	1920	1921
January to April	17.37	23.70	30.41	20.73
May	3.56	6.96	5.70	1.14
June	3.60	2.72	6.10	4.26
July	5.90	1.54	3.32	6.74
August	3.87	5.24	9.93	3.78
September to December	14.67	22.08	12.93	14.42
Total	48.97	62.24	68.39	51.07

It will be noted from these figures that the total rainfall for the three experimental years, 1919 to 1921, was higher in every case than the average for the five preceding years. The total of 68.39 inches for 1920 was higher than for several years previous. However, these total figures are of much less significance than the rainfall of the growing season. The year 1919 was quite wet during the early spring and dry during the growing period, with adequate rainfall during the period of approaching maturity. The following year was exceedingly wet during the spring and also during August, but a drought during July was very detrimental to the early corn. The 1921 season was exceedingly dry the first half of the growing period, beginning at the time of planting, but moisture conditions were good later. The records scarcely give a true picture of the extremely dry conditions during May and June, since several local showers which fell at Florence did not touch the experimental fields.

CYANAMID.

The germination of cotton and corn was not appreciably affected under any conditions by applications of cyanamid at not to exceed the equivalent of 40 pounds of ammonia per acre. With double this quantity there was a distinct retarding, and in instances where the moisture was deficient the germination was slightly below normal and many of the plants died soon after appearing above the surface. Under similar conditions ammonium sulphate and sodium nitrate also produced bad effects, but to a lesser extent.

The early growth with cyanamid was decidedly different from that with any of the other materials used. For about one or two weeks in the case of corn and three to five weeks with cotton the plants were retarded and usually made no better growth than on the check plats receiving no nitrogen. The larger the application the greater the amount of retardation. With both crops, especially cotton, the plants became an unusually dark green, the color persisting until maturity. During the first and third years, when moisture was deficient, cyanamid at the larger rates of application produced a marked burning of the leaves. Where side applications were made, a similar burning was observed after these late applications but disappeared shortly after rain fell.

The later growth of corn showed a rapid recovery from any initial injuries, and usually there was no appreciable difference between the cyanamid, ammonium-sulphate, and sodium-nitrate plats. With cotton the results were frequently very strikingly different. For instance, during the season of 1919 when cyanamid was used in mixture with acid phosphate, approximately two months were required for any increase in growth even with the smallest application. The characteristic dark-green color was early in evidence. The first plants to show increased growth were those receiving the smallest applications of nitrogen. This peculiar behavior was undoubtedly due to the high content of dicyanodiamid which formed from the cyanamid in the presence of acid phosphate. During the season of 1920 and 1921 where the cyanamid was either mixed with basic phosphates or applied separately with acid phosphate the observations were quite different, as shown by Plate I, Figures 1 and 2. There was always a retarding period of two to four weeks, which was nearly always overcome. However, the material was not as satisfactory a nitrogen carrier for cotton as either sodium nitrate or ammonium sulphate.

The time of maturity of corn was not appreciably affected by the various cyanamid treatments. With cotton, however, the early retarding effects were never entirely overcome, and as a result the plants usually did not grow quite as large or the bolls mature as quickly as with sodium nitrate. The difference usually amounted to two or three weeks and played an exceedingly important part in the final yields for two main reasons: (1) The damage by boll weevils, which are always present in the largest numbers late in the season, was greatly increased; (2) cotton requires warm weather and a long growing season, and the delay in the growth in many instances resulted in the plants being killed by frosts before the growth was completed. This was especially important in these experimental results, due to the fact that Muscle Shoals is located within about 75 miles of the northern limit of the Cotton Belt.

The effect of cyanamid on the growth of wheat, rye, oats, and grass was not appreciably different from the responses with sodium nitrate and ammonium sulphate. Where all of the cyanamid was applied in the fall, there was sufficient time for the nitrogen to become available before being used by the plants the following spring. Consequently the resulting growth was good. Where a portion of the cyanamid was applied in the spring to wheat and rye, a retardation resulted, and these plants were slow to recover. On the whole cyanamid was a much more satisfactory fertilizer for the winter crops than for cotton.

The use of calcium nitrate with cyanamid was tried out on a small scale in an effort to stimulate the early growth. The results were not entirely satisfactory, due perhaps to the fact that the mixture used was somewhat incompatible. The combination included cyanamid, calcium nitrate, and basic slag. The nitrate absorbed sufficient moisture from the air to result in the formation of unusually hard cakes. Probably at the same time some of the cyanamid was converted into dicyanodiamid, a poison for many plants. Under such conditions the cyanamid–calcium-nitrate mixture was no better than cyanamid alone, but it is felt that these unsatisfactory tests are no indication that the use of nitrate nitrogen with cyanamid will not prove profitable provided the materials are applied separately or in a compatible mixture.

AMMONIUM NITRATE, DOUBLE SALT, AND MIXED SALTS.

The effects on growth produced by ammonium nitrate and the combinations which may be made from it for the purpose of overcoming part of its objectionable hygroscopic properties were exactly alike so far as the eye could detect. The observations are therefore discussed under the same heading.

The germination and early growth of cotton and corn in the presence of these materials corresponded in every respect with that noted with sodium nitrate. Where moisture was deficient there was a delay of two or three days in germination with the two larger rates of application, and sometimes a slight burning effect, especially in the case of corn. These slight temporary injuries occurred only under extreme conditions and were no greater than with sodium nitrate. Ammonium nitrate and its combinations all gave quick responses and behaved in identically the same manner as sodium nitrate. The growth with cotton and corn is shown by Plate II, Figures 1 and 2.

Late growth and maturity also corresponded to that on the plats receiving equivalent amounts of nitrogen in the forms of sodium nitrate and ammonium sulphate. The smaller applications hastened

FIG. 1.—FIELD OF COTTON SHOWING INJURY CAUSED BY A HEAVY APPLICATION OF CYANAMID USED IN MIXTURE WITH ACID PHOSPHATE. FIELD I, SEASON OF 1919.

At left, cyanamid, 1,000 pounds 8-8-0 fertilizer per acre; yield 548 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-0 fertilizer per acre; yield 980 pounds of seed cotton.

FIG. 2.—COTTON GROWN THE FOLLOWING YEAR ON THE SAME AREA SHOWN ABOVE, USING CYANAMID WITH ACID PHOSPHATE APPLIED SEPARATELY. FIELD I, SEASON OF 1920.

At left, cyanamid, 1,000 pounds 8-8-4 fertilizer per acre; yield 1,908 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-4 fertilizer per acre; yield 1,204 pounds of seed cotton.

FIG. 1.—GROWTH OF COTTON WITH AMMONIUM NITRATE. FIELD 1, SEASON OF 1920.

At left, no nitrogen, 1,000 pounds 0-8-4 fertilizer per acre; yield 952 pounds of seed cotton. At right, ammonium nitrate, 1,000 pounds 8-8-4 fertilizer per acre; yield 2,040 pounds of seed cotton

FIG. 2.—GROWTH OF CORN WITH AMMONIUM NITRATE. FIELD 1, SEASON OF 1921.

At left, ammonium nitrate, 1,000 pounds 4-4-2 fertilizer per acre; yield 25.7 bushels. At right, no nitrogen, 1,000 pounds 0-4-2 fertilizer per acre; yield 7.4 bushels.

maturity slightly while the largest amounts produced a slight retardation, as is usually the case with other readily available sources of nitrogen.

Ammonium nitrate where used on winter crops gave exactly the same effects as sodium nitrate, and it was impossible to detect any difference between the two treatments at any time during the growing season.

AMMONIUM PHOSPHATE AND AMMONIATED SUPERPHOSPHATE.

The early-growth effects in the experiments with ammonium phosphate and ammoniated superphosphate were excellent, both the cotton and corn usually being as large as or larger than any in the field during the first six weeks of growth. The materials were as available as ammonium sulphate and showed no bad effects except in cases of extreme drought, where large applications of all soluble salts injured the plants. The materials were unquestionably good nitrogen carriers.

The growth during the latter half of the season was likewise good, but owing to the abnormally large quantities of phosphorus supplied the increases over the check plats tended to become less and less pronounced as the season advanced. Even though the primary purpose of these experiments was to determine the availability of the nitrogen it was impossible at the same time to avoid adding an abnormally large quantity of available phosphorus. The soils on the experimental areas were rather deficient in this element, and hence its stimulating effect largely obliterated the responses produced by the nitrogen.

AMMONIUM CHLORID.

Germination was slightly injured by the largest rates of application in a few instances, the effects being a little more pronounced than with equivalent applications of sodium nitrate or ammonium sulphate used under similar conditions. During the two weeks subsequent to germination there occurred a distinct burning in some instances, particularly with corn receiving 40 pounds of ammonia per acre. During the season of 1920 this injury was sufficient to kill about 10 per cent of the corn plants.

The later growth corresponded to that on near-by ammonium sulphate plats except where the most severe burning took place. In these cases the plants never seemed to overcome entirely the early retardation. With the smaller applications, where no burning occurred, the corn and cotton seemed to make even better growth than with ammonium sulphate. These facts suggested a possible injury in the presence of a large concentration of the chlorid ion and a stimulation with smaller quantities. Any bad effects noted were much more pronounced in 1920 than in 1921, even though used on the same soil both years. The latter year ammonium chlorid produced effects more nearly corresponding to those noted with ammonium sulphate.

UREA.

The observations during growth showed no difference at any time between the urea plats and those receiving either of the two standard materials. Urea produced no germination injuries, was immediately available for the young corn and cotton plants, and continued to produce good effects until maturity. The material gave every evidence of being a satisfactory nitrogen carrier from all standpoints.

UREPHOS.

The effect of Urephos on wheat and rye, the only crops which received this material, was not markedly different from that with the standard materials. In the case of wheat the growth with Urephos was very good, while the growth of rye was somewhat poorer. This was undoubtedly due to the marked soil variations. No toxic or retarding effects were observed at any time.

EXPERIMENTAL RESULTS.

The experimental work of the first year was of a rather miscellaneous nature and in general differed considerably from the later work. It will therefore be discussed separately.

EXPERIMENTS OF 1919.

Two series of fertilizer tests were started in 1919, one with summer crops and the other with winter crops. The former included experiments with cyanamid and ammonium nitrate on corn, cotton, and miscellaneous crops on field No. 1. The latter experiments were with the same fertilizers on wheat, rye, oats, and grass. A new fertilizer known as Urephos was also used to a limited extent on wheat and rye. These winter crops were grown on field No. 2.

Field No. 1.

Three sets of experiments were carried out on this area during the first season, using cyanamid and ammonium nitrate in comparison with sodium nitrate. They were as follows: (1) Availability experiments with cotton and corn, (2) time-of-application studies with cotton and corn, and (3) availability tests on various types of crops. The work was started late in the season and was delayed by wet weather. The yields were accordingly diminished, and furthermore in some cases frosts came before maturity was reached.

AMMONIUM NITRATE, SODIUM NITRATE, AND CYANAMID ON COTTON AND CORN.—SECTION I.

This experiment was planned to determine the relative values of ammonium nitrate and cyanamid at different rates of application as compared with sodium nitrate, using the materials in the row at the time of seeding, as is commonly done. The yields are given in Table 3.

It will be observed that ammonium nitrate gave as large increases of cotton and corn as did sodium nitrate, any differences being within the range of possible experimental error. Thus, the yields agreed with the observations previously mentioned.

The results with cyanamid were poorer than with either of the other two fertilizers. This was due almost entirely to the fact that the cyanamid was mixed with acid phosphate and allowed to stand for a few days before use. Laboratory studies later showed that under such conditions a considerable portion of the cyanamid may be changed to dicyanodiamid. The latter material is not only unavailable as a fertilizer but is toxic for some crops and delays the nitrification of the soil organic matter or of any nitrogen added as a fertilizer. Furthermore, in mixtures of cyanamid and acid phosphate, such as were used in these experiments, there occurs a reversion of the phosphorus to a less available form.

TABLE 3.—*Yields per acre of cotton and corn from Section I of field No. 1.*

Fertilizer ratio.[1]	Plat.	Yields of seed cotton (pounds).			Plat.	Yields of corn.			
		Actual.	Average.	Increase over check.		Stalks (pounds).	Grain (bushels).		
							Actual.	Average.	Increase over check.
Series A.—Ammonium nitrate:									
0-0-0	......	150	150	....	......	760	8.0	8.0	....
0-8-0	1	713	739.0	....	9	1,960	20.6	19.6	....
	5	765			13	1,760	18.6		
2-8-0	2	1,273	1,180.0	441.0	10	2,600	27.4	28.6	9.0
	6	1,087			14	2,500	29.7		
4-8-0	3	1,250	1,240.0	501.0	11	2,800	34.9	36.2	16.6
	7	1,230			15	2,620	37.4		
8-8-0	4	1,362	1,357.5	618.5	12	2,560	33.4	36.3	16.7
	8	1,353			16	2,880	39.1		
Series B.—Sodium nitrate:									
0-0-0	......	293	293	....	......	....	....	....	....
0-8-0	1	818	861.5	....	9	2,480	31.4	30.9	....
	5	905			13	2,260	30.3		
2-8-0	2	1,110	1,195.0	333.5	10	3,200	39.4	36.6	5.7
	6	1,280			14	2,920	33.7		
4-8-0	3	1,353	1,379.0	517.5	11	3,040	44.6	45.8	14.9
	7	1,405			15	3,440	46.9		
8-8-0	4	1,430	1,405.0	543.5	12	3,600	54.3	49.5	18.6
	8	1,380			16	2,800	44.6		
Series C.—Cyanamid:									
0-0-0	......	225	349.0	....	......	....	....	....	....
		473							
0-8-0	1	1,115	1,047.5	....	9	2,400	26.9	22.3	....
	5	980			13	1,580	17.7		
2-8-0	2	1,208	1,206.5	159.0	10	2,680	24.9	21.2	−1.1
	6	1,205			14	1,900	17.4		
4-8-0	3	1,113	1,134.0	86.5	11	2,360	32.0	29.6	7.3
	7	1,155			15	2,360	27.1		
8-8-0	4	548	690.0	−357.5	12	2,120	30.6	29.6	7.3
	8	832			16	1,920	28.6		

[1] The term "fertilizer ratio" used in Tables 3 to 7, inclusive, refers to the percentages of N, P_2O_5, and K_2O per acre, in the order named. The applications were made at the rate of 1,000 pounds per acre.

It is quite evident, therefore, that no particular weight should be attached to these yields with cyanamid, used under conditions that are known to be unsatisfactory. They are, nevertheless, valuable in demonstrating that cyanamid should not be used in large proportions in fertilizer mixtures containing acid phosphate.

TIME-OF-APPLICATION STUDIES WITH AMMONIUM NITRATE, SODIUM NITRATE, AND CYANAMID ON COTTON AND CORN.—SECTION II.

In order to determine the best time to apply the nitrogenous fertilizers, a series of plats was planted to cotton and corn, some plats receiving the nitrogen in the row at the time of seeding, others one month later, and a third group receiving half of the fertilizer when seeded and the remainder one month later. Where the fertilizer was applied after planting, the material was distributed by hand in the furrows left by the cultivator used for the second cultivation. The distance varied from 6 to 12 inches from the row. The fertilizer was then mixed with the soil by means of a spring-tooth cultivator. Table 4 gives the yields from the various plats.

TABLE 4.—*Yields per acre of cotton and corn from Section II of field No. 1.*

Fertilizer ratio.	Application of nitrogen.		Plat.	Yields of seed cotton (pounds).			Plat.	Yields of corn.			
	With seed.	One month later.		Actual.	Average.	Increase over check.		Stalks (lbs).	Grain (bushels). Actual.	Grain (bushels). Average.	Grain (bushels). Increase over check.
Series A.—Ammonium nitrate:											
0-0-0	......	......	......	310 338	324	......	......	......	......	......	......
0-8-0	......	......	1 5	840 990	915	......	9 13	2,380 1,760	31.1 22.9	27.0	......
4-8-0	All...	......	2 6	1,358 1,382	1,370	455	10 14	3,220 2,820	40.0 35.7	37.9	10.9
4-8-0	Half..	Half..	3 7	1,230 1,405	1,318	403	11 15	2,960 2,780	46.6 38.6	42.6	15.6
4-8-0	......	All...	4 8	1,040 1,310	1,175	260	12 16	2,840 2,260	44.9 34.3	39.6	12.6
4-0-0	......	All...	......	190	190	......	......	1,300	15.1	15.1	......
Series B.—Sodium nitrate:											
0-0-0	......	......	......	275 308	292	......	......	1,520	7.4	7.4	......
0-8-0	......	......	1 5	653 608	631	......	9 13	2,120 2,320	22.0 26.0	24.0	......
4-8-0	All...	......	2 6	1,068 1,220	1,144	513	10 14	3,340 3,280	46.6 47.4	47.0	23.0
4-8-0	Half..	Half..	3 7	1,125 1,220	1,173	542	11 15	3,220 2,880	48.9 43.1	46.0	22.0
4-8-0	......	All...	4 8	863 1,070	967	336	12 16	2,980 2,500	43.1 38.3	40.7	16.7
4-0-0	......	All...	......	60	60	......	......	1,520	7.4	7.4	......
Series C.—Cyanamid:											
0-0-0	......	......	......	283	283	......	......	1,240	6.3	6.3	......
0-8-0	......	......	1 5	1,300 1,163	1 232	......	9 13	2,400 2,780	25.7 33.4	29.6	......
4-8-0	All...	......	2 6	1,228 985	1,107	−125	10 14	3,540 3,360	42.3 40.0	41.2	11.6
4-8-0	Half..	Half..	3 7	1,300 1,110	1,205	− 27	11 15	3,400 3,000	42.9 41.4	42.2	12.6
4-8-0	......	All...	4 8	1,118 988	1,053	−179	12 16	3,320 2,820	43.4 40.0	41.7	12.1
4-0-0	......	All...	......	193	193	......	......	780	4.9	4.9	......

In considering the results it is necessary to emphasize the wide variations in the natural fertility of the soil on different portions of the field. This accounts for most of the irregularities shown by the figures in Table 3. Ammonium nitrate again gave responses similar to sodium nitrate, although the increases in yields were not quite as large. Cyanamid was a very unsatisfactory fertilizer, for the reasons already given. From the standpoint of time of application there was no great difference in the yields whether all or only half of the fertilizer was applied with the seed. Where no fertilizer was applied with the seed the yields were nearly always lower. This emphasizes the necessity of having sufficient nitrogen available for seedlings to give them a rapid start.

The deficiency of phosphorus in the soil is shown in Table 4. The yields of both cotton and corn were usually larger on the untreated plats than where nitrogen alone was used. With both nitrogen and phosphorus there was a very large increase in yields.

AMMONIUM NITRATE, SODIUM NITRATE, AND CYANAMID ON MISCELLANEOUS CROPS.

Experiments with the three fertilizers mentioned were made on a wide variety of crops, including cowpeas, soy beans, string beans, sweet potatoes, tomatoes, potatoes, tobacco, okra, Lima beans, sorghum, millet, turnips, and Sudan grass. The results were of a qualitative nature and hence are not here reported in detail. A few of the more significant effects of the fertilizer treatments are, however, included.

Ammonium nitrate gave results comparable with sodium nitrate. The material was readily available and suitable for forcing vegetables. Cyanamid was much slower acting and gave lower yields because of its dicyanodiamid content. But even where used according to best practice cyanamid as the only source of nitrogen will not be a suitable fertilizer for quick-growing crops.

FIELD NO. 2.

Three sets of experiments were conducted in 1919 on field No. 2, as follows: (1) Availability studies with ammonium nitrate and cyanamid at different rates of application, using sodium nitrate and ammonium sulphate as standards; (2) studies of the effect of lime on availability, using the same materials; and (3) tests of the fertilizing value of cyanamid and Urephos in comparison with the two standards.

The crops grown included rye, wheat, oats, and a mixture of redtop and orchard grass. Planting was done December 10, 1919, just subsequent to broadcasting the fertilizers. A wheat drill was used for seeding the grains, while the grass seed was distributed by hand. The rye plats were harvested on June 8 and the other crops on June 21. The crops were allowed to remain on the ground until thoroughly dry, and then the total weights were obtained. Unfortunately there was no equipment available for threshing and hence the grain yields were not determined.

The fertilizer application included nitrogen in the different forms at varying rates up to 80 pounds per acre, together with phosphorus and potassium. The latter two elements were applied at the rate of 80 pounds of P_2O_5 and 40 pounds of K_2O to all plats of Sections I and II except those designated as "no fertilizer." On Section III 65 pounds of P_2O_5 was used on all plats except those receiving Urephos, where the application was 90 pounds of P_2O_5. The sources of phosphorus are shown later in Table 7. The fertilizers were mixed about one week before applying them except where cyanamid was used, it being applied separately. The method of making fall applications was to broadcast the mixtures by hand, followed by a thorough harrowing before seeding. The spring applications of nitrogen where given were broadcasted on the various plats about April 15.

In considering the experimental results reported below it will be observed that in many instances the variations in yields between duplicates are quite large. This is due to the fact that in nearly all instances duplicate plats were located at a considerable distance from each other and the soil variations were sufficient to account for the discrepancies. While these variations were large, nevertheless there was usually a gradual change in productivity from one portion of the field to another.

AVAILABILITY STUDIES WITH RYE AND WHEAT.—SECTION I.

This experiment was planned to give comparisons in yield between ammonium nitrate, sodium nitrate, ammonium sulphate, and cyanamid at the rates of 10, 20, 40, and 80 pounds of nitrogen per acre. Half of the nitrogen was applied in the fall and the remainder as a spring top-dressing except in one series, where all the cyanamid was applied in the fall for the purpose of comparison with the other method of use.

The differences in growth on the various plats were quite marked and also fairly uniform for the different sources of nitrogen at any given rate of application. Very early in April the growth on all plats was quite poor because of the late planting and very heavy rainfall both in the fall and spring. The soil on the entire area, and especially the ammonium-nitrate series, was not quite as well drained as is desirable. Soon after making the spring applications of nitrogen there was a very rapid growth which corresponded approximately to the total nitrogen supplied. The rye and wheat which received no nitrogen were the smallest and lightest in color, while that receiving the largest amount of nitrogen grew very rapidly and had a very dark green color. There was no appreciable difference between the different series of plats, except that where the spring application of cyanamid was made there was a slight retarding effect as compared with the other cyanamid series.

The yields of grain and straw from the plats receiving the four different sources of nitrogen are given in Table 5. In considering the results for rye it will be noticed that usually the larger the amount applied up to the maximum application of 80 pounds of nitrogen per acre, the larger was the yield. With regard to the merits of the four sources of nitrogen, making allowance for soil variations, neither the growth nor yields indicated any marked differences. Ammonium nitrate produced larger yields than did the adjoining sodium-nitrate series, but the check plats were also better. The yields from the plats where all of the cyanamid was applied in the fall were the largest of any of the series and likewise showed the largest increases over the checks. The soil variations are too great to justify making sharp distinctions, but there is not the least doubt that cyanamid, when applied in the fall, produced results equally as good as any other fertilizer used.

The wheat yields agreed very closely with those for rye and showed that under the conditions ammonium nitrate and cyanamid were as satisfactory sources of nitrogen as sodium nitrate and ammonium sulphate. The application of all of the cyanamid in the fall again gave slightly better results than the use of half in the fall and the remainder in the spring.

TABLE 5.—*Yields per acre of rye and wheat from Section I of field No. 2.*

Fertilizer ratio.	Yields of rye (pounds.)			Yields of wheat (pounds).		
	Grain and straw.	Average.	Increase over check.	Grain and straw.	Average.	Increase over check.
Series A.—Ammonium nitrate:						
0-8-4	1,640 1,240	1,440	....	680 1,640	1,160	....
1-8-4	2,720 1,280	2,000	560	1,360 1,480	1,420	260
2-8-4	2,240 1,480	1,860	420	1,840 1,600	1,720	560
4-8-4	2,280 1,640	1,960	520	2,680 2,200	2,440	1,280
8-8-4	3,400 2,280	2,840	1,400	2,040 3,040	2,540	1,380
8-8-4 [1]	2,280 2,920	2,600	1,160	2,560 2,520	2,540	1,380
Series B.—Sodium nitrate:						
0-0-0	1,200 880	1,040	....	1,040 1,160	1,100	....
0-8-4	1,360 960	1,160	....	1,680 2,480	2,080	....
1-8-4	1,400 1,360	1,380	220	2,120 1,960	2,040	-40
2-8-4	1,760 1,640	1,700	540	2,840 1,880	2,360	280
4-8-4	1,880 2,040	1,960	800	2,200 2,200	2,500	420
8-8-4	1,840 2,920	2,380	1,220	3,360 2,320	2,840	760
Series C.—Ammonium sulphate:						
0-0-0	1,000 1,280	1,140	....	1,720 1,960	1,840	....
0-8-4	960 1,560	1,260	....	1,720 1,760	1,740	....
1-8-4	1,560 1,280	1,420	160	1,440 1,560	1,500	-240
2-8-4	1,840 2,120	1,980	720	2,640 1,880	2,260	520
4-8-4	2,720 1,920	2,320	1,060	2,360 2,680	2,520	780
8-8-4	3,200 2,520	2,860	1,600	2,720 2,720	2,720	980
Series D.—Cyanamid:						
0-0-0	560 1,280	920	....	1,000 640	820	....
0-8-4	1,040 960	1,000	....	1,280 720	1,000	....
1-8-4	1,400 1,360	1,380	380	1,320 880	1,100	100
2-8-4	1,960 1,400	1,680	680	1,400 1,040	1,220	220
4-8-4	1,960 2,680	2,320	1,320	1,880 2,160	2,020	1,020
8-8-4	2,320 2,880	2,600	1,600	3,000 2,400	2,700	1,700
Series E.—Cyanamid (applied in the fall):						
0-0-0	920 920	920	....	1,040 920	980	....
0-8-4	1,200 1,800	1,500	....	1,400 680	1,040	....
1-8-4	1,680 2,000	1,840	340	1,600 960	1,280	240
2-8-4	2,520 1,920	2,220	720	2,120 1,240	1,680	640
4-8-4	2,800 3,240	3,020	1,520	2,320 2,000	2,160	1,120
8-8-4	2,920 4,000	3,460	1,960	3,000 2,800	2,900	1,860

[1] Half of the nitrogen was derived from ammonium nitrate and the remainder from sodium nitrate.

INFLUENCE OF LIME ON THE UTILIZATION OF NITROGEN FROM THE VARIOUS SOURCES.—SECTION II.

The importance of the soil reaction on the availability of ammonium nitrate and cyanamid was determined for wheat, rye, oats, and grass. Nitrogen was supplied at the rate of 40 pounds per acre, half at the time of planting and the remainder as a spring top-dressing. Where lime was used, the rate of application was 2 tons of air-slaked material per acre.

The growth on this group of plats was rather disappointing early in the spring, owing to a poor stand and the retarding effect produced by wet weather. However, as the season advanced very good stooling took place and the poor stand was partially overcome, resulting in fairly uniform growth on plats similarly treated. Since the apparent discrepancies in the yields shown in Table 6 may in many cases be explained by observations during growth, the two will be discussed together.

TABLE 6.—*Yields per acre of wheat, oats, rye, and grass from Section II of field No. 2.*

Crop and fertilizer ratio.	Limed or unlimed.	Yields of grain and straw (pounds).			
		Series A.—Ammonium nitrate.	Series B.—Sodium nitrate.	Series C.—Ammonium sulphate.	Series D.—Cyanamid.
Wheat:					
0-0-0	Unlimed	160	760	720	....
4-8-4	...do	1,640	2,520	2,760	1,520
4-8-4	Limed	2,400	2,440	2,320	2,000
Increase due to lime		760	−80	−440	480
Rye:					
0-0-0	Limed	1,640	1,760	1,400	....
4-8-4	Unlimed	2,440	2,480	2,800	2,760
4-8-4	Limed	2,960	3,440	3,000	2,200
Increase due to lime		520	960	200	−560
Oats:					
4-8-4	Unlimed	2,880	3,320	2,200	2,400
4-8-4	Limed	2,520	1,920	2,160	2,720
Increase due to lime		−360	−1,400	−40	320
Grass:					
4-8-4	Unlimed	2,000	2,320	1,600	1,240
4-8-4	Limed	2,920	2,720	1,640	1,240
Increase due to lime		920	400	40	0

The addition of lime, judging from Table 6, produced a rather marked increase in the growth of wheat fertilized with ammonium nitrate and cyanamid, while slight losses were shown with sodium nitrate and ammonium sulphate. However, the plats receiving the latter two sources of nitrogen had a very poor stand. Had the number of plants and the soil conditions been the same in all cases there is little doubt, judged by the results obtained by other investigators, that lime would have given increased growth with all sources of nitrogen and particularly with ammonium sulphate, since this material leaves an acid residue in the soil.

The yields of rye were increased by additions of lime in the case of all of the fertilizers except cyanamid. It is barely possible that the lime exerted a harmful effect, but more likely the soil variations largely explain the results. The plat which yielded 2,760 pounds appeared to the eye to be naturally more fertile than the plat which yielded 2,200 pounds.

The yields of oats are no doubt misleading, since cyanamid is the only one of the fertilizers which shows an increased yield with lime, the very reverse of what was obtained with rye. Early-spring observations showed that the stand was much poorer on the limed than on the unlimed plats, thus accounting, at least partially, for the lower yields.

The growth of redtop and orchard grass was good and the stand quite uniform. The results are therefore more significant, lime being without effect with cyanamid but beneficial with the other nitrogen carriers.

CYANAMID AND UREPHOS AS FERTILIZERS WITH DIFFERENT PHOSPHATE CARRIERS.—SECTION III.

This experiment was planned primarily to compare mixtures of cyanamid and either basic slag or calcined phosphate with sodium nitrate and ammonium sulphate as standards. In addition, a few plats received Urephos, which contains both nitrogen and phosphorus. In all cases except on the check plats nitrogen was supplied at the rate of 40 pounds per acre, half in the fall and the remainder in the spring. Phosphorus and potash were supplied to all plats in the fall at the rate of 65 pounds P_2O_5 and 40 pounds K_2O. In the case of Urephos either basic slag or acid phosphate was used to bring the total phosphoric acid content to 65 pounds for the fall application, but when an additional application of this material was made in the spring the total phosphoric acid was brought up to 90 pounds per acre. The crops grown were wheat and rye.

In considering the yields shown in Table 7, it will be observed that there are several wide variations in the yields of plats receiving the same treatments. This is because the duplicate plats were located at a considerable distance from each other, and the variations merely show the natural soil irregularities, which were beyond control.

TABLE 7.—*Yields per acre of wheat and rye from Section III of field No. 2.*

Treatment.	Fertilizer ratio.	Yields of wheat (pounds).			Yields of rye (pounds).		
		Grain and straw.	Average.	Increase over check.	Grain and straw.	Average.	Increase over check.
No nitrogen (basic slag)	0-6.5-4	1,040 440	740		960 2,040	1,500	
Sodium nitrate (calcined phosphate)	4-6.5-4	1,800 1,320	1,560	820	1,720 2,360	2,040	540
Sodium nitrate (acid phosphate)	4-6.5-4	2,240 1,360	1,800	1,060	1,800 2,280	2,040	540
Sodium nitrate (basic slag)	4-6.5-4	2,160 1,800	1,980	1,240	2,200 2,400	2,300	800
Ammonium sulphate (acid phosphate)	4-6.5-4	2,200 1,760	1,980	1,240	2,440 2,120	2,280	780
Cynamid (calcined phosphate)	4-6.5-4	2,120 1,880	2,000	1,260	2,360 2,120	2,240	740
Cyanamid (basic slag)	4-6.5-4	2,080 2,120	2,100	1,360	2,560 1,880	2,220	720
Urephos (basic slag)	4-9-4	2,320 2,480	2,400	1,660	1,920 1,560	1,740	240
Urephos (acid phosphate)	4-9-4	1,840 1,960	1,900	1,160			

The growth and yields in the case of wheat showed no appreciable difference between cyanamid with either of the two basic phosphates and ammonium sulphate with acid phosphate. The yields of wheat with sodium nitrate used in mixture with basic slag were also on a par with the cyanamid and ammonium-sulphate results. With calcined phosphate and acid phosphate sodium nitrate gave smaller increases than any of the other mixtures. No significance should be attached to this, however, since these plats were located on poorer soil. Urephos gave very good growth, giving the best yield with basic slag of any of the mixtures and an average yield with acid phosphate. The large application of phosphorus may have partially accounted for the good results.

The growth and yields of rye showed no appreciable difference between cyanamid, ammonium sulphate, and sodium nitrate with the different phosphate carriers except that some of the yields with sodium nitrate were low because of the poor soil on this portion of the field. This is shown by the wide variations in the yields of the two check plats. The yields of rye where fertilized with Urephos and basic slag were the lowest of any of the forms of nitrogen. The soil is decidedly poorer on this portion of the field, and doubtless this largely accounts for the low yields. Urephos seemed to give as good responses in growth as the other materials, but the fact that approximately 30 per cent of the nitrogen is present as guanylurea sulphate leaves some doubt as to its value in general, since the latter compound is probably only very slowly available for plant use.

EXPERIMENTS OF 1920 AND 1921.

The agricultural experiments reported above were continued at Muscle Shoals during the following two years. Modifications in the manner of using cyanamid were made, and the scope of the work was enlarged to include several additional nitrogen carriers.

The methods of carrying out the experiments were essentially the same as those used previously except for variations in the fertilization. In order to make nitrogen the limiting factor all plats except those designated as "no fertilizer" received potassium and phosphorus. The rates of application used as a basis were 80 pounds of P_2O_5 and 40 pounds of K_2O for cotton and usually half these quantities for corn, but certain modifications had to be made where the nitrogen carriers contained either of these two elements. The sources of phosphorus and potassium were acid phosphate and potassium sulphate unless otherwise noted.

The experimental area included the 10 acres used previously, the yields from which have been given, and three additional fields of about 5 acres each, located near by. The layout of the plats, giving treatments for the season of 1921, are shown in the diagrams. (Figs. 1 to 4.)

FIELD No. 1.

The experimental work of 1919 on field No. 1 was continued during the following two years, using the same plat arrangements and so far as possible similar treatments for the same plats. The results are discussed under three headings corresponding to the three sections of the field. A diagram of the field, showing the plat arrangements and treatments, is shown as Figure 1.

AMMONIUM NITRATE, SODIUM NITRATE, AND CYANAMID.—SECTION I.

Results with cotton.—This set of experiments was practically a duplication of the work of 1919 except that where cyanamid and acid phosphate were used the materials were applied separately.

The yields for the two years, given in Table 8, show a slight difference in favor of sodium nitrate over ammonium nitrate. However, it is felt that the soil variations were great enough to account for most, if not all, of the differences. Both the sodium-nitrate and cyanamid series were more favorably located in this respect than the

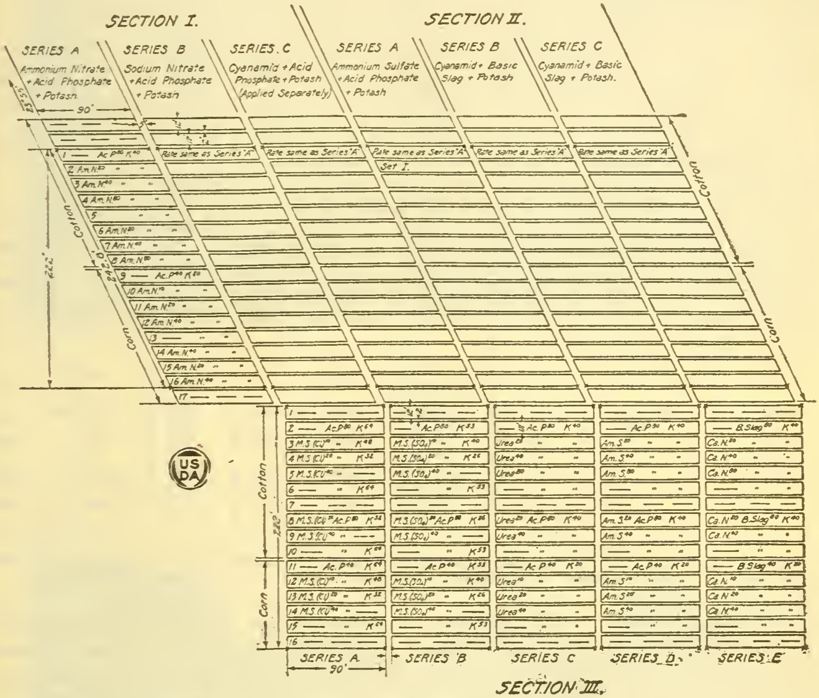

FIG. 1.—Diagram of field No. 1 located at Muscle Shoals, Ala., showing plat arrangements and treatments for the season of 1921. The soil type is Clarksville loam. Three rows per plat without buffer row. Size of plats, one-fortieth of an acre. The index figures refer to the number of pounds of NH_3, P_2O_5, and K_2O used per acre. Ac. P. = Acid phosphate; B. Slag = duplex basic slag; K = potassium sulphate; Am. S. = ammonium sulphate; S. N. = sodium nitrate; Am. N. = ammonium nitrate; Ca. N. = calcium nitrate; M. S. (Cl.) = mixed salt made from potassium chlorid and ammonium nitrate; M. S. (SO_4) = mixed salt made from potassium sulphate and ammonium nitrate.

ammonium-nitrate series. Plate III, Figure 2, illustrates the relative cotton yields with the different rates of application of ammonium nitrate.

Cyanamid was not as satisfactory a fertilizer as the other two materials, but the results were much better than those obtained the first year on the same plats using cyanamid in mixture with acid phosphate. At the smaller rates of application the differences for the two years were less noticeable, but at the equivalent of 80 pounds of ammonia per acre the material failed to give quite as good results as sodium nitrate. The difference was not great, however, as shown by Plate IV, Figure 1. The retarding effect of heavy applications at the beginning of the season was a handicap from which the plants were never able to recover completely.

TABLE 8.—*Yields per acre of cotton from Section I of field No. 1 in 1920 and 1921.*

Fertilizer ratio.[1]	Plat.	Yields of seed cotton (pounds).					
		1920			1921		
		Actual.	Average.	Increase over check.	Actual.	Average.	Increase over check.
Series A.—Ammonium nitrate:							
0-0-0	......	116 252	184	....	36 92	64	....
0-8-4	1 5	1,296 952	1,124	....	840 596	718	....
2-8-4	2 6	1,508 1,136	1,322	198	1,016 728	872	154
4-8-4	3 7	1,836 1,460	1,648	524	1,396 1,048	1,222	504
8-8-4	4 8	2,052 1,884	1,968	844	1,620 1,524	1,572	854
Series B.—Sodium nitrate:							
0-0-0	......	164 324	244	....	108 148	128	....
0-8-4	1 5	1,112 1,124	1,118	....	640 588	614	....
2-8-4	2 6	1,364 1,416	1,390	272	804 960	882	268
4-8-4	3 7	1,536 1,760	1,648	530	1,136 1,308	1,222	608
8-8-4	4 8	2,040 2,208	2,124	1,006	1,500 1,648	1,574	960
Series C.—Cyanamid (with acid phosphate applied separately):							
0-0-0	......	280 360	320	....	72 128	100	....
0-8-4	1 5	1,504 1,204	1,354	....	928 640	784	....
2-8-4	2 6	1,684 1,512	1,598	244	992 948	970	186
4-8-4	3 7	1,832 1,888	1,860	506	1,160 1,272	1,216	432
8-8-4	4 8	1,908 2,096	2,002	648	1,228 1,704	1,466	682

[1] The term "fertilizer ratio" used in this and subsequent tables refers to the percentage of NH_3, P_2O_5, and K_2O per acre, in the order named. Applications were made at the rate of 1,000 pounds per acre.

Results with corn.—The effects of the various fertilizer treatments on corn were quite different from those on cotton. Cyanamid produced growth corresponding to that made by sodium nitrate except that the early retarding period was a few days longer. However, the nitrogen became available about as soon as needed, and no permanent injuries were in evidence. Ammonium nitrate was very readily available, as shown by Plate V, Figure 1. The yields are given in Table 9. In considering the figures for the unfertilized plats it should be borne in mind that these plats received heavy applications of nitrogen during the season of 1919, and the effects undoubtedly persisted during the following two years.

The differences between the three sources of nitrogen when used as fertilizers for corn were not great when due allowance is made for soil variations. The increases in yields obtained with ammonium nitrate were usually larger than with sodium nitrate or cyanamid, but the actual yields were smaller. This was because the soil was very shallow, due to continuous erosion. Cyanamid gave practically the same increases as sodium nitrate and seemed to be about as effective a source of nitrogen for corn as either of the two nitrate forms of nitrogen.

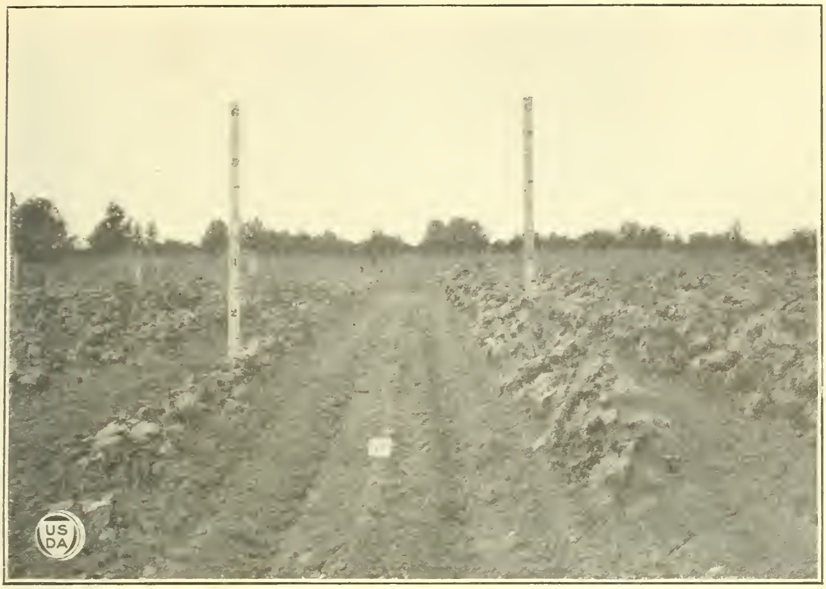

FIG. 1.—EARLY GROWTH OF COTTON WITH SULPHATE MIXED SALT. FIELD 2, SEASON OF 1921.

At left, no nitrogen, 1,000 pounds 0–8–5 fertilizer per acre; yield 540 pounds of seed cotton. At right, mixed salt, 1,000 pounds 4–8–5 fertilizer per acre; yield 872 pounds of seed cotton.

FIG. 2.—YIELDS OF COTTON FROM PLATS RECEIVING DIFFERENT AMOUNTS OF AMMONIUM NITRATE. FIELD 1, SEASON OF 1921.

Left to right: No fertilizer; yield 64 pounds of seed cotton per acre. No nitrogen, 1,000 pounds 0–8–4 fertilizer per acre; yield 718 pounds. Ammonium nitrate, 1,000 pounds 2–8–4 fertilizer per acre; yield 872 pounds. Ammonium nitrate, 1,000 pounds 4–8–4 fertilizer per acre; yield 1,222 pounds. Ammonium nitrate, 1,000 pounds 8–8–4 fertilizer per acre; yield 1,520 pounds.

FIG. 1.—GROWTH OF COTTON WITH SODIUM NITRATE AND CYANAMID (ACID PHOSPHATE APPLIED SEPARATELY). FIELD 1, SEASON OF 1920.

At left, sodium nitrate, 1,000 pounds 8-8-4 fertilizer per acre; yield 2,208 pounds of seed cotton. At right, cyanamid, 1,000 pounds 8-8-4 fertilizer per acre; yield 2,096 pounds of seed cotton

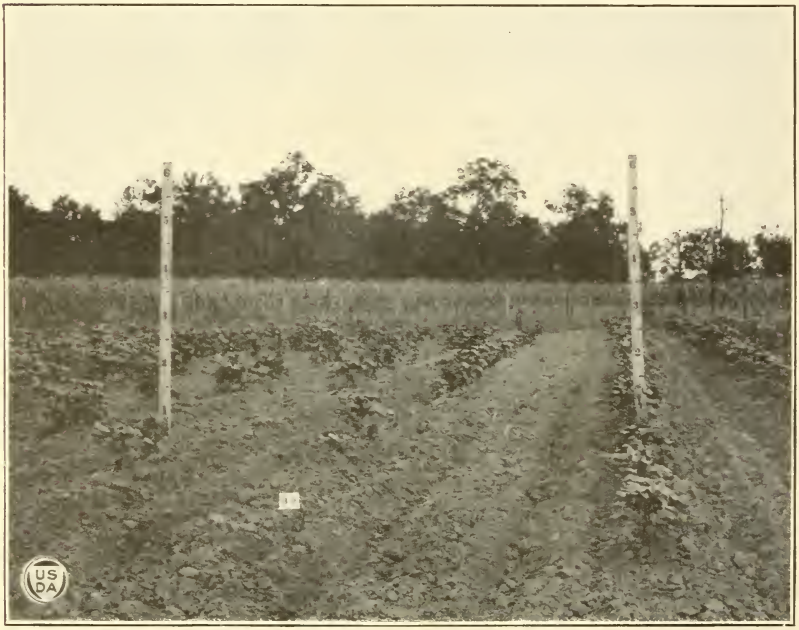

FIG. 2.—FIELD OF COTTON, SHOWING INJURY PRODUCED BY A HEAVY APPLICATION OF CYANAMID DURING A VERY DRY PERIOD. FIELD 2, SEASON OF 1921.

At left, cyanamid (with basic slag), 1,000 pounds 8-8-4 fertilizer per acre; more than half of the plants died: yield 556 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-4 fertilizer per acre; stand good; yield 424 pounds of seed cotton.

FIG. 1.—EARLY GROWTH OF CORN WITH AMMONIUM NITRATE. FIELD 1, SEASON OF 1921.

At left, ammonium nitrate, 1,000 pounds 4-4-2 fertilizer per acre; yield 28.6 bushels. At right, no fertilizer; yield 8 bushels.

FIG. 2.—EARLY GROWTH OF CORN WITH CYANAMID (AND BASIC SLAG). FIELD 1, SEASON OF 1921.

At left, cyanamid, 1,000 pounds 4-4-2 fertilizer per acre; yield 36.6 bushels. At right, no fertilizer; yield 8 bushels.

FIG. 1.—CORN GROWN WITH CYANAMID (AND CALCINED PHOSPHATE). FIELD 1, SEASON OF 1920.

At left, cyanamid, 1,000 pounds 4-4-2 fertilizer per acre; yield 27.4 bushels. At right, no fertilizer; yield 11.4 bushels.

FIG. 2.—CORN GROWN WITH CYANAMID (AND BASIC SLAG). FIELD 1, SEASON OF 1920.

At left, cyanamid, 1,000 pounds 4-4-2 fertilizer per acre; yield 34.3 bushels. At right, no fertilizer; yield 9.7 bushels.

TABLE 9.—*Yields per acre of corn from Section I of field No. 1 in 1920 and 1921.*

Fertilizer ratio.	Plat.	1920 Stalks (pounds).	1920 Grain (bushels). Actual.	1920 Grain (bushels). Average.	1920 Grain (bushels). Increase over check.	1921 Stalks. (pounds).	1921 Grain (bushels). Actual.	1921 Grain (bushels). Average.	1921 Grain (bushels). Increase over check.
Series A.—Ammonium nitrate:									
0-0-0	17	840	10.3	10.3	....	1,040	8.0	8.0	....
0-4-2	9	1,500	10.3	8.9	....	1,880	13.1	10.3	....
	13	1,320	7.4			1,600	7.4		
1-4-2	10	2,080	15.4	13.2	4.3	2,240	19.4	16.0	5.7
	14	2,080	10.9			2,120	12.6		
2-4-2	11	2,400	17.1	16.6	7.7	2,360	21.7	19.2	8.9
	15	2,440	16.0			2,160	16.6		
4-4-2	12	2,160	22.9	24.3	15.4	2,600	25.7	27.2	16.9
	16	2,440	25.7			2,480	28.6		
Series B.—Sodium nitrate:									
0-0-0	17	1,600	18.3	18.3	....	1,240	14.9	14.9	....
0-4-2	9	2,040	18.0	16.5	....	2,160	26.9	22.9	....
	13	1,800	14.9			2,040	18.9		
1-4-2	10	2,720	21.1	18.3	1.8	2,400	28.6	25.5	2.6
	14	2,240	15.4			2,040	22.3		
2-4-2	11	2,800	21.1	20.9	4.4	2,600	28.6	28.6	5.7
	15	2,600	20.6			2,360	28.6		
4-4-2	12	3,200	30.3	30.6	14.1	2,640	37.1	37.1	14.2
	16	2,920	30.9			2,560	37.1		
Series C.—Cyanamid (with acid phosphate applied separately):									
0-0-0	17	1,720	14.8	14.8	....	1,120	8.6	8.6	....
0-4-2	9	2,040	15.4	12.0	....	2,360	20.6	15.5	....
	13	1,280	8.6			1,760	10.3		
1-4-2	10	2,360	12.6	10.6	−1.4	2,080	20.6	16.0	.5
	14	1,920	8.6			2,000	11.4		
2-4-2	11	2,720	16.6	16.3	4.3	2,160	21.1	20.9	5.4
	15	2,560	16.0			2,200	20.6		
4-4-2	12	2,800	28.0	28.3	16.3	2,440	29.7	28.9	13.4
	16	3,000	28.6			2,280	28.0		

The relative percentages of grain and stover varied to a marked extent for the two seasons. In 1920 the wet period of early spring and summer was followed by a drought at the time of ear formation. A heavy stalk production without the corresponding grain yield was the natural result. Exactly reverse weather conditions in 1921 gave a much larger proportion of grain. It will be noticed also that in Table 9, as well as in subsequent tables, there was a rather general tendency for small nitrogen applications to produce stalks rather than grain, particularly in 1920.

CYANAMID AND AMMONIUM SULPHATE.—SECTION II.

This series of plats was planned primarily to determine the advisability of using cyanamid in mixture with either calcined phosphate or basic slag. However, during the season of 1921 it was impossible to secure sufficient calcined phosphate and it became necessary to use basic slag on all cyanamid plats. Ammonium sulphate was used, with acid phosphate as a standard for comparison. The experiments were conducted on the same soil used in 1919 for the time-of-application studies. Since acid phosphate was used on the plats at that time the later results can not be considered as an estimate of the relative merits of the three forms of phosphorus, but merely a measure of the returns from the nitrogen applied in mixture with the phosphorus carriers. The experiments were conducted at the same time and in the same manner as those of Section I, previously discussed, and the data are therefore comparable.

Results with cotton.—The yields of cotton for the two years are given in Table 10. The increases produced by ammonium sulphate were of about the same order as those produced by the two nitrates of Section I. Any variations may be attributed largely to factors other than the source of nitrogen. The use of cyanamid in mixture with either calcined phosphate or basic slag was entirely satisfactory, as is shown by Plate VI, Figures 1 and 2, and Plate V, Figure 2. While the yields show considerable difference with these two mixtures, the figures are in reality somewhat misleading. The soil of series B was very shallow and located on the side of the hill where moisture conditions were often the limiting factor to growth. Series C was on lower and richer soil. It is felt that the use of cyanamid with either of the two basic phosphates or with acid phosphate applied separately is satisfactory and where used under exactly the same conditions would give about equally good yields.

TABLE 10.—*Yields per acre of cotton from Section II of field No. 1 in 1920 and 1921.*

Fertilizer ratio.	Plat.	Yields of seed cotton (pounds).					
		1920			1921		
		Actual.	Average.	Increase over check.	Actual.	Average.	Increase over check.
Series A.—Ammonium sulphate:							
0-0-0	......	200 224	212	....	84 136	110	....
0-8-4	1 5	1,080 1,344	1,212	....	596 724	660	....
2-8-4	2 6	1,272 1,792	1,532	320	952 1,144	1,048	388
4-8-4	3 7	1,440 2,112	1,776	564	1,024 1,468	1,246	586
8-8-4	4 8	1,868 2,368	2,118	906	1,208 1,712	1,460	800
Series B.—Cyanamid (with calcined phosphate in 1920; with basic slag in 1921):							
0-0-0	......	172 256	214	....	44 116	80	....
0-8-4	1 5	612 660	636	....	324 300	312	....
2-8-4	2 6	776 1,144	960	324	428 648	538	226
4-8-4	3 7	1,008 1,236	1,122	486	596 920	758	446
8-8-4	4 8	1,348 1,792	1,570	934	704 1,028	866	554
Series C.—Cyanamid (with basic slag):							
0-0-0	......	225 178	202	....	200 276	238	....
0-8-4	1 5	1,066 1,104	1,085	....	708 744	726	....
2-8-4	2 6	1,449 1,388	1,419	334	1,064 996	1,030	304
4-8-4	3 7	1,520 1,656	1,588	503	1,188 1,112	1,150	424
8-8-4	4 8	1,618 1,744	1,681	596	936 1,260	1,098	372

Results with corn.—The yields from the group of plats given in Table 11 show increases in favor of cyanamid over ammonium sulphate regardless of whether the former material was used with calcined phosphate or basic slag. A portion of the increase may be attributed to the fact that the two cyanamid series were located on slightly lower ground than the other series. Nevertheless, there is no doubt that under the conditions cyanamid was just as satisfactory a source of nitrogen for corn as ammonium sulphate. It seems that corn is able to utilize ammonia nitrogen, while cotton requires a large percentage of nitrate nitrogen for its best growth.

TABLE 11.—*Yields per acre of corn from Section II of field No. 1 in 1920 and 1921.*

Fertilizer ratio.	Plat No.	1920 Stalks (pounds).	1920 Grain (bushels). Actual.	1920 Grain (bushels). Average.	1920 Grain (bushels). Increase over check.	1921 Stalks (pounds).	1921 Grain (bushels). Actual.	1921 Grain (bushels). Average.	1921 Grain (bushels). Increase over check.
Series A.—Ammonium sulphate:									
0-0-0	17	960	6.3	6.3	....	680	5.1	5.1	....
0-4-2	9	2,220	13.7	14.0	....	2,120	20.0	17.5	....
	13	1,800	14.3			1,880	14.9		
1-4-2	10	2,720	19.4	17.7	3.7	2,320	22.3	19.2	1.7
	14	2,240	16.0			2,040	16.0		
2-4-2	11	3,000	22.9	18.9	4.9	2,400	25.7	22.0	4.5
	15	2,720	14.9			2,240	18.3		
4-4-2	12	2,600	26.9	24.3	10.3	2,640	34.9	31.8	14.3
	16	2,480	21.7			2,480	28.6		
Series B.—Cyanamid (with calcined phosphate):[1]									
0-0-0	17	1,240	11.4	11.4	....	920	9.7	9.7	....
0-4-2	9	1,560	6.3	9.5	....	1,880	9.7	14.0	....
	13	2,360	12.6			1,920	18.3		
1-4-2	10	2,800	20.0	18.9	9.4	2,080	23.4	22.3	8.3
	14	2,680	17.7			2,120	21.1		
2-4-2	11	3,200	18.3	20.3	10.8	2,240	25.7	25.4	11.4
	15	2,800	22.3			2,240	25.1		
4-4-2	12	3,080	24.6	26.0	16.5	2,160	30.9	30.6	16.6
	16	2,840	27.4			2,080	30.3		
Series C.—Cyanamid (with basic slag):									
0-0-0	17	1,120	9.7	9.7	....	840	8.0	8.0	....
0-4-2	9	2,240	20.6	21.5	....	1,680	17.1	20.9	....
	13	2,880	22.3			2,160	24.6		
1-4-2	10	3,480	30.3	28.6	7.1	2,560	34.3	32.0	11.1
	14	3,320	26.9			2,320	29.7		
2-4-2	11	3,440	28.6	28.4	6.9	2,480	32.6	34.6	13.7
	15	3,520	28.1			2,640	36.6		
4-4-2	12	3,880	38.3	36.3	14.8	2,680	38.3	37.5	16.6
	16	3,280	34.3			2,400	36.6		

[1] Basic slag was substituted for calcined phosphate in 1921.

MIXED SALTS, SODIUM NITRATE, UREA, AMMONIUM SULPHATE, AND CALCIUM NITRATE.—SECTION III.

This series of fertilizer experiments was carried out on the area used during the season of 1919 for the miscellaneous crop tests. This previous treatment did not seem to affect appreciably the results for the following two years.

TABLE 12.—*Yields per acre of cotton from Section III of field No. 1 in 1920 and 1921.*

Fertilizer ratio.	Plat.	Yields of seed cotton (pounds). 1920 Actual.	1920 Average.	1920 Increase over check.	1920 Average increase.	1921 Actual.	1921 Average.	1921 Increase over check.	1921 Average increase.
Series A.—Mixed salt (from KCl):									
0-0-0	1	1,076	870	....	....	580	580	....	....
	7	664				580			
0-8-6	2	996	1,040	....	....	632	776	....	....
	6	1,084				920			
1-8-6	3	1,052	1,052	12	12	768	768	−8	−8
2-8-6	4	1,240	1,240	200	133	972	972	196	174
4-8-6	5	1,444	1,444	404	335	1,376	1,376	600	520
0-8-6	6	1,084	830	....	....	920	732	....	....
	10	576				544			
2-8-6	8	896	896	66	....	884	884	152	....
4-8-6	9	1,096	1,096	266	....	1,172	1,172	440	....
Series B.—Sodium nitrate: [1]									
0-0-0	1	868	630	....	....	440	362	....	....
	7	392				284			
0-8-4	2	788	806	....	....	496	500	....	....
	6	824				504			
1-8-4	3	900	900	94	94	656	656	156	156
2-8-4	4	1,568	1,568	762	361	940	940	440	280
4-8-4	5	1,945	1,945	1,139	746	1,260	1,260	760	620
0-8-4	6	824	716	....	....	504	516	....	....
	10	608				528			
2-8-4	8	676	676	−40	....	636	636	120	....
4-8-4	9	1,068	1,068	352	....	996	996	480	....
Series C.—Urea:									
0-0-0	1	628	628	....	....	364	416	....	....
	7	628				468			
0-8-4	2	860	1,030	....	....	460	652	....	....
	6	1,200				844			
2-8-4	3	1,268	1,268	238	119	896	896	244	210
4-8-4	4	1,744	1,744	714	589	1,316	1,316	664	580
8-8-4	5	2,060	2,060	1,030	1,030	1,568	1,568	916	916
0-8-4	6	1,200	1,084	....	....	844	724	....	....
	10	968				604			
2-8-4	8	1,084	1,084	0	....	900	900	176	....
4-8-4	9	1,548	1,548	464	....	1,220	1,220	496	....
Series D.—Ammonium sulphate:									
0-0-0	1	824	718	....	....	536	494	....	....
	7	612				452			
2-8-4	2	928	906	....	....	668	670	....	....
	6	884				672			
2-8-4	3	1,508	1,508	602	468	1,176	1,176	506	442
4-8-4	4	[2] 1,120	....	....	826	1,260	1,260	590	642
8-8-4	5	2,040	2,040	1,134	1,134	1,564	1,564	894	894
0-8-4	6	884	986	....	....	672	674	....	....
	10	1,088				676			
2-8-4	8	1,320	1,320	334	....	1,052	1,052	378	....
4-8-4	9	1,812	1,812	826	....	1,368	1,368	694	....
Series E.—Urea: [3]									
0-0-0	1	208	128	....	....	100	70	....	....
	7	48				40			
0-8-4	2	936	836	....	....	656	540	....	....
	6	736				424			
2-8-4	3	1,228	1,228	392	310	976	976	436	345
4-8-4	4	1,340	1,340	504	532	1,044	1,044	504	497
8-8-4	5	1,412	1,412	576	576	1,048	1,048	508	508
0-8-4	6	736	796	....	....	424	546	....	....
	10	856				668			
2-8-4	8	1,024	1,024	228	....	800	800	254	....
4-8-4	9	1,356	1,356	560	....	1,036	1,036	490	....

[1] Mixed salt (from K_2SO_4) was substituted for sodium nitrate in 1921. The potash content of the fertilizer mixtures containing sodium nitrate was 4 per cent and with the mixed salt 5 per cent.
[2] This plat is omitted from the averages because through mistake it received no nitrogen.
[3] Calcium nitrate with basic slag was substituted for urea in 1921.

Results with cotton.—Table 12 gives the yields of seed cotton for the two years. These show considerable variations between treatments, ammonium sulphate usually giving the largest increases. Sodium nitrate and urea were about as good, however. With regard to urea it will be noticed that there was a wide variation between the yields of series C and E in 1920. This again emphasizes the marked soil variations and shows the necessity of disregarding small differences in judging the value of any particular source of nitrogen. Series A, which received mixed salt, was likewise located on a very poor area with a shallow surface soil. Taking these points into consideration, there seemed to be little difference between the fertilizing values of urea, ammonium sulphate, sodium nitrate, and the two mixed salts. Calcium nitrate was not as satisfactory as the other materials, probably because the nitrate-basic slag mixture became very hard after mixing and could not be distributed properly. The data are scarcely adequate for drawing sharp lines of distinction. The growth of cotton with urea is shown in Plate VII, Figure 1, and with the two mixed salts in Plate VIII, Figures 1 and 2.

TABLE 13.—*Yields per acre of corn from Section III of field No. 1 in 1920 and 1921.*

Fertilizer ratio.	Plat.	Yields of corn. 1920 Stalks (pounds).	1920 Grain (bushels). Actual.	1920 Grain (bushels). Average.	1920 Grain (bushels). Increase over check.	1921 Stalks (pounds).	1921 Grain (bushels). Actual.	1921 Grain (bushels). Average.	1921 Grain (bushels). Increase over check.
Series A.—Mixed salt (from KCl):									
0-0-0	16	640	8.0	8.0	....	1,760	13.1	13.1	....
0-4-2	11	1,200	7.7	9.9	....	1,560	4.6	9.2	....
	15	1,440	12.0			1,920	13.7		
1-4-2	12	2,160	8.0	8.0	−1.9	2,000	10.3	10.3	1.1
2-4-2	13	2,240	10.3	10.3	.4	2,200	17.1	17.1	7.9
4-4-2	14	2,720	20.0	20.0	10.1	2,560	30.9	30.9	21.7
Series B.—Sodium nitrate:[1]									
0-0-0	16	1,860	19.7	19.7	....	2,160	34.9	34.9	....
0-4-2	11	2,700	18.0	21.9	....	1,920	13.1	20.9	....
	15	2,760	25.7			2,200	28.6		
1-4-2	12	3,520	17.7	17.7	−4.2	2,240	21.1	21.1	.2
2-4-2	13	3,480	21.1	21.1	−.8	2,360	24.6	24.6	3.7
4-4-2	14	3,720	38.3	38.3	16.4	2,720	37.7	37.7	16.8
Series C.—Urea:									
0-0-0	16	1,920	20.6	20.6	....	2,120	29.1	29.1	....
0-4-2	11	2,640	12.0	18.9	....	1,800	6.3	15.5	....
	15	2,840	25.7			2,120	24.6		
1-4-2	12	3,280	14.9	14.9	−4.0	2,040	14.9	14.9	−.6
2-4-2	13	3,480	21.1	21.1	2.2	2,320	24.6	24.6	9.1
4-4-2	14	3,800	38.3	38.3	19.4	2,640	41.1	41.1	25.6
Series D.—Ammonium sulphate:									
0-0-0	16	1,440	10.3	10.3	....	1,760	21.1	21.1	....
0-4-2	11	2,100	12.0	14.0	....	1,680	8.0	12.0	....
	15	2,480	16.0			1,720	16.0		
1-4-2	12	2,360	5.7	5.7	−8.3	1,680	9.1	9.1	−2.9
2-4-2	13	2,680	9.7	9.7	−4.3	2,120	14.3	14.3	2.3
4-4-2	14	3,200	26.3	26.3	12.3	2,480	32.0	32.0	20.0
Series E.—Urea:[2]									
0-0-0	16	1,600	20.6	20.6	....	1,840	27.4	27.4	....
0-4-2	11	2,220	24.0	30.0	....	1,680	21.7	30.0	....
	15	3,000	36.0			2,560	38.3		
1-4-2	12	3,040	22.9	22.9	−7.1	2,320	31.4	31.4	1.4
2-4-2	13	2,760	25.1	25.1	−4.9	2,760	37.1	37.1	7.1
4-4-2	14	3,480	38.9	38.9	8.9	2,920	45.1	45.1	15.1

[1] Mixed salt (from K_2SO_4) was substituted for sodium nitrate in 1921.
[2] Calcium nitrate with basic slag was substituted for urea in 1921.

Results with corn.—The yields given in Table 13 again show the wide differences in fertility between series and within the same series. The results for series E for the season of 1920 should be discarded, since these plats were located on very wet soil. During the rainy period of early spring about half of the plants died and the area had to be replanted. The extremely wide variations between check plats of all of the series during 1921 were due primarily to weather conditions. The plats were located on a gentle slope, the lower ones being much better supplied with moisture than the upper.

It is useless to try to state the relative merits of the fertilizers, for the reasons given. The observations during growth as well as yields, however, did not indicate any appreciable differences between urea, the two mixed salts, ammonium sulphate, and sodium nitrate. Even calcium nitrate gave a good increase in yield regardless of its slow start, due probably, as already stated, to the poor mechanical condition of the mixture when applied. The growth of corn with urea is shown in Plate VII, Figure 2.

The figures given in Table 13 and elsewhere show a marked tendency for small applications of nitrogen to produce stalks rather than grain in many instances. The season of 1920 was especially favorable for a high percentage of stalks, while the reverse was true in 1921. This was due chiefly to two factors: (1) Fewer stalks were left per given area in 1921 than in 1920, thus making available more food, sunlight, and moisture for each plant; (2) the wet growing season of 1920 produced a very rapid growth and probably a limited root system, since plenty of plant food was available in the vicinity of the seedlings. As this supply neared exhaustion the late growth and maturity suffered, because there was not enough nitrogen to produce a grain yield proportionate to the large stalk production. The lack of a wide-spreading root system left the plants at a greater disadvantage than those which received no nitrogen. On the other hand, during the season of 1921 the early plant growth was slowed down because of lack of moisture. Plant development was gradual throughout the year, and the stalks were really smaller than normal. Plenty of rain at the time of seed formation favored a grain production proportionate to the weight of the stalk, even with the smallest quantities of nitrogen. These facts emphasize the importance of a study of the best methods of applying fertilizers, for example, in the drill, by side applications or broadcasting.

FIELD NO. 2.

This field, a diagram of which is shown as Figure 2, is the one that was planted to winter crops in the fall of 1919. After harvesting the crops in June the soil was allowed to remain barren until the spring of 1921, when the experiments with cotton and corn reported on below were started.

AMMONIUM NITRATE, UREA, AMMONIUM SULPHATE, AND CYANAMID (SINGLY AND IN MIXTURE WITH CALCIUM NITRATE).—SECTION I.

Results with cotton.—The importance of the weather conditions in this experiment necessitates a special reference to this factor. Planting was done near the end of a very wet period and was followed by a prolonged period of dry hot weather. There was adequate moisture to produce almost perfect germination, but the subsequent drought caused the burning and death of a large number of plants on

FIG. 1.—GROWTH OF COTTON WITH UREA. FIELD 1, SEASON OF 1920.

At left, urea, 1,000 pounds 8-8-4 fertilizer per acre; yield 1,412 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-4 fertilizer per acre; yield 736 pounds of seed cotton.

FIG. 2.—GROWTH OF CORN WITH UREA. FIELD 1, SEASON OF 1921.

At left, urea, 1,000 pounds 4-4-2 fertilizer per acre; yield 41.1 bushels. At right, no nitrogen, 1,000 pounds 0-4-2 fertilizer per acre; yield 24.6 bushels.

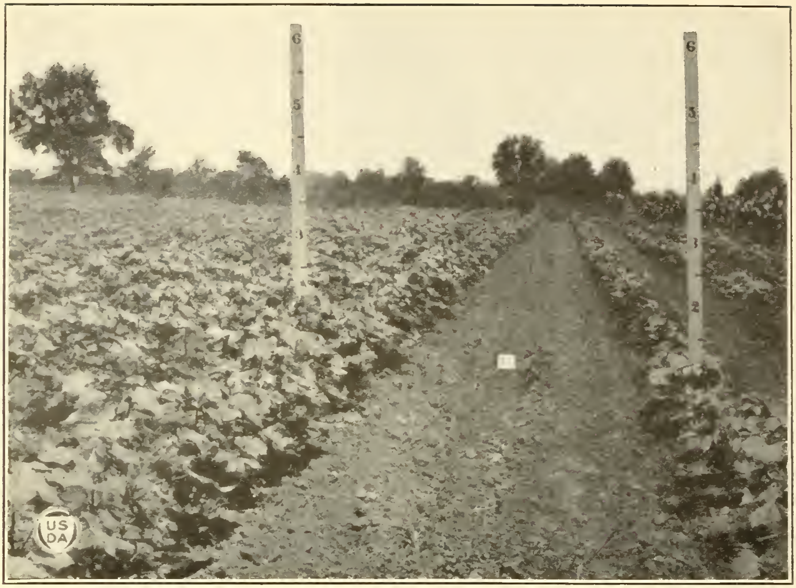

FIG. 1.—EARLY GROWTH OF COTTON WITH SULPHATE MIXED SALT. FIELD I, SEASON OF 1921.

At left, mixed salt, 1,000 pounds 4-8-5 fertilizer per acre; yield 996 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-5 fertilizer per acre; yield 528 pounds of seed cotton.

FIG. 2.—EARLY GROWTH OF COTTON WITH CHLORID MIXED SALT. FIELD I, SEASON OF 1921.

At left, mixed salt, 1,000 pounds 4-8-6 fertilizer per acre; yield 1,172 pounds of seed cotton. At right, no nitrogen, 1,000 pounds 0-8-6 fertilizer per acre; yield 544 pounds of seed cotton.

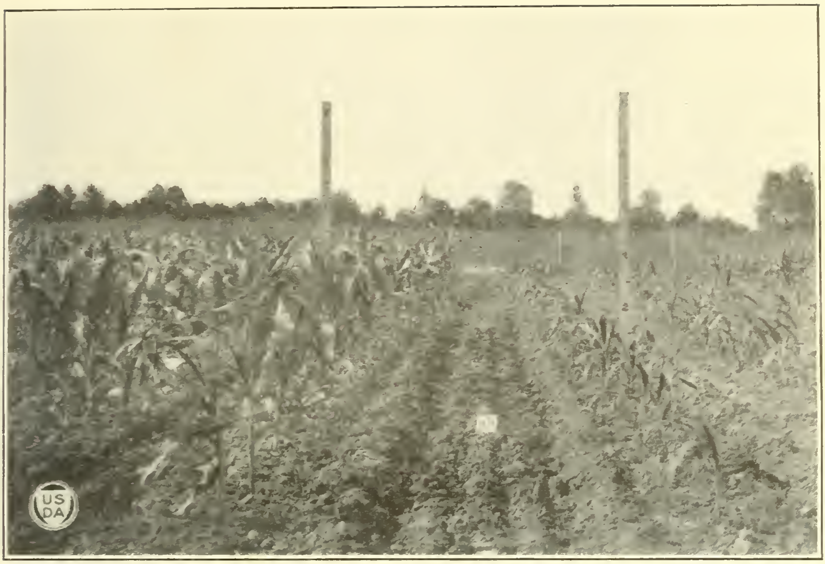

FIG. 1.—EARLY GROWTH OF CORN WITH SULPHATE MIXED SALT. FIELD 2, SEASON OF 1921.

At left, mixed salt, 1,000 pounds 1-8-5 fertilizer per acre; yield 38.5 bushels. At right, no fertilizer; yield 33.7 bushels.

FIG. 2.—EARLY GROWTH OF CORN WITH AMMONIUM CHLORID. FIELD 2, SEASON OF 1921.

At left, ammonium chlorid, 1,000 pounds 1-8-4 fertilizer per acre; yield 17.7 bushels. At right, no fertilizer; yield 6.3 bushels.

FIG. 1.—EARLY GROWTH OF COTTON WITH DOUBLE SALT. FIELD 3, SEASON OF 1921.

At left, no fertilizer; yield 120 pounds of seed cotton per acre. At right, double salt, 1,000 pounds 2-8-4 fertilizer per acre; yield 763 pounds of seed cotton.

FIG. 2.—GROWTH OF CORN WITH DOUBLE SALT. FIELD 3, SEASON OF 1920.

At extreme left, no nitrogen, 1,000 pounds 0-4-2 fertilizer per acre; yield 19.6 bushels. Center (1 row), no fertilizer; yield 17.1 bushels. At right, double salt, 1,000 pounds 4-4-2 fertilizer per acre; yield 33.9 bushels.

certain areas. However, it was only where cyanamid was used that enough plants were killed to affect the stand appreciably. At the rate of 40 pounds per acre of ammonia, as cyanamid, the injuries were temporary, but with 80 pounds about half of the plants were killed, as is shown in Plate IV, Figure 2. Where calcium nitrate was used with cyanamid the extent of injury depended almost wholly upon the amount of cyanamid used.

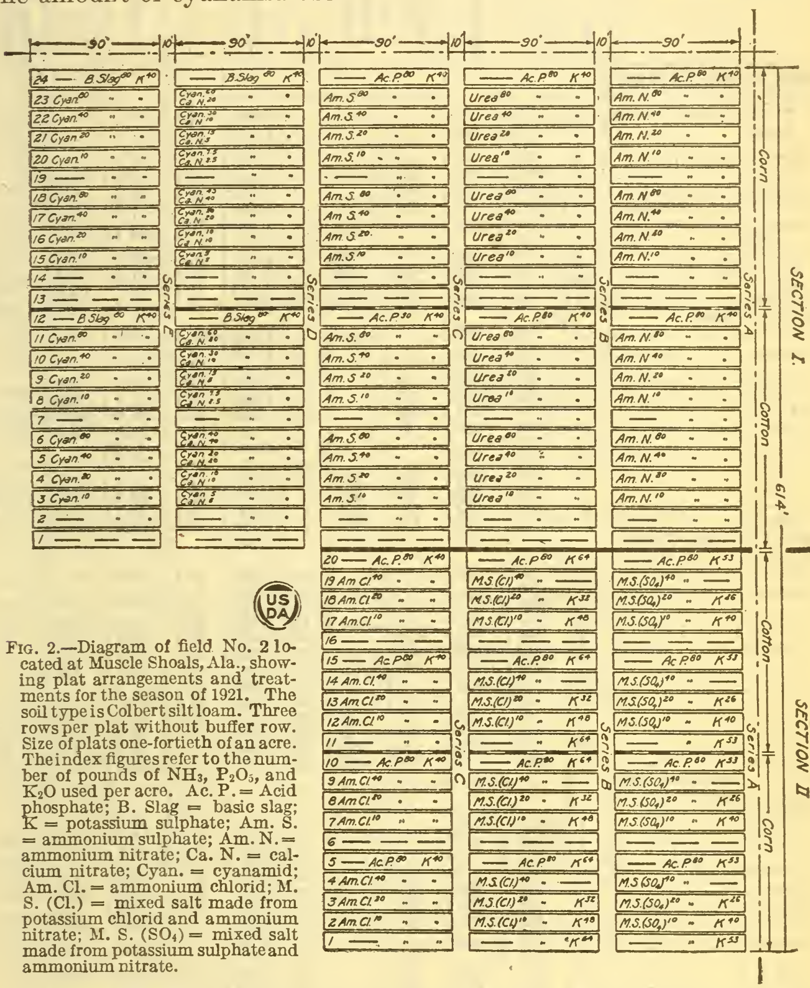

FIG. 2.—Diagram of field No. 2 located at Muscle Shoals, Ala., showing plat arrangements and treatments for the season of 1921. The soil type is Colbert silt loam. Three rows per plat without buffer row. Size of plats one-fortieth of an acre. The index figures refer to the number of pounds of NH_3, P_2O_5, and K_2O used per acre. Ac. P. = Acid phosphate; B. Slag = basic slag; K = potassium sulphate; Am. S. = ammonium sulphate; Am. N. = ammonium nitrate; Ca. N. = calcium nitrate; Cyan. = cyanamid; Am. Cl. = ammonium chlorid; M. S. (Cl.) = mixed salt made from potassium chlorid and ammonium nitrate; M. S. (SO_4) = mixed salt made from potassium sulphate and ammonium nitrate.

The soil variations were a greater factor in determining yields than the fertilizer treatments. On the ammonium-nitrate series the soil was the most uniform and best adapted to cotton of any. On the other hand, the soil of series B and C was too heavy and compact for cotton and too fertile to give satisfactory results in a fertilizer experiment. On these two series early growth was slow, while the late growth was unusually rapid. The result was a heavy stalk production, poor fruiting, and maximum boll-weevil injury, especially with the largest applications of nitrogen. The soil of series D and E was exceedingly variable, one side being very productive and the other the poorest in the field.

TABLE 14.—*Yields per acre of cotton and corn from Section I of field No. 2.*

[In series D tests marked with a star (*) cyanamid and calcium nitrate were used in equal proportions in those marked with a dagger (†) the proportions were 75 per cent cyanamid and 25 per cent calcium nitrate.]

Fertilizer ratio.	Plat.	Yields of seed cotton (pounds).				Plat.	Yields of corn.				
							Stalks (pounds).	Grain (bushels).			
		Actual.	Average.	Increase over check.	Average increase.			Actual.	Average.	Increase over check.	Average increase.
Series A.—Ammonium nitrate:											
0-0-0	1	460	460	......	......	13	2,320	28.6	28.6	......	......
0-8-4	2 7	632 988	810	......	......	14 19	2,520 2,680	30.3 37.1	33.7	......	......
1-8-4	3	760	760	−50	......	15	2,680	33.7	33.7	0	......
2-8-4	4	1,048	1,048	238	......	16	2,560	34.9	34.9	1.2	......
4-8-4	5	1,508	1,508	698	......	17	2,720	39.4	39.4	5.7	......
8-8-4	6	1,560	1,560	750	......	18	2,920	41.1	41.1	7.4	......
0-8-4	7 12	988 728	858	......	......	19 24	2,680 3,040	37.1 41.7	39.4	......	......
1-8-4	8	836	836	−22	−36	20	2,680	36.0	36.0	−3.4	−1.7
2-8-4	9	772	772	−86	76	21	2,720	37.1	37.1	−2.3	−.6
4-8-4	10	984	984	126	412	22	3,040	41.7	41.7	2.3	4.0
8-8-4	11	1,460	1,460	602	676	23	3,040	41.1	41.1	1.7	4.6
Series B.—Urea:											
0-0-0	1	440	440	......	......	13	2,040	21.1	21.1	......	......
0-8-4	2 7	892 972	932	......	......	14 19	2,120 2,400	16.6 10.9	13.8	......	......
1-8-4	3	1,088	1,088	156	......	15	2,040	17.1	17.1	3.3	......
2-8-4	4	1,308	1,308	376	......	16	2,000	17.1	17.1	3.3	......
4-8-4	5	1,288	1,288	356	......	17	2,320	26.9	26.9	13.1	......
8-8-4	6	984	984	52	......	18	2,480	36.0	36.0	22.2	......
0-8-4	7 12	972 628	800	......	......	19 24	2,400 2,520	10.9 30.3	20.6	......	......
1-8-4	8	1,044	1,044	244	200	20	2,240	14.9	14.9	−5.7	−1.2
2-8-4	9	892	892	92	234	21	2,360	22.3	22.3	1.7	2.5
4-8-4	10	952	952	152	254	22	2,400	33.7	33.7	13.1	13.1
8-8-4	11	1,152	1,152	352	202	23	2,720	36.0	36.0	15.4	18.8
Series C.—Ammonium sulphate:											
0-0-0	1	392	392	......	......	13	2,440	38.3	38.3	......	......
0-8-4	2 7	796 688	742	......	......	14 19	3,000 2,320	42.9 13.7	28.3	......	......
1-8-4	3	880	880	138	......	15	2,680	40.0	40.0	11.7	......
2-8-4	4	708	708	−34	......	16	2,600	38.9	38.9	10.6	......
4-8-4	5	1,012	1,012	270	......	17	2,560	35.4	35.4	7.1	......
8-8-4	6	512	512	−230	......	18	2,040	33.1	33.1	4.8	......
0-8-4	7 12	688 844	766	......	......	19 24	2,320 2,440	13.7 29.7	21.7	......	......
1-8-4	8	740	740	−26	56	20	2,440	14.3	14.3	−7.4	2.2
2-8-4	9	844	844	78	22	21	2,480	20.6	20.6	−1.1	4.8
4-8-4	10	920	920	154	212	22	2,440	31.4	31.4	9.7	8.4
8-8-4	11	648	648	−118	−174	23	2,880	40.6	40.6	18.9	11.9
Series D.—Cyanamid and calcium nitrate (with basic slag):											
0-0-0	1	396	396	......	......	13	1,800	12.6	12.6	......	......
0-8-4	2 7	672 284	478	......	......	14 19	2,120 2,320	18.3 18.3	18.3	......	......
*1-8-4	3	684	684	206	......	15	2,480	21.7	21.7	3.4	......
*2-8-4	4	712	712	234	......	16	2,520	30.9	30.9	12.6	......
*4-8-4	5	808	808	330	......	17	2,720	34.9	34.9	16.6	......
*8-8-4	6	728	728	250	......	18	2,480	35.4	35.4	17.1	......
0-8-4	7 12	284 292	288	......	......	19 24	2,320 2,720	18.3 39.4	28.9	......	......
†1-8-4	8	404	404	116	......	20	2,400	21.1	21.1	−7.8	......
†2-8-4	9	524	524	236	......	21	2,560	30.3	30.3	1.4	......
†4-8-4	10	616	616	328	......	22	2,720	38.9	38.9	10.0	......
†8-8-4	11	528	528	240	......	23	2,840	36.6	36.6	7.7	......
Series E.—Cyanamid (with basic slag):											
0-0-0	1	524	524	......	......	13	1,840	23.4	23.4	......	......
0-8-4	2 7	708 424	566	......	......	14 19	2,440 2,440	20.6 36.6	28.6	......	......
1-8-4	3	796	796	230	......	15	2,280	25.7	25.7	−2.9	......
2-8-4	4	872	872	306	......	16	2,480	37.7	37.7	9.1	......
4-8-4	5	968	968	402	......	17	2,640	42.3	42.3	13.7	......
8-8-4	6	556	556	−10	......	18	2,400	39.4	39.4	10.8	......
0-8-4	7 12	424 440	432	......	......	19 24	2,440 2,120	36.6 41.7	39.2	......	......
1-8-4	8	516	516	84	157	20	2,520	39.4	39.4	.2	−1.4
2-8-4	9	576	576	144	225	21	2,760	42.9	42.9	3.7	6.4
4-8-4	10	748	748	316	359	22	2,880	46.3	46.3	7.1	10.4
8-8-4	11	672	672	240	115	23	2,920	46.3	46.3	7.1	9.0

The yields are given in Table 14. Ammonium nitrate produced good increases and was an entirely satisfactory nitrogen carrier for cotton. The yields with the various rates of application of urea and ammonium sulphate were unsatisfactory because of the soil, as previously pointed out. The two materials affected growth and maturity in the same manner. The yields with urea were slightly better than with ammonium sulphate, but the differences are not significant. The yields with cyanamid or cyanamid and calcium nitrate were considerably below those on the other three series, due largely to the poorer soil. In addition, the retarding effect of cyanamid did directly lower the yields and increased the boll-weevil injury. The failure of calcium nitrate to improve the mixture is contrary to results reported in the literature.

Results with corn.—Because of dry weather a decided injury was noted on all of the corn plats receiving 80 pounds of the ammonia equivalent, regardless of source. Cyanamid was more injurious than the other materials, but no more so than the same quantities of nitrogen supplied in a calcium-nitrate–cyanamid mixture. The materials were all equally available so far as observations could determine. Table 14 gives the results.

A consideration of the yields on the check plats of this entire section of the field emphasizes the marked irregularities of the soil. Variations of 100 per cent or more are not uncommon between check plats of the same series or between corresponding check plats of two different series joined end to end. Small differences between treatments are therefore unimportant.

The ammonium-nitrate series of plats was located on the most productive and wettest portion of the field. Consequently, the yields on all plats were good, regardless of fertilizer treatment. The increases produced by ammonium nitrate were slight, and the data do not permit any conclusions other than to say that the material gave responses similar to urea and ammonium sulphate.

The value of the yields with urea are likewise minimized by irregular soil conditions, but since the fertility was much lower than on the ammonium-nitrate series the increases produced by the urea were much more marked. Taking into consideration the check plats, urea seems equally as good as ammonium sulphate.

Cyanamid, either alone or with calcium nitrate, gave very good increases in yields except where the soil was already so rich that the fertilizer was ineffective. Neither the observations during growth nór the final yields showed cyanamid to be inferior to the other nitrogen carriers. The mixture with calcium nitrate gave larger increases in yields in some cases than cyanamid alone, but the soil was somewhat poorer.

AMMONIUM CHLORID AND THE MIXED SALTS.—SECTION II.

Results with cotton.—The relative values of the two mixed salts and ammonium chlorid, as shown by the figures in Table 15, are practically the same. The largest increases in yields were produced by the chlorid mixed salt, ammonium chlorid being second and the sulphate mixed salt third. It will be noted, however, that the chlorid mixed salt was used on the poorest soil. The actual yields were usually smaller with this material than with the others, but since the check plats were low the increases were comparatively larger. The wide variations in fertility and the boll-weevil damage makes the slight differences insignificant. The results do not justify the making of any distinctions between the merits of the three sources of nitrogen. Undoubtedly they are all very readily available, as is shown by Plate III, Figure 1.

Results with corn.—The yields of corn given in Table 15 show just as inconclusive results as with cotton. The soil of series A and B was so fertile that the increases produced by fertilizers were insignificant. The yields on series C were somewhat lower than on the other two, due to the poorer soil, but the increases over the checks were quite good. Ammonium chlorid seemed to be an entirely satisfactory source of nitrogen. No conclusions can be drawn from the results with the two mixed salts. Plate IX, Figures 1 and 2, shows the rapidity with which these materials are utilized by corn.

TABLE 15.—*Yields per acre of cotton and corn from Section II of field No. 2.*

Fertilizer ratio.	Plat.	Yields of seed cotton (pounds).				Plat.	Yields of corn.				
								Grain (bushels).			
		Actual.	Average.	Increase over check.	Average increase.		Stalks (pounds).	Actual.	Average.	Increase over check.	Average increase.
Series A.—Mixed salt (from K_2SO_4):											
0-0-0	16	580	580			6	2,720	33.7	33.7		
0-8-5	11 15	716 684	700			1 5	2,920 2,840	30.3 38.9	34.6		
1-8-5	12	828	828	128		2	2,960	32.0	32.0	−2.6	
2-8-5	13	756	756	56		3	2,640	33.1	33.1	−1.5	
4-8-5	14	1,000	1,000	300		4	2,880	37.1	37.1	2.5	
0-8-5	15 20	684 396	540			5 10	2,840 3,000	38.9 36.6	37.8		
1-8-5	17	764	764	224	176	7	2,960	38.3	38.3	.5	−1.1
2-8-5	18	580	580	40	48	8	2,960	39.4	39.4	1.6	.1
4-8-5	19	872	872	332	316	9	3,120	44.0	44.0	6.2	4.4
Series B.—Mixed salt (from KCl):											
0-0-0	16	340	340			6	2,000	22.9	22.9		
0-8-6	11 15	460 408	434			1 5	2,880 2,400	40.0 26.3	33.2		
1-8-6	12	516	516	82		2	2,640	35.4	35.4	2.2	
2-8-6	13	660	660	226		3	2,880	36.6	36.6	3.4	
4-8-6	14	764	764	330		4	2,780	35.4	35.4	2.2	
0-8-6	15 20	408 672	540			5 10	2,400 2,480	26.3 14.3	20.3		
1-8-6	17	616	616	76	79	7	2,440	20.6	20.6	.3	1.3
2-8-6	18	820	820	280	253	8	2,520	20.0	20.0	−.3	1.6
4-8-6	19	1,076	1,076	536	433	9	2,920	26.9	26.9	6.6	4.4
Series C.—Ammonium chlorid:											
0-0-0	16	556	556			6	1,040	6.3	6.3		
0-8-4	11 15	204 748	476			1 5	2,160 2,120	16.6 9.7	13.2		
1-8-4	12	444	444	−32		2	2,320	14.9	14.9	1.7	
2-8-4	13	612	612	136		3	2,360	19.4	19.4	6.2	
4-8-4	14	952	952	476		4	2,780	22.3	22.3	9.1	
0-8-4	15 20	748 1,024	886			5 10	2,120 2,200	9.7 13.1	11.4		
1-8-4	17	1,068	1,068	182	75	7	2,200	17.7	17.7	6.3	4.0
2-8-4	18	1,048	1,048	162	149	8	2,560	22.9	22.9	11.5	8.9
4-8-4	19	1,120	1,120	234	355	9	2,720	25.1	25.1	13.7	11.4

FIELD NO. 3.

This field, which was located quite near field No. 2, was used for experimental purposes during the seasons of 1920 and 1921. The soil was rather low and very widely different in productiveness on various portions of the plat. It was well suited to corn but too compact for the best results with cotton. The nitrogenous fertilizers used were ammonium sulphate, ammonium chlorid, double salt, ammoniated superphosphate, ammonium phosphate, and cyanamid. The plat arrangements are shown in Figure 3.

Results with cotton.—The yields of seed cotton for the two successive seasons are shown in Table 16. These show a decrease of about 10 to 30 per cent on the average for 1921 as compared with 1920, due to the dry weather and the boll weevil. The latter injury was rather uniformly distributed over the field and for the most part limited to the late crop. Consequently, the injury was greatest on those plats where the cotton was slowest in reaching maturity. These were the unfertilized areas and the plats receiving the largest applications of nitrogen, especially cyanamid.

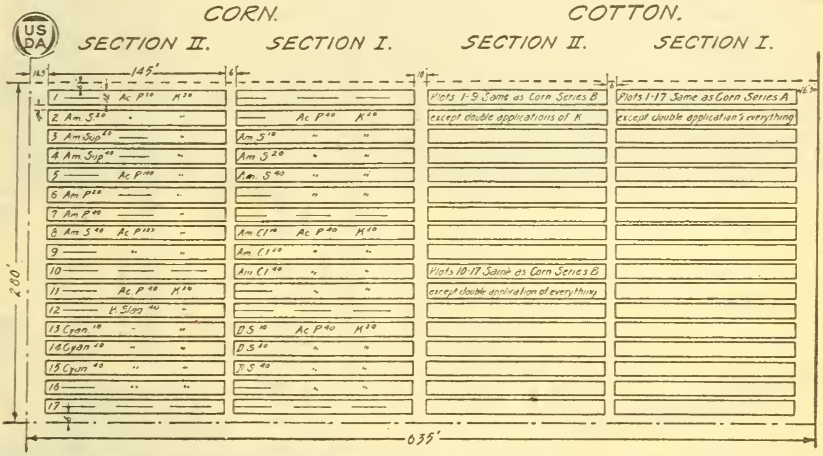

FIG. 3.—Diagram of field No. 3 located at Muscle Shoals, Ala., showing plat arrangements and treatments for the season of 1921. The soil type is Colbert silt loam. Three rows per plat with buffer row. Size of plats, one twenty-fifth of an acre. The index figures refer to the number of pounds of NH_3, P_2O_5, and K_2O used per acre. Ac. P. = Acid phosphate; K = potassium sulphate; Cyan. = cyanamid; Am. S. = ammonium sulphate; Am. Cl. = ammonium chlorid; D. S. = double salts; Am. Sup. = ammoniated superphosphate; Am. P. = ammonium phosphate; B. Slag = basic slag.

The increases in seed cotton produced by ammonium sulphate and double salt were of about the same magnitude, the yields with both materials increasing as the food supplied increased. On the other hand, ammonium chlorid showed opposite results for both seasons, the largest yield being obtained with the smallest nitrogen treatment. These plats were located on soil that seemed to be quite uniform. This would indicate that under the conditions of this test the chlorid ion was toxic when used in large concentrations and stimulating at the smaller rates. The responses of cotton to double salt and ammonium chlorid are shown in Plate X, Figure 1, and Plate XI, Figure 1, respectively.

The ammonium phosphate and ammoniated superphosphate plats of Section II were located on soil that was too rich in nitrogen to give large responses to additions of this element. Phosphorus was somewhat deficient, however, and its use largely blotted out the effects of the nitrogen. The effects of ammonium phosphate and ammoniated superphosphate on growth corresponded to those noted with ammonium sulphate, and it is believed that the materials are of about equal value as nitrogen carriers. The early responses are shown in Plate XI, Figure 2, and Plate XII, Figures 1 and 2.

TABLE 16.—*Yields per acre of cotton from Sections I and II of field No. 3 in 1920 and 1921.*

Treatment.	Fertilizer ratio.	Plat.	Yields of seed cotton (pounds). 1920 Actual.	1920 Average.	1920 Increase over check.	1921 Actual.	1921 Average.	1921 Increase over check.
Section I:								
No fertilizer	0-0-0	1	355	263	....	268	195	....
		7	170			122		
No nitrogen	0-8-4	2	538	550	....	540	490	....
		6	562			440		
Ammonium sulphate	2-8-4	3	850	850	300	833	833	343
	4-8-4	4	1,045	1,045	495	1,018	1,018	528
	8-8-4	5	1,250	1,250	700	1,080	1,080	590
No fertilizer	0-0-0	7	170	238	....	123	122	....
		12	305			120		
No nitrogen	0-8-4	6	562	643	....	440	474	....
		11	723			508		
Ammonium chlorid	2-8-4	8	1,230	1,230	587	948	948	474
	4-8-4	9	1,125	1,125	482	783	783	309
	8-8-4	10	1,088	1,088	445	715	715	241
No fertilizer	0-0-0	12	305	268	....	120	143	....
		17	230			165		
No nitrogen	0-8-4	11	723	611	....	508	483	....
		16	498			458		
Double salt	2-8-4	13	1,050	1,050	439	763	763	280
	4-8-4	14	1,075	1,075	464	925	925	442
	8-8-4	15	1,218	1,218	607	1,083	1,083	600
Section II:								
No nitrogen	0-5-4	1	1,008	1,008	....	745	745	....
Ammonium sulphate	2-5-4	2	1,050	1,050	42	735	735	−10
Ammoniated superphosphate	2-5-4	3	805	805	−203	553	553	−192
No nitrogen	0-10-4	5	643	643	....	300	300	....
Ammonium phosphate	2-7-4	6	943	943	300	608	608	308
Ammoniated superphosphate	4-10-4	4	1,125	1,125	482	868	868	568
No fertilizer	0-0-0	10	388	388	....	108	108	....
No nitrogen	0-13-4	9	1,048	1,048	....	620	620	....
Ammonium phosphate	4-13-4	7	1,223	1,223	175	890	890	270
Ammonium sulphate	4-13-4	8	1,425	1,425	377	958	958	338
No fertilizer	0-0-0	10	388	388	....	108	108	....
No nitrogen (acid phosphate)	0-8-4	11	668	668	280	483	483	375
No nitrogen (calcined phosphate)[1]	0-8-4	12	633	633	245	433	433	325
No fertilizer	0-0-0	10	388	391	....	108	198	....
		17	393			288		
No nitrogen (calcium phosphate)	0-8-4	12	633	573	....	433	469	....
		16	513			505		
Cyanamid (with calcined phosphate)[1]	2-8-4	13	793	793	220	618	618	149
	4-8-4	14	835	835	262	655	655	186
	8-8-4	15	715	715	142	568	568	99

[1] Basic slag was substituted for calcined phosphate in 1921.

Cyanamid gave low yields in both years and was not as satisfactory a fertilizer as any of the other materials. The plants were very green but failed to grow rapidly or form large numbers of bolls. Nitrification was probably slow in this heavy soil and dicyanodiamid production was favored. It is believed that the poor yields with cyanamid can not be attributed to the use of basic slag or calcined phosphate.

FIG. 1.—EARLY GROWTH OF COTTON WITH AMMONIUM CHLORID. FIELD 3, SEASON OF 1921.

At left, no fertilizer; yield 123 pounds of seed cotton per acre. At right, ammonium chlorid, 1,000 pounds 2-8-4 fertilizer per acre; yield 948 pounds of seed cotton.

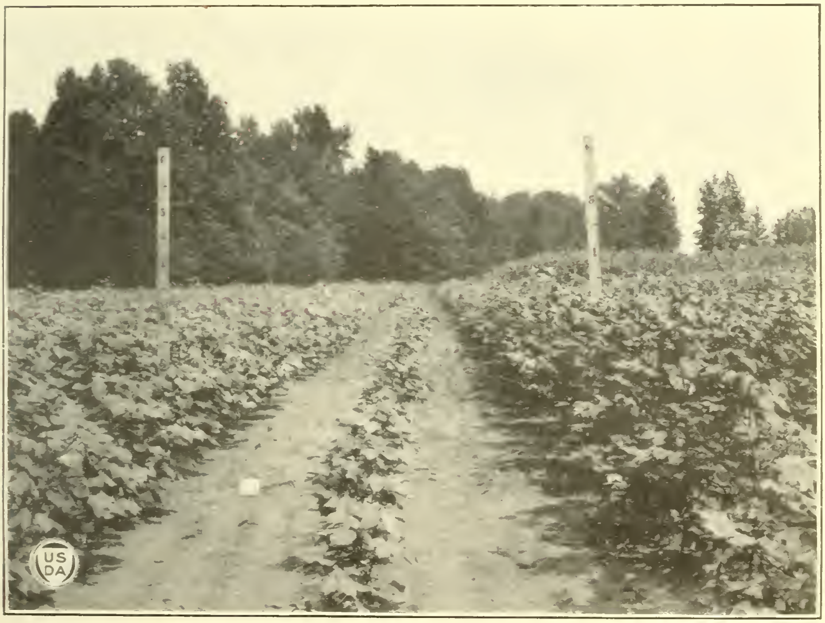

FIG. 2.—GROWTH OF COTTON WITH AMMONIUM PHOSPHATE. FIELD 3, SEASON OF 1921.

At left, no nitrogen, 1,000 pounds 0-10-4 fertilizer per acre; yield 300 pounds of seed cotton. Center (1 row), no fertilizer; yield 165 pounds of seed cotton per acre. At right, ammonium phosphate, 1,000 pounds 2-7-4 fertilizer per acre; yield 608 pounds of seed cotton.

FIG. 1.—GROWTH OF COTTON WITH AMMONIUM PHOSPHATE AND AMMONIUM SULPHATE. FIELD 3, SEASON OF 1921.

At left, ammonium phosphate, 1,000 pounds 4-13-4 fertilizer per acre; yield 890 pounds of seed cotton. Center (1 row), no fertilizer; yield 285 pounds of seed cotton. At right, ammonium sulphate, 1,000 pounds 4-13-4 fertilizer per acre; yield 958 pounds of seed cotton.

FIG. 2.—EARLY GROWTH OF COTTON WITH AMMONIUM SULPHATE AND AMMONIATED SUPERPHOSPHATE. FIELD 3, SEASON OF 1921.

At left, ammonium sulphate, 1,000 pounds 2-5-4 fertilizer per acre; yield 735 pounds of seed cotton. Center (1 row), no fertilizer; yield 188 pounds of seed cotton per acre. At right, ammoniated superphosphate, 1,000 pounds 2-5-4 fertilizer per acre; yield 553 pounds of seed cotton. (Soil somewhat poorer on this plat.)

FIG. 1.—GROWTH OF COTTON WITH UREA. FIELD 4, SEASON OF 1920.

At left (1 row), no fertilizer; yield 624 pounds of seed cotton per acre. At right, urea, 1,000 pounds 4-8-4 fertilizer per acre; yield 1,164 pounds of seed cotton. (Yields are for 1921 season.)

FIG. 2.—GROWTH OF CORN WITH AMMONIUM SULPHATE AND AMMONIUM PHOSPHATE. FIELD 4, SEASON OF 1920.

At left, ammonium sulphate, 1,000 pounds 4-13-2 fertilizer per acre; yield 26 bushels. Center (1 row), no fertilizer; yield 16.3 bushels. At right, ammonium phosphate, 1,000 pounds 4-13-2 fertilizer per acre; yield 24.9 bushels

FIG. 1.—YIELDS OF CORN WITH AMMONIUM NITRATE. FIELD 4, SEASON OF 1920.

At left, no nitrogen, 1,000 pounds 0-4-2 fertilizer per acre; yield 32.6 bushels. At right, ammonium nitrate, 1,000 pounds 2-4-2 fertilizer per acre; yield 50.6 bushels

FIG. 2.—YIELDS OF CORN WITH AMMONIATED SUPERPHOSPHATE. FIELD 4, SEASON OF 1920.

At left, no nitrogen, 1,000 pounds 0-10-2 fertilizer per acre; yield 18.6 bushels. At right, ammoniated superphosphate, 1,000 pounds 4-10-2 fertilizer per acre; yield 33.4 bushels.

The comparisons between acid phosphate and calcined phosphate as sources of phosphorus showed a small difference in favor of the former. This difference was in evidence to a slight extent during growth, the calcined phosphate being somewhat slower to stimulate growth.

TABLE 17.—*Yields per acre of corn from Sections I and II of field No. 3 in 1920 and 1921.*

Treatment.	Fertilizer ratio.	Plat.	Yields of corn.							
			1920				1921			
			Stalks (pounds).	Grain (bushels).			Stalks (pounds).	Grain (bushels).		
				Actual.	Average.	Increase over check.		Actual.	Average.	Increase over check.
Section I:										
No fertilizer	0-0-0	1	2,950	45.7	43.1	....	1,950	30.7	31.6	......
		7	2,550	40.4			2,000	32.5		
No nitrogen	0-4-2	2	2,300	33.9	36.8	....	2,200	31.4	32.0	......
		6	2,750	39.6			2,300	32.5		
Ammonium sulphate	1-4-2	3	2,950	43.2	43.2	6.4	2,300	32.1	32.1	0.1
	2-4-2	4	3,175	48.2	48.2	11.4	2,625	40.7	40.7	8.7
	4-4-2	5	3,600	54.6	54.6	17.8	2,725	43.6	43.6	11.6
No fertilizer	0-0-0	7	2,550	40.4	28.4	....	2,000	32.5	20.9	......
		12	1,500	16.3			1,325	9.3		
No nitrogen	0-4-2	6	2,750	39.6	29.6	....	2,300	32.5	22.3	......
		11	1,800	19.6			1,700	12.1		
Ammonium chlorid	1-4-2	8	3,150	42.5	42.5	12.9	2,175	28.6	28.6	6.3
	2-4-2	9	3,100	44.6	44.6	15.0	2,200	32.9	32.9	10.6
	4-4-2	10	2,975	38.2	38.2	8.6	2,500	36.1	36.1	13.8
No fertilizer	0-0-0	12	1,500	16.3	18.0	....	1,325	9.3	11.5	......
		17	2,425	19.6			1,250	13.6		
No nitrogen	0-4-2	11	1,800	19.6	19.6	....	1,700	12.0	11.9	......
		16	1,975	19.6			1,750	11.8		
Double salt	1-4-2	13	2,400	17.5	17.5	−2.1	1,700	12.1	12.1	.2
	2-4-2	14	2,825	24.3	24.3	4.7	1,900	17.9	17.9	6.0
	4-4-2	15	3,075	33.9	33.9	14.3	2,075	26.1	26.1	14.2
Section II:										
No nitrogen	0-5-2	1	2,925	46.1	46.1	....	2,900	50.7	50.7	......
Ammonium sulphate.	2-5-2	2	3,100	47.1	47.1	1.0	2,750	45.4	45.4	−5.3
Ammoniated superphosphate.	2-5-2	3	3,125	43.2	43.2	−2.9	2,525	38.6	38.6	−12.1
No nitrogen	0-10-2	5	2,725	40.4	40.4	....	2,075	28.2	28.2	......
Ammonium phosphate.	2-7-2	6	2,950	33.2	33.2	−7.2	2,050	31.8	31.8	3.6
Ammoniated superphosphate.	4-10-2	4	3,225	37.5	37.5	−2.9	2,800	40.0	40.0	11.8
No fertilizer	0-0-0	10	2,250	37.9	37.9	....	1,800	36.1	36.1	......
No nitrogen	0-13-2	9	2,975	43.9	43.9	....	2,200	33.6	33.6	......
Ammonium phosphate.	4-13-2	7	3,700	46.8	46.8	2.9	2,225	38.2	38.2	4.6
Ammonium sulphate.	4-13-2	8	3,650	45.7	45.7	1.8	2,450	35.0	35.0	1.4
No fertilizer	0-0-0	10	2,250	37.9	37.9	....	1,800	36.1	36.1	......
No nitrogen (acid phosphate).	0-4-2	11	2,275	37.9	37.9	0	1,950	32.9	32.9	−3.2
No nitrogen (calcined phosphate).[1]	0-4-2	12	1,925	30.7	30.7	−7.2	2,000	27.5	27.5	−8.6
No fertilizer	0-0-0	10	2,250	37.9	35.8	....	1,800	36.1	33.6	......
		17	1,925	33.6			1,825	31.1		
No nitrogen (calcined phosphate) [1]	0-4-2	12	1,925	30.7	35.6	....	2,000	27.5	31.6	......
		16	2,425	40.4			2,200	35.7		
Cyanamid (with calcined phosphate).[1]	1-4-2	13	2,525	36.4	36.4	.8	2,100	35.0	35.0	3.4
	2-4-2	14	2,975	41.1	41.1	5.5	2,025	37.1	37.1	5.5
	4-4-2	15	3,250	48.6	48.6	13.0	2,575	45.0	45.0	13.4

[1] Basic slag was substituted for calcined phosphate in 1921.

Results with corn.—Table 17 shows that the increases in yields produced by ammonium chlorid and double salt were of about the same order as with ammonium sulphate. The soil of this section lacked uniformity, the yields from the check plats varying from 9.3 to 32.5 bushels for the second year. Hence, no accurate quantitative comparisons can be made between treatments. Ammonium chlorid seemed to be slightly toxic the first year at the largest rate of application but gave strictly normal results the second year, the yields increasing as the nitrogen supply increased. Plate X, Figure 2, shows the marked contrast in the growth of corn with and without double salt.

The fertilizer tests comparing ammonium phosphate, ammonium sulphate, and ammoniated superphosphate were unsatisfactory because the natural fertility of the soil was considerably above the average. No conclusions can be drawn. Cyanamid produced unusually good increases in yields considering that the soil was very fertile. It was not injurious even when applied in the row at the rate of 40 pounds of ammonia. The results compared very favorably with those obtained in Section I with ammonium sulphate. Again, it has been shown that corn can utilize cyanamid nitrogen under conditions where it is largely unavailable for cotton.

Field No. 4.

This field, a diagram of which appears as Figure 4, was used for experimental work during the seasons of 1920 and 1921. Cotton and corn were grown both years, but a combination of late planting and an unusually bad attack of boll weevils resulted in practically no cotton for the first year. These results are omitted from this report. The sources of nitrogen used were ammonium sulphate, urea, ammonium chlorid, ammonium nitrate, ammoniated superphosphate, ammonium phosphate, cyanamid, and double salt.

Results with cotton.—The extremely dry weather during the first part of the growing season undoubtedly played an important part in the yields. There was not sufficient rainfall during the period of 10 weeks subsequent to planting to moisten all of the dry surface soil. The result was a dwarfing of the plants and little effect from the fertilizer treatments. The moisture was adequate during the latter half of the season, and an exceedingly rapid growth resulted. At the time of maturity the plants were normal in size and the fruiting good, but the bolls were small.

The cotton yields are given in Table 18. These figures show no appreciable difference in the availability of the nitrogen in urea, ammonium chlorid, and ammonium nitrate. At the largest rate of application the results with all of these newer materials were better than with ammonium sulphate. The soil irregularities probably were responsible for this, as shown by differences in yields on the unfertilized plats of Section I, ranging from 368 to 1,040 pounds of seed cotton per acre. The responses to growth produced by all of these materials indicated that they were equally good. The growth with urea is shown in Plate XIII, Figure 1.

The yields from the plats of Section II show that this soil was nearly as variable as on series A, the check plats showing yields of 351 to 840 pounds of seed cotton per acre. In the comparisons between ammonium phosphate and ammoniated superphosphate, using ammonium sulphate as a standard, there was a slight difference in favor of ammonium phosphate at both rates of application. At the smaller rate ammonium phosphate and ammonium sulphate were of equal value, but with the larger application ammonium sulphate was considerably better, the actual yields from the adjoining plats being 1,428 pounds of seed cotton with this material and 1,280 pounds with ammonium phosphate. Cyanamid gave good results

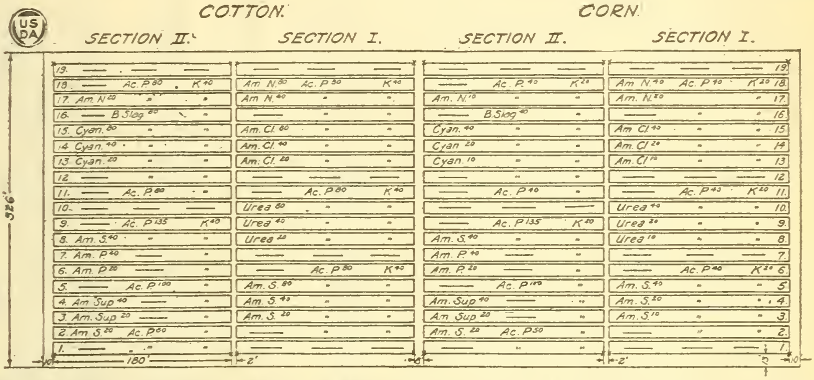

FIG. 4.—Diagram of field No. 4, located at Muscle Shoals, Ala., showing plat arrangements and treatments for the season of 1921. The soil type is Decatur silt loam. Three rows per plat with buffer row. Size of plats, one-twentieth of an acre. The index figures refer to the number of pounds of NH_3, P_2O_5 and K_2O used per acre. Ac. P. = acid phosphate; K = potassium sulphate; Cyan. = cyanamid; Am. Cl. = ammonium chlorid; Am. S. = ammonium sulphate; Am. N. = ammonium nitrate; Am. P. = ammonium phosphate; Am. Sup. = ammoniated superphosphate; B. Slag = basic slag.

on this area, the increases over the checks being approximately as large as with any other material used. The actual yields were considerably lower, however, because the soil at this point was very poor. At the largest rate of application cyanamid produced injuries and delayed growth and maturity to such an extent that the yield was less with 80 pounds of the ammonia equivalent than with 40 pounds. The plants on the cyanamid plats were a dark green and rather small but bushy. The bolls were slightly above the average in size and were nor destroyed to as great an extent by the boll weevil as were those on adjoining plats.

TABLE 18.—*Yields per acre of cotton from Sections I and II of field No. 4.*

Treatment.	Fertilizer ratio.	Plat.	Yields of seed cotton (pounds). Actual.	Average.	Increase over check.
Section I:					
No fertilizer	0- 0-0	1 7	554 448	501	....
No nitrogen	0- 8-4	2 6	792 664	728	....
Ammonium sulphate	2- 8-4 4- 8-4 8- 8-4	3 4 5	940 990 790	940 990 790	212 262 62
No fertilizer	0- 0-0	7 12	448 1,040	744	....
No nitrogen	0- 8-4	6 11	664 1,190	927	....
Urea	2- 8-4 4- 8-4 8- 8-4	8 9 10	920 1,164 1,330	920 1,164 1,330	−7 237 403
No fertilizer	0- 0-0	12	1,040	1,040	....
No nitrogen	0- 8-4	11 16	1,190 974	1,082	....
Ammonium chlorid	2- 8-4 4- 8-4 8- 8-4	13 14 15	1,510 1,390 1,500	1,510 1,390 1,500	428 308 418
No fertilizer	0- 0-0	19	368	368	....
No nitrogen	0- 8-4	16	974	974	....
Ammonium nitrate	4- 8-4 8- 8-4	17 18	1,380 1,470	1,380 1,470	406 496
Section II:					
No nitrogen	0- 5-4	1	840	840	....
Ammonium sulphate	2- 5-4	2	1,014	1,014	174
Ammoniated superphosphate	2- 5-4	3	880	880	40
No nitrogen	0-10-4	5	840	840	....
Ammonium phosphate	2- 7-4	6	1,010	1,010	170
Ammoniated superphosphate	4-10-4	4	1,110	1,110	270
No fertilizer	0- 0-0	10	580	580	....
No nitrogen	0-13-4	9	840	840	....
Ammonium phosphate	4-13-4	7	1,280	1,280	440
Ammonium sulphate	4-13-4	8	1,428	1,428	588
No fertilizer	0- 0-0	10	580	580	....
No nitrogen (acid phosphate)	0- 8-4	11	840	840	260
No nitrogen (basic slag)	0- 8-4	12	694	694	114
No fertilizer	0- 0-0	10	580	580	....
No nitrogen (with basic slag)	0- 8-4	12 16	694 304	499	....
Cyanamid (with basic slag)	2- 8-4 4- 8-4 8- 8-4	13 14 15	840 1,070 984	840 1,070 984	341 571 485
No fertilizer	0- 0-0	19	140	140	....
No nitrogen	0- 8-4	18	351	351	....
Ammonium nitrate	2- 8-4	17	823	823	472

Results with corn.—The yields of corn for the two years are given in Table 19. The results for Section I show good increases with all the materials. Urea, double salt, ammonium chlorid, and ammonium nitrate gave about as good results as ammonium sulphate. The severe weather conditions the second year as well as the natural soil variations make slight differences insignificant.

TABLE 19.—*Yields per acre of corn from Sections I and II of field No. 4 in 1920 and 1921.*

Treatment.	Fertilizer ratio.	Plat.	Yields of corn. 1920 Stalks (pounds).	1920 Grain (bushels). Actual.	1920 Grain (bushels). Average.	1920 Grain (bushels). Increase over check.	1921 Stalks (pounds).	1921 Grain (bushels). Actual.	1921 Grain (bushels). Average.	1921 Grain (bushels). Increase over check.
Section I:										
No fertilizer	0–0–0	1	2,020	18.6	19.8	....	1,020	17.7	21.3	......
		7	2,320	20.9			1,480	24.9		
No nitrogen	0–4–2	2	2,400	17.1	20.3	....	1,060	16.3	21.2	......
		6	3,000	23.4			1,440	26.0		
Ammonium sulphate	1–4–2	3	2,820	18.6	18.6	−1.7	1,280	18.6	18.6	−2.6
	2–4–2	4	2,960	24.9	24.9	4.6	1,480	23.1	23.1	1.9
	4–4–2	5	3,620	36.3	36.3	16.0	1,780	31.1	31.1	9.9
No fertilizer	0–0–0	7	2,320	20.9	20.9	....	1,480	24.9	25.0	......
		12	2,320	20.9			1,460	25.1		
No nitrogen	0–4–2	6	3,000	23.4	23.2	....	1,440	26.0	25.6	......
		11	2,400	22.9			1,680	25.1		
Urea	1–4–2	8	3,180	28.6	28.6	5.4	1,960	32.6	32.6	7.0
	2–4–2	9	3,280	29.1	29.1	5.9	2,240	34.3	34.3	8.7
	4–4–2	10	3,580	37.4	37.4	14.2	2,460	37.1	37.1	11.5
No fertilizer	0–0–0	12	2,320	20.9	20.9	....	1,460	25.1	25.1	......
No nitrogen	0–4–2	11	2,400	22.9	27.8	....	1,680	25.1	28.7	......
		16	3,120	32.6			2,280	32.3		
Double salt[1]	1–4–2	13	2,540	24.0	24.0	−3.8	1,960	27.1	27.1	−1.6
	2–4–2	14	3,040	26.9	26.9	− .9	2,300	33.1	33.1	4.4
	4–4–2	15	3,500	40.0	40.0	12.2	2,560	37.4	37.4	8.7
No fertilizer	0–0–0	19	3,020	43.1	43.1	....	2,640	42.0	42.0	......
No nitrogen	0–4–2	16	3,120	32.6	32.6	....	2,280	32.3	32.3	......
Ammonium nitrate	2–4–2	17	3,440	50.6	50.6	18.0	2,880	39.7	39.7	7.4
	4–4–2	18	4,180	54.0	54.0	21.4	3,080	46.0	46.0	13.7
Section II:										
No nitrogen	0–5–2	1	2,980	30.0	30.0	....	1,580	27.1	27.1	......
Ammonium sulphate	2–5–2	2	3,100	29.4	29.4	− .6	1,600	27.1	27.1	0
Ammoniated superphosphate	2–5–2	3	2,980	26.9	26.9	−3.1	1,560	25.1	25.1	−2.0
No nitrogen	0–10–2	5	2,360	18.6	18.6	....	1,180	18.0	18.0	......
Ammonium phosphate	2–7–2	6	2,980	20.6	20.6	2.0	1,560	23.7	23.7	5.7
Ammoniated superphosphate	4–10–2	4	3,280	33.4	33.4	14.8	1,760	30.6	30.6	12.6
No fertilizer	0–0–0	10	1,920	17.4	17.4	....	1,040	15.7	15.7	......
No nitrogen	0–13–2	9	2,240	12.9	12.9	....	1,180	14.9	14.9	......
Ammonium phosphate	4–13–2	7	3,360	26.0	26.0	13.1	1,740	29.1	29.1	14.2
Ammonium sulphate	4–13–2	8	3,140	24.9	24.9	12.0	1,680	28.9	28.9	14.0
No fertilizer	0–0–0	10	1,920	17.4	17.4	....	1,040	15.7	15.7	......
No nitrogen (acid phosphate)	0–4–2	11	2,640	22.0	22.0	4.6	1,360	19.4	19.4	3.7
No nitrogen (calcined phosphate)[2]	0–4–2	12	2,580	23.4	23.4	6.0	1,340	19.1	19.1	3.4
No fertilizer	0–0–0	10	1,920	17.4	17.4	....	1,040	15.7	15.7	......
No nitrogen (calcined phosphate)[2]	0–4–2	12	2,580	23.4	16.3	....	1,340	19.1	13.7	......
		16	1,920	9.1			580	8.3		
Cyanamid (with calcined phosphate)[2]	1–4–2	13	2,580	18.3	18.3	2.0	1,300	18.6	18.6	4.9
	2–4–2	14	2,800	17.1	17.1	.8	1,400	17.4	17.4	3.7
	4–4–2	15	2,740	18.9	18.9	2.6	1,440	21.7	21.7	8.0
No fertilizer	0–0–0	19	1,540	8.9	8.9	....	640	6.9	6.9	......
No nitrogen	0–4–2	18	1,900	12.9	12.9	....	1,120	9.7	9.7	......
Ammonium nitrate	1–4–2	17	2,220	16.0	16.0	3.1	1,300	13.4	13.4	3.7

[1] Ammonium chlorid was substituted for double salt in 1921.
[2] Basic slag was substituted for calcined phosphate in 1921.

The yields from Section II show no marked differences between ammonium phosphate, ammoniated superphosphate, and ammonium sulphate. Cyanamid gave smaller increases than the other nitrogen carriers, due to the extremely poor and rocky soil. It will be noted that where ammonium nitrate was used under these conditions it also failed to give a good growth. We can not, therefore, say that cyanamid was not as good a source of nitrogen for corn as the other materials used. The early growth of corn with ammonium sulphate and ammonium phosphate is shown in Plate XIII, Figure 2, and the yields with ammonium nitrate and ammoniated superphosphate in Plate XIV, Figures 1 and 2.

Field No. 5.

Another area of approximately 5 acres was used for experimental purposes in 1920. The treatments and general plat arrangements were an exact duplicate of field No. 3. Unfortunately, the soil was so fertile that the fertilizers produced negligible increases in most cases. For this reason work was not continued on this area during 1921.

The yields mean very little except on those plats receiving ammonium chlorid and cyanamid and planted to corn. It happened that the soil on this portion of the field was rather poor and quite uniform. These figures are given in Table 20, but all others are omitted.

Table 20.—*Yields per acre of corn from Sections I and II of field No. 5.*

Fertilizer ratio.	Plat.	Yields of corn.			
		Stalks (pounds).	Grain (bushels).		
			Actual.	Average.	Increase over check.
Section I.—Ammonium chlorid:					
0-0-0	7 12	2,140 1,780	24.3 25.4	24.9	....
0-4-2	6 11	2,200 2,240	24.0 33.1	28.6	....
1-4-2	8	2,800	32.6	32.6	4.0
2-4-2	9	2,960	42.9	42.9	14.3
4-4-2	10	2,580	41.1	41.1	12.5
Section II.—Cyanamid:					
0-0-0	10	1,440	14.8	14.8	....
0-4-2	12	1,688	16.1	16.1	....
1-4-2	13	2,273	16.7	16.7	.6
2-4-2	14	2,790	28.6	28.6	12.5
4-4-2	15	3,083	33.1	33.1	17.0

The increases in yields produced by ammonium chlorid were very good, but the material again shows indications of being slightly toxic when applied in high concentrations. Soon after germination the plants showed a distinct burning and some yellowing of the leaves with the application of 40 pounds of ammonia per acre. A few plants died, but the others apparently recovered. The yields indicate that the bad effects were never completely overcome.

Cyanamid gave excellent results on corn and showed a much higher yield with 40 pounds of the ammonia equivalent than with 20 pounds.

At the smallest rate most of the nitrogen was utilized for stalk production rather than grain. The probable causes for this are the same as previously stated in connection with other plats. Under the conditions of this test cyanamid produced just as satisfactory early effects and also gave as good increases in yields as could be expected from any fertilizer.

REVIEW OF THE RESULTS.

An examination of the results here reported shows that with the exception of cyanamid all of the nitrogen materials tested gave responses quite similar to those from ammonium sulphate and sodium nitrate. It should be pointed out, however, that some of the materials, especially Urephos, were not tested on a sufficiently large number of plats to show clearly their relative values, but nevertheless, under the conditions of the test cyanamid was the only fertilizer which in some instances gave very erratic results. Because of the erratic results obtained with cyanamid and the unusual interest attached to this material as one of the important synthetic sources of nitrogen, special consideration of it seems desirable. In the following discussion the various phases of cyanamid fertilization will be considered, both from the standpoint of the present study and in the light of results reported by other investigators.

The importance of avoiding the use of cyanamid in large proportions in fertilizer mixtures containing acid materials has been emphasized. Where large amounts of cyanamid were mixed with acid phosphate the growth and yields of the various crops were poor. This was due to the polymerization of a portion of the cyanamid nitrogen to dicyanodiamid, which is not only unavailable as a fertilizer but also toxic for some plants. When cyanamid and acid phosphate were applied separately the undesirable changes were avoided; likewise in the case of mixtures containing basic phosphates. It is customary in American fertilizer practice to use not to exceed 60 pounds of cyanamid per 1,000 pounds of acid phosphate in mixed fertilizers. While under such conditions a small amount of dicyanodiamid may be formed, the quantity is not sufficient to be particularly objectionable and the mechanical condition of the mixture is considerably improved.

The method of using cyanamid in the field is very important. In the experimental work at Muscle Shoals the conditions of use adopted were made to conform as nearly as possible to American agricultural practice. This fact needs to be especially emphasized, since in many cases it largely explains the poor results with cyanamid. The main factors, namely, soils, crops, and time and methods of application deserve special mention.

The soils which are usually considered most suitable for cyanamid fertilization are those in best tilth, neutral, and having high nitrifying efficiencies. Those which are not suitable are acid soils, very sandy soils, acid humus soils, and very heavy plastic clays. A good supply of colloids and organic matter is also considered desirable; likewise a high absorptive capacity provided the aeration is adequate. The soils used for the experiments here reported were loams and therefore apparently satisfactory. However, all of the soil types were slightly acid and some of them poorly aerated, especially on fields 2 and 3. The nitrifying powers were likewise low, as shown by laboratory experiments with soils from fields 1, 2, 3, and 4. In every case the soils nitrified ammonium sulphate satisfactorily, but the nitrates present in the soils two months after receiving cyanamid were frequently less than in untreated portions. A general average of the numerous determinations made showed that the soil of field 1 nitrified best, that from field 4 came second, while fields 2 and 3 were the poorest. This agrees almost exactly with the relative increases in cotton yields obtained from these various fields. The fact that all soils readily nitrified ammonium sulphate but not cyanamid indicates rather definitely that the dicyanodiamid formation in the poorly aerated and sometimes poorly drained soils of fields 2 and 3 was primarily responsible for the lack of nitrification and poor cotton yields with cyanamid. Very small amounts of this material are sufficient to prevent nitrification entirely.

The crops which usually give the best results with cyanamid, judging from results reported in the literature and those here obtained, are the ones that have a long growing period and can utilize ammonia nitrogen. Crops that require nitrate nitrogen frequently make very poor growth, because cyanamid nitrifies so slowly. This fact is thought to explain the results here reported, where cotton frequently gave poor responses to cyanamid nitrogen, while corn always grew rapidly and produced as good yields as with standard fertilizers. Since the transformation of cyanamid nitrogen to nitrate nitrogen is usually a slow process, cyanamid should never be used as a fertilizer for quick-growing crops, such as vegetables, unless the material is applied several days or weeks before seeding. Even then a nitrate fertilizer would probably prove more profitable. The use of nitrate nitrogen in combination with cyanamid is advisable provided such a mixture is a compatible one, as was not the case in the tests reported in this bulletin.

The time and method of application are of very great importance in cyanamid fertilization. In order that sufficient time will be available for nitrification, the material should be applied at least 10 days before seeding, or in the case of most perennial crops an early spring application before growth begins is best. In these experiments the cyanamid was usually applied at the time of seeding in order to conform to the prevailing American practice. A retarded early growth and a delayed maturity were the natural results. Applications to growing crops usually depress growth for a month following. This occurred in the time-of-application studies reported on previous pages, particularly with cotton. Since corn can utilize ammonia it is less susceptible to what is ordinarily considered as bad practice in the use of cyanamid. With regard to the method of application, it seems that a more intimate mixing of the cyanamid with the soil than can be obtained by distribution in the row is desirable.

The explanation for the peculiar behavior of cyanamid under some of the conditions outlined depends upon the chemical changes which take place. From the studies which have been reported on this subject and from those made in connection with the present investigation, it appears that almost immediately upon coming into contact with moist soil cyanamid changes into calcium-acid cyanamid, then free cyanamid ($H_2 CN_2$), urea, and eventually ammonia. A varying quantity of dicyanodiamid may be produced as a side reaction. The free cyanamid and dicyanodiamid are toxic to the nitrifying bacteria, and the ammonia can not be oxidized to nitrates until the injurious compounds are so dispersed, changed, or absorbed as to be no longer present in sufficient concentration to be injurious. Until this does occur the plants are forced to take up ammonia or undergo nitrogen starvation. The unusually green color of many plants fertilized with cyanamid is probably in some way connected with ammonia absorption.

The explanation of why the retardation period following the use of cyanamid lasts for only a few days in one case and throughout the summer in another probably depends upon the particular compound primarily responsible for the effect. If it is merely ammonia or free cyanamid, these materials will be quickly changed or dispersed and nitrate production may proceed normally. If dicyanodiamid, the effect may be expected to continue for a considerable period, since the compound is not only relatively insoluble but not readily attacked by chemical or biological agents.

SUMMARY.

This bulletin presents the results of field tests with 10 atmospheric-nitrogen products conducted during a period of three years on an area of about 10 acres the first year and 20 acres the last two years.

Cyanamid usually was not as satisfactory as the other sources of nitrogen, chiefly because so many factors influence the rate and manner in which the material is decomposed either in fertilizer mixtures or in the soil. When mixed with acid phosphate in large proportions the results were poor, probably owing to the transformation of a portion of the cyanamid nitrogen to dicyanodiamid, a compound which is not only unavailable but toxic for some crops and for the nitrifying bacteria. Where applied separately with acid phosphate the results were good even with 1,000 pounds of an 8–8–4 fertilizer. Calcined phosphate and basic slag appear to be entirely satisfactory as to compatibility as sources of phosphorus for use with cyanamid.

The behavior of cyanamid in the soil depends upon a number of factors, such as time and method of application and the type, composition, temperature, and moisture content of the soil. Applications should be made at the time of seeding, or preferably earlier. It is, furthermore, believed that thorough mixing of the cyanamid with the soil is preferable to drilling in the row. Even under the best conditions cyanamid nitrogen is converted to nitrates rather slowly and for this reason is usually slow to act. The soil conditions which are known to hasten nitrification are, in general, the ones which favor an efficient utilization of cyanamid.

The marked differences in the response of different crops to cyanamid under the same conditions has been very clearly brought out by the experiments with corn and cotton. Corn gave as good yields in most instances with cyanamid as with any other fertilizer used. Only a very temporary period of retardation was in evidence during early growth. Cotton was usually retarded for a considerable period subsequent to germination and in most cases never produced as good growth or as large yields with cyanamid as with ammonium sulphate or sodium nitrate. This is believed to have been due to the fact that cotton requires nitrate nitrogen for its best growth, while corn can efficiently utilize ammonia. Further experimentation with cyanamid as a possible corn fertilizer seems especially desirable.

Where used on winter grains with half of the nitrogen supplied in the fall and the remainder in the spring, cyanamid gave about as good increases on the average as the two standard materials. Where all the nitrogen was applied in the fall to wheat and rye, the results were even better. This emphasizes the desirability of allowing a considerable period of time for cyanamid to become available in order that it may produce the maximum yields.

The comparisons between acid phosphate, calcined phosphate, and basic slag made in connection with the use of cyanamid showed only slight differences in yields, but the experiments were on too limited an area and for a period too short to justify a definite statement as to their relative values.

The attempts to utilize cyanamid more effectively by the addition of calcium nitrate to mixtures containing it were not entirely successful. This was attributed to the fact that where calcium nitrate is used with basic slag the mixture becomes moist during damp weather and on drying produces very hard cakes. At the same time the moisture probably favors the production of dicyanodiamid from the cyanamid present. If a compatible nitrate-cyanamid mixture could be developed, such a combination would undoubtedly be more desirable than cyanamid alone. In such a mixture the nitrate nitrogen would supply the needs of the plants while the cyanamid nitrogen was being made available.

Ammonium nitrate gave results comparable with sodium nitrate and ammonium sulphate. It was readily available and no abnormal effects were noted. The chief limitation to its use is its property of absorbing moisture from the air, making it somewhat unsuitable for fertilizer mixtures. This objectionable feature can be partially overcome by either graining and oil coating the material or by manufacturing double or mixed salts from it.

Double salt, made from ammonium nitrate and ammonium sulphate, produced effects comparable with either of the materials used singly. The material is somewhat hygroscopic, but not nearly to the same extent as ammonium nitrate.

The two mixed salts, made from ammonium nitrate and either potassium chlorid or potassium sulphate, were of approximately equal value. So far as may be judged from the limited use of these materials, they are as available as either ammonium nitrate or ammonium sulphate. Although somewhat hygroscopic they are less objectionable in this respect than ammonium nitrate.

Ammonium phosphate and ammoniated superphosphate are excellent nitrogen carriers. They gave quick responses, good growth, and satisfactory yields. The large quantities of phosphorus in the materials partially masked the nitrogen effects.

Ammonium chlorid was as readily available as ammonium sulphate, but on a few plats 40 and 80 pounds of ammonia per acre showed some toxic effects and gave slightly lower yields than the equivalent amount of nitrogen as ammonium sulphate. This may have been due to too high a concentration of the chlorid ion, but no work was done to determine this point.

Urea seemed to be as readily available as sodium nitrate and equally as good in all respects as any other material used. Since urea is an excellent material physically and leaves neither a basic nor acid residue in the soil it should prove to be an almost ideal nitrogen carrier for all types of soils.

Urephos gave somewhat variable results, due to the wide soil variations, the yields being especially good with wheat but much poorer with rye. The limited use of the material does not justify conclusions as to its value.

It should be noted that nearly all the fertilizer materials tested have a much higher plant-food content than those now commonly employed. While some of these materials are suitable for direct use in mixed fertilizers, others will require some modifications of present-day fertilizer practice, owing to their physical condition.

The results as a whole may be summed up by the statement that under the conditions of these experiments all of the nitrogen materials tested with the exception of cyanamid were of about the same value as sodium nitrate and ammonium sulphate. With regard to the latter two materials, if there was any difference between them it was slightly in favor of ammonium sulphate. Further experimentation is necessary, however, to establish more definitely the relative values of all of these materials and to determine the conditions under which they can be most advantageously used. Such experimentation is now in progress by the Office of Soil-Fertility Investigations. It is hoped, however, that similar studies will be undertaken by others, since atmospheric-nitrogen products are becoming increasingly important in supplying the needs of agriculture.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE.

October 15, 1923.

Secretary of Agriculture	HENRY C. WALLACE.
Assistant Secretary	HOWARD M. GORE.
Director of Scientific Work	E. D. BALL.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	HENRY C. TAYLOR, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	C. A. BROWNE, *Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD. *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Division of Accounts and Disbursements	A. ZAPPONE, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration / *Grain Future Trading Act Administration*	CHESTER MORRILL, *Assistant to the Secretary.*
Office of the Solicitor	R. W. WILLIAMS, *Solicitor.*

This bulletin is a contribution from

Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Tobacco and Plant Nutrition Investigations	W. W. GARNER, *in Charge.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Chemical Division	JOSEPH M. BRAHAM, *in Charge*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY

△