TEXAS AGRICULTURAL EXPERIMENT STATION
A. B. CONNER, DIRECTOR
COLLEGE STATION, BRAZOS COUNTY, TEXAS

BULLETIN NO. 469 DECEMBER, 1932

DIVISION OF AGRONOMY

Fertilizer Experiments with Cotton

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The results of seven years experiments with fertilizers on cotton at Troup, Nacogdoches, Angleton, College Station, Beeville, Temple, and Denton, Texas, are reported in this Bulletin.

The Kirvin fine sandy loam at Troup and the Nacogdoches and Ruston fine sandy loams at Nacogdoches are deficient in nitrogen, phosphoric acid, and to a somewhat lesser extent in potash. The use of 200 to 400 pounds per acre of a 4-8-4 or 4-6-4 fertilizer or a fertilizer which furnishes equivalent amounts and proportions of plant food is suggested for cotton on these soils.

The Lake Charles clay, an extensive soil in the Gulf Coast Prairie, is markedly deficient in phosphoric acid, as indicated by the results obtained on this soil at Angleton. The use of 100 pounds of superphosphate or 200 to 600 pounds of a 4-8-0 fertilizer per acre is recommended for cotton on the Lake Charles clay and similar soils of the region.

The Lufkin fine sandy loam at College Station responded better to applications of phosphoric acid and of potash than to applications of nitrogen. The 4-12-4 and 0-12-4 fertilizers used at the rate of 400 pounds per acre were the most profitable treatments on this soil.

The dark-colored Goliad fine sandy clay loam at Beeville, the Houston black clay and Houston clay at Temple, and the San Saba clay at Denton, gave some response to fertilizers, but as a rule the use of fertilizers on these soils was not profitable.

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Climatic conditions, especially temperature, evaporation, and the amount and distribution of rainfall, have a profound influence on the development of soils and on the physical, chemical, and biological properties of the soil. Normal soils developed under humid conditions are usually more or less leached and do not contain, as a rule, as much available plant food as normal soils formed under sub-humid or arid conditions. For instance, the more completely developed soils in the eastern part of the United States, where humid conditions prevail, are in general leached of lime and other bases and are acid in the surface and subsoil. On the other hand, soils developed under less humid conditions, such as those prevailing in the Great Plains Region, instead of being leached of plant food, have an accumulation of lime, usually in the subsoil.

The soils in warm, moist climates, such as the climate in the cotton-belt states, usually do not contain large amounts of organic matter, because the high temperatures and favorable moisture conditions lead to the rapid decomposition of the organic matter. Under these conditions, the processes of decay and decomposition take place so rapidly that large amounts of organic matter do not accumulate in the soil.

On the other hand, in cool climates, with an equivalent amount of rainfall, as in the Northern states and Canada, the soils contain more organic matter than those in hot climates. This is due to the fact that here the environmental conditions, including temperature and moisture, during the growing season are favorable for abundant vegetative growth, while during the long, cold winters, the processes of decay take place slowly or are retarded entirely on account of the low temperature. These conditions, therefore, are favorable for the accumulation of large amounts of organic matter in the soil.

The climate in Texas ranges from extremely humid in the southeastern part, where the average annual rainfall is 50 inches or more, to arid in the extreme western part, where the rainfall is approximately 10 inches. These climatic differences account in part for the occurrence of so great a variety of soils in the State.

The many different kinds, or types, of soils in Texas range in texture from light sandy soils to stiff, heavy clay soils, and vary considerably in chemical composition and in content of plant food. These soils also vary widely in productiveness, on account of the differences of plant food, texture, and structure. It is obvious that different soils may require different kinds of fertilizers. For example, light, deep sandy soils are more likely to be deficient in potash than are clay soils, because they contain smaller amounts of potash-containing minerals. Further, the dark-colored soils of the Lake Charles series in the Gulf Coast Prairie are deficient in phosphoric acid, as shown by the fact that they respond readily to applications of phosphatic fertilizers. Other soils respond to applications of complete

fertilizers. In the western part of the State, moisture, and not plant food, is generally the first limiting factor in crop production, and fertilizers as a rule have had little or no influence on crop production except under irrigation.

REVIEW OF PREVIOUS FERTILIZER WORK IN TEXAS

When the Texas Agricultural Experiment Station was established in 1888, field experiments with various field and garden crops were begun to determine the most practical methods of production under the diverse conditions prevailing in the State. These experiments included trials with different fertilizers and fertilizer materials for the purpose of ascertaining the best kinds and amounts for the main crops on the more important soils.

The results of the first of these experiments, which dealt with cotton, corn, and wheat at McKinney and Wichita Falls, were published in Bulletin 34 (1895). In a discussion of the results obtained with cotton at McKinney, it was stated, "Using the past year's results as a basis of calculation, it is highly probable that a judicious combination of phosphoric acid and nitrogen will give a satisfactory profit on their use in growing cotton on the black lands." The fact that the soil responded somewhat to applications of nitrogen and phosphoric acid agree in general with the more recent work with fertilizers on the Houston soils at Temple, although the fertilizers were not profitable.

Experiments with fertilizers conducted at College Station in 1897 and 1898 indicated that the soil (Lufkin fine sandy loam) responded more readily to applications of nitrogen and of phosphoric acid than to applications of potash. As an average for the two years, superphosphate increased the yield of cotton 23.9 per cent; bone black, 38.8 per cent; cottonseed meal, 39.9 per cent; and potash, 6 per cent.

In 1903, Dr. H. H. Harrington, then Chemist of the Experiment Station and State Chemist, on the basis of the results obtained with fertilizers in Texas up to that time, suggested some fertilizers for various crops. For example, he recommended a 3-9-4 fertilizer for cotton, which is practically equivalent to the 4-8-4 analysis in total plant food now used so extensively in Texas and other States.

Experiments conducted at Troup from 1902 to 1911 with fertilizers for sweet potatoes, Irish potatoes, watermelons, and strawberries indicated that the gray, sandy soil (now called the Kirvin fine sandy loam) was deficient in phosphoric acid and nitrogen and to some extent in potash. The results of the work on Irish potatoes, published in Bulletin 101, showed that the soil needed mostly nitrogen and phosphoric acid, although potash was beneficial to some extent. In trials with sweet potatoes, superphosphate increased the yield 33 1-3 per cent; cottonseed meal, 36 per cent; and nitrate of soda, 31 per cent. A mixture of three parts of superphosphate and two parts of cottonseed meal gave the best results. A complete fertilizer gave the largest yield of watermelons. With strawberries, however, the largest yields were obtained from a mixture of cottonseed meal and superphos-

phate; potash was not effective. More recent work has confirmed the earlier results, and, in addition, has shown that potash is needed by most crops.

The results of fertilizer work conducted with cotton, corn, and tomatoes on the red lands at Nacogdoches from 1911 to 1920 also pointed to a deficiency of nitrogen and phosphoric acid, which also has been confirmed by later fertilizer work with cotton and corn.

Results of fertilizer experiments with cotton at Beaumont in 1916 and 1917 showed that the soil was deficient in both nitrogen and phosphoric acid and that phosphoric acid is the first limiting element. The results of trials with fertilizers on rice over a period of 13 years, published in Bulletin 398, show that the soil also responds to a complete fertilizer, although the most profitable results were obtained from the use of sulphate of ammonia alone.

Dr. G. S. Fraps, in his capacity as State Chemist in charge of the fertilizer control law, conducted a large number of field experiments with fertilizers on several crops in cooperation with farmers in the different parts of the State from 1908 to 1917. The results of these experiments were published in Bulletins 138 and 235. Of the 151 experiments conducted with cotton as reported in Bulletin 235, 74 per cent gave an increase in yield with superphosphate, 68 per cent with cottonseed meal, and 58 per cent with potash. It was stated in Bulletin 138 that "Texas soils are likely to be deficient in phosphoric acid first of all, next in nitrogen, and last and least in potash."

The above discussion of the earlier fertilizer work conducted by the Experiment Station indicates in a general way that the sandy soils in the eastern part of the State are deficient in nitrogen and phosphoric acid and to some extent in potash. Further, the black waxy soils (Houston soils) showed some response to nitrogen and phosphoric acid. These earlier results, however, did not indicate definitely the best proportions of plant food (nitrogen, phosphoric acid, and potash) and the rate of application to be used on specific soils.

In view of this fact the fertilizer work was revised and expanded in 1927 with the view of determining definitely the best kinds and amounts of fertilizer for the more important field crops on the major soil types in the different parts of the State. Cotton, corn, wheat, and oats were the crops used in these studies. It is the object of this Bulletin to report the results obtained with cotton at the several substations. Later it is planned to publish the results of the fertilizer work with corn, wheat, and oats in other bulletins.

METHOD OF CONDUCTING THE FERTILIZER WORK

In this work a 4-12-4 fertilizer made up from sulphate of ammonia, superphosphate, and muriate of potash, applied at the rate of 400 pounds per acre, was used as the basic treatment. Then the percentage of each element—nitrogen, phosphoric acid, and potash—was varied in turn, while the other two were kept constant. For example, the percentage of nitrogen ranged from 0 to 8 per cent by using 0-12-4, 4-12-4, 6-12-4, and 8-12-4

analyses. It will be observed that the content of phosphoric acid remained at 12 per cent and the content of potash at 4 per cent, while the nitrogen varied from 0 to 8 per cent. In these analyses, the first figure means the percentage of nitrogen, the second the percentage of available phosphoric acid, and the third the percentage of water-soluble potash. Variations in the percentage of phosphoric acid and of potash were studied in a like manner. This arrangement enables one to determine the best analysis of fertilizer (the ratio of nitrogen, phosphoric acid, and potash) for the various soil types.

Grades and Amounts of Fertilizers Used

The following fertilizer treatments were used in these experiments:

Analyses	Rate, pounds per acre
Nitrogen varied:	
N P K	
0-12-4	400
4-12-4	400
6-12-4	400
8-12-4	400
Phosphoric acid varied:	
N P K	
4-0-4	400
4-6-4	400
4-8-4	400
4-12-4	400
Potash varied:	
N P K	
4-12-0	400
4-12-2	400
4-12-4	400
Rates varied:	
N P K	
4-12-4	200
4-12-4	400
4-12-4	600
4-12-4	800
8-12-8	800

Other treatments, including manure, were used at some of the stations and these will be mentioned in the discussion of the results at the places concerned.

Method of Applying Fertilizer

The various grades of fertilizer with the desired ratio of nitrogen, phosphoric acid, and potash were made up by weighing the correct amounts of sulphate of ammonia, superphosphate, and muriate of potash, mixed, and applied to the soil soon afterward. In most cases the fertilizers were applied by distributing as uniformly as possible by hand in a furrow about two weeks before planting and ridges or beds were made on the fertilizer. The cotton was planted on these beds, the seed being placed about 1½ to 2 inches above the fertilizer. Each fertilizer treatment occurred two to four times in the experiment at each station.

Crop Rotations

The fertilizer work at each substation was conducted in a rotation of crops. The rotation used at a particular substation is given in the discussion of the experiment at that station.

In connection with the judicious use of fertilizers it may be well to emphasize the fact that the growing of suitable legumes, such as cowpeas, soybeans, and vetches, in a suitable cropping system with cotton and feed crops is good farm practice. The legumes if used properly aid in maintaining the organic matter and nitrogen in the soil. The summer-growing legumes are more valuable when they are used for grazing and the resulting residues are plowed under for soil improvement, than when used exclusively for soil improvement, because both the feeding value and soil-improving value are utilized. Winter-growing legumes, such as hairy vetch and Austrian winter peas, may be grown to advantage for green manure in the eastern part of the State. The plowing under of non-legume plant residues, such as cotton stalks, corn stalks, weeds, and grass will also improve the land by adding vegetable matter, but the practice will not actually increase the amount of nitrogen in the soil as it merely returns to the soil the nitrogen and other plant food which were taken up from the soil by the growing plants.

The growing of suitable legumes provides valuable protein feed for the farm livestock and at the same time improves the land. The practice of plowing under both leguminous and non-leguminous crop residues in connection with a suitable cropping system will gradually improve the land so that larger amounts of fertilizers can be used with increasing profits.

Location of the Work

The fertilizer work is conducted at the following places in the State: At the Main Station Farm, College Station, in east central Texas; Substation No. 1, Beeville, in southern Texas; Substation No. 2, Troup, in northeastern Texas; Substation No. 3, Angleton, in the Gulf Coast Prairie; Substation No. 5, Temple, in the Blackland Prairie; Substation No. 6, Denton, on the Grand Prairie in central north Texas; and at Substation No. 11, Nacogdoches, in the "red lands" of eastern Texas.

A brief statement of the soil types and climatic conditions is given in the discussion of the work at each station.

EXPERIMENTAL RESULTS

The results obtained in the fertilizer experiments are discussed separately for each station as a matter of convenience.

Results Obtained on Kirvin Fine Sandy Loam at Troup

The Kirvin fine sandy loam soil has responded to applications of nitrogen, of phosphoric acid, and of potash. On the basis of the results obtained

at Substation No. 2, Troup, during the four years, 1927, 1928, 1929, and 1930, the use of 200 to 400 pounds per acre of a 4-6-4 or a 4-8-4 fertilizer, or a fertilizer furnishing similar ratios and amounts of plant food is suggested for cotton on the Kirvin soils.

The Kirvin fine sandy loam is a grayish sandy surface soil underlain by a stiff, plastic red clay subsoil. The Kirvin soils occupy extensive areas in northeastern Texas. The soil on which the fertilizer work was conducted contains .049 per cent of nitrogen, .039 per cent of phosphoric acid, 30 parts per million of active phosphoric acid, and 134 parts per million of active potash in the surface soil, according to analyses made by the Division of Chemistry.

The average yearly rainfall at Troup was 42.86 inches during the 26 years, 1905 to 1930, inclusive. The rainfall for 1927, 1928, 1929, and 1930 was 42.74, 44.98, 41.75, and 45.90 inches, respectively. The rainfall is fairly well distributed during the months of the year, although in individual years the distribution is much less uniform, and periods of drought, or deficient rainfall, frequently occur during June, July, and August. The distribution of rainfall during the growing season has a greater influence than the total rainfall on the yield of cotton. The variation in yield from year to year was due largely to differences in distribution of rainfall.

A two-year rotation of cotton and corn has been used in these studies, the fertilizers being applied to both crops.

Nitrogen: The Kirvin fine sandy loam is somewhat deficient in nitrogen. The 4-12-4 fertilizer made an average yield of 248 pounds of lint per acre for the four years of the experiment, as compared with a yield of 200 pounds for the 0-12-4 fertilizer (Table 1). This is an average increase of 48 pounds of lint, which may be attributed chiefly to the 4 per cent of nitrogen (16 pounds) in the 4-12-4 fertilizer, although the presence of phosphoric acid in connection with the nitrogen was responsible for some of the increase. The 4 per cent of nitrogen apparently furnished enough nitrogen for cotton on the Kirvin fine sandy loam, since larger amounts did not produce significant increases in yield. There was practically no difference in the yield of cotton where all of the nitrogen in the fertilizer was supplied in sulphate of ammonia and where two-thirds was supplied in sulphate of ammonia and one-third in cottonseed meal.

Phosphoric Acid: The soil responded to applications of phosphoric acid. The 4-6-4 fertilizer produced an average yield of 254 pounds of lint per acre, or 55 pounds more than the yield of the fertilizer which contained no phosphoric acid (the 4-0-4 fertilizer), as shown in Table 1. This increase of 55 pounds of lint is attributed largely to the 24 pounds of phosphoric acid in the 4-6-4 fertilizer, and is about two and one-fourth pounds of lint for each pound of phosphoric acid applied. Further increases in the percentage of phosphoric acid made no additional increases in the yield of cotton. It is concluded from these data that 6 to 8 per cent of phosphoric acid in 400 pounds of fertilizer, or 24 to 32 pounds of phosphoric

acid, is enough phosphoric acid with the nitrogen and potash used, for cotton on this particular soil.

Potash: Applications of potash increased the yield of cotton on the Kirvin fine sandy loam. The 4-12-4 fertilizer made an average yield of 248 pounds of lint per acre, while the fertilizer which contained no potash (the 4-12-0 fertilizer) produced only 224 pounds (Table 1). The 16 pounds

TABLE 1—Yield per acre in pounds of lint cotton at Troup, Texas, 1927 to 1930, when 400 pounds of fertilizers of different analyses were applied and when a 4-12-4 fertilizer was applied at different rates per acre

Fertilizer used	1927	1928	1929	1930	Average	Average increase produced by fertilizer
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
No fertilizer	294	207	132	128	190	
Nitrogen varied:						
0-12-4	294	210	139	155	200	10
4-12-4	347	255	210	178	248	58
4*-12-4	349	258	215	165	247	57
6-12-4	345	258	206	179	247	57
8-12-4	353	267	229	170	255	65
Phosphoric acid varied:						
4- 0-4	294	212	142	148	199	9
4- 6-4	347	254	226	187	254	64
4- 8-4	359	240	224	178	250	60
4-12-4	347	255	210	178	248	58
Potash varied:						
4-12-0	324	240	177	153	224	34
4-12-2	341	235	181	168	231	41
4-12-4	347	255	210	178	248	58
Rates of 4-12-4:						
200 lbs.	327	221	188	168	226	36
400 lbs.	347	255	210	178	248	58
600 lbs.	358	269	242	194	266	76
800 lbs.	365	266	239	178	262	72

*One-third of nitrogen was supplied in cottonseed meal and two-thirds in sulphate of ammonia.

of potash in the 4-12-4 fertilizer, in the presence of the nitrogen and phosphoric acid, made an average increase of 24 pounds of lint per acre, or one and one-half pounds of lint for each pound of potash used.

Rates of Application of Fertilizer: The average yield of cotton increased as the rate of application of the 4-12-4 fertilizer was increased from 200 to 600 pounds per acre, as shown in Table 1. The 800-pound application, however, made no further increase in yield. It will be noted that the smaller applications were relatively more efficient than the larger applications. For example, in Table 2, it is shown that the use of 200 pounds of fertilizer made an increase of 36 pounds of lint, or 18 pounds of lint for each 100 pounds of fertilizer, while the use of 800 pounds of fertilizer produced an increase of 72 pounds of lint, or only 9 pounds of lint for each 100 pounds of fertilizer used. Thus it is seen that the yield of cotton increased with the rate of application of fertilizer but the efficiency of the fertilizer decreased as the rate was increased.

Omission of One Element Reduces Effectiveness of Fertilizer: It should not be inferred from the preceding discussion that the increase in yield produced by a complete fertilizer would be the sum of the increase pro-

duced separately by the nitrogen, by the phosphoric acid, and by the potash. The yields of cotton obtained indicate that all three elements—nitrogen, phosphoric acid, and potash—must be present to secure the

TABLE 2.—Average increase in yield of lint produced by the 4-12-4 fertilizer used at different rates per acre and increase in yield of lint per 100 pounds of fertilizer used at Troup, Texas, 1927 to 1930

Rate per acre pounds	Average yield per acre	Increase over unfertilized soil	Increase in yield produced by 100 pounds of fertilizer
	Lbs. lint	Lbs. lint	Lbs. lint
None	190	---	---
200	226	36	18
400	248	58	15
600	266	76	13
800	262	72	9

greatest effect of the fertilizer. Or, stated in another way, the omission of either one of the three elements renders the fertilizer less effective. This is shown clearly by the following comparisons:

Treatment	Yield in pounds of lint
None	190
0-12-4	200
4- 0-4	199
4-12-0	224
4-12-4	248

It will be noted from the above figures that the addition of either nitrogen or phosphoric acid without the other does not increase the yield appreciably, which indicates that the soil is equally deficient in both elements, which must be used together for satisfactory results.

Fertilizers Suggested for the Kirvin Soils: From the results obtained at Troup the use of 200 to 400 pounds per acre of a 4-6-4 or 4-8-4 fertilizer or fertilizer furnishing similar amounts and ratios of plant food is suggested for the average Kirvin soils of the region. Under more favorable conditions, that is on more productive soils, larger amounts may be used to advantage.

Results Obtained on the "Red Lands" at Nacogdoches

The experimental plats, consisting mostly of small areas of Ruston Orangeburg, and Nacogdoches fine sandy loams intermingled, at Nacogdoches have responded readily to applications of phosphoric acid and nitrogen and to some extent to applications of potash. Phosphoric acid, however, appears to be needed before either nitrogen or potash for the production of cotton on this soil. On the basis of the results obtained at Substation No. 11, Nacogdoches, during the five years 1927 to 1931, inclusive, the use of 200 to 400 pounds per acre of a 4-6-4 or 4-8-4 fertilizer or a fertilizer carrying somewhat similar amounts and ratios of plant food is suggested for cotton on the Nacogdoches and associated soils.

The land on which the fertilizer work was conducted consists principally of Nacogdoches, Norfolk, and Orangeburg fine sandy loams intermingled. The Nacogdoches soils are typically red in color, and are the main soils of the so-called "Red Lands" in the eastern part of the State. The topography is rolling to hilly and consequently the soils under cultivation are subject to serious erosion unless protected by suitable terraces. The soil used in the experiment contained .026 per cent of nitrogen, .038 per cent of phosphoric acid, 17 parts per million of active phosphoric acid, and 140 parts per million of active potash, according to analyses made by the Division of Chemistry, Texas Agricultural Experiment Station.

A three-year rotation of cotton, corn, and cowpeas is used in the experiment. Fertilizer has been applied to the cotton and corn only, the cowpeas receiving the residual effects of the fertilizer. The cowpeas have been harvested for seed and the vines plowed under for soil improvement.

The average annual rainfall at Nacogdoches during the 19 years, 1913 to 1931, inclusive, was 48.58 inches. The annual rainfall in 1927, 1928, 1929, 1930, and 1931 was 45.72, 39.99, 49.65, 48.77, and 50.15 inches, respectively. While the average monthly rainfall is fairly uniform, periods of deficient rainfall sometimes occur in July or August which reduce the yield of crops.

TABLE 3.—Yield of cotton in pounds of lint per acre at Nacogdoches, Texas, 1927 to 1931, when 400 pounds of fertilizers of different analyses were used and when a 4-12-4 fertilizer was applied at different rates per acre

Fertilizer used	1927	1928	1929	1930	1931	Average	Average increase produced by fertilizers
None	141	171	82	103	102	120	----
8-12-8 (800 lbs.)	197	240	209	-----	-----	215**	----
Nitrogen varied:							
0-12-4	143	242	92	200	138	163	43
4-12-4	159	298	169	142	204	194	74
4*-12-4	171	323	187	132	190	201	81
6-12-4	196	280	148	176	211	202	82
8-12-4	195	304	174	140	220	207	87
Phosphoric acid varied:							
4-0-4	129	103	52	105	116	101	—19
4-6-4	185	281	161	121	206	191	71
4-8-4	149	266	182	161	253	202	82
4-12-4	159	298	169	142	204	194	74
Potash varied:							
4-12-0	153	275	130	192	252	200	80
4-12-2	171	271	149	200	181	194	74
4-12-4	159	298	169	142	204	194	74
Rates of 4-12-4:							
200 lbs.	130	330	133	173	168	187	67
400 lbs.	159	298	169	142	204	194	74
600 lbs.	161	328	180	137	257	213	93
800 lbs.	184	287	180	112	297	212	92
Manure:							
8 tons	181	280	212	-----	-----	224**	----
12 tons	167	342	256	-----	-----	255**	----
12 tons and 400 lbs. superphosphate	149	369	263	-----	-----	260**	----

*One-third of nitrogen supplied in cottonseed meal and two-thirds in sulphate of ammonia.
**Average for 1927, 1928, and 1929.

The yields of cotton for each year and the average yield for the five years, 1927 to 1931, are given in Table 3. The effect of various amounts of nitrogen, phosphoric acid, potash, and rates of application of the 4-12-4 fertilizer are discussed separately as a matter of convenience.

Phosphoric Acid: As mentioned above, the soil responded to applications of phosphoric acid, which seems to be the first limiting element for the production of cotton on this soil. The 4-8-4 fertilizer made an average yield of 202 pounds of lint per acre for the five years, or twice as much as the fertilizer which contained no phosphoric acid (the 4-0-4 analysis) (Table 3). The 32 pounds of phosphoric acid in the 400 pounds of the 4-8-4 fertilizer, therefore, produced 101 pounds of lint, or about 3 pounds of lint for each pound of phosphoric acid applied. Larger amounts of phosphoric acid did not produce further increases in yield, a fact which indicates that two parts of phosphoric acid to one part of nitrogen is a good ratio of these two plant foods on this soil.

Nitrogen: Applications of nitrogen increased the yield of cotton to some extent but not nearly as much as did phosphoric acid. The 4-12-4 fertilizer gave an average yield of 194 pounds of lint for the five years, or 31 pounds more than the fertilizer which contained no nitrogen (the 0-12-4 analysis), as shown in Table 3. This gain of 31 pounds is attributed to the 16 pounds of nitrogen in the 400 pounds of the 4-12-4 fertilizer or about 2 pounds of lint for each pound of nitrogen applied. The 16 pounds of nitrogen apparently is a sufficient amount of nitrogen because larger amounts, 6 and 8 per cent, did not produce additional significant increases in yield of cotton.

Potash: The soil responded to applications of potash three of the five years. In 1931, however, the 4-12-0 fertilizer made a considerably larger yield than the fertilizer containing potash, which raised its average yield slightly above the average yields of the 4-12-2 and 4-12-4 analyses (Table 3). The results, while not conclusive, indicate that the soil needs some potash, and 4 per cent of potash is suggested.

Rates of Application of Fertilizer: The yield of cotton increased as the rate of application of the 4-12-4 fertilizer was increased up to 600 pounds

TABLE 4.—Average increase in yield of lint produced by the 4-12-4 fertilizer applied at different rates and increase per 100 pounds of fertilizer at Nacogdoches, Texas, 1927 to 1931, inclusive

Rate per acre pounds	Average yield per acre	Increase over unfertilized soil	Increase in yield produced by 100 pounds of fertilizer
	Lbs. lint	Lbs. lint	Lbs. lint
None	120	---	---
200	187	67	33.5
400	194	74	18.5
600	213	93	15.5
800	212	92	11.5

per acre, as shown in Table 4. The yield produced per 100 pounds of fertilizer, however, decreased as the rate of application increased. The 200-

pound application made a gain of 67 pounds of lint, or 33.5 pounds of lint for each 100 pounds of fertilizer used, while the yield gradually decreased to 11.5 pounds of lint for each 100 pounds of fertilizer where 800 pounds of fertilizer was used.

Manure: Manure was used at the rate of 8 tons and 12 tons per acre in 1927, 1928, and 1929 but its use was discontinued thereafter. During the three years, the 8 tons and the 12 tons of manure produced average gains of 93 pounds and 124 pounds of lint, respectively, over the yield of the unfertilized soil. Each ton of manure in the 8-ton application produced on the average about 11 pounds of lint and in the 12-ton application, about 10 pounds of lint. The addition of 400 pounds of superphosphate to the 12 tons of manure made a slight but not profitable increase in the yield of cotton.

Fertilizers Suggested for the Nacogdoches and Ruston Soils: On the basis of the results obtained at Nacogdoches, a 4-8-4 or 4-6-4 fertilizer used at the rate of 200 to 400 pounds per acre or a fertilizer furnishing equivalent amounts and proportions of plant food is recommended for the Nacogdoches, Ruston, and associated soils of the region.

Results Obtained on the Lake Charles Soils at Angleton

The Lake Charles soils are deficient in phosphoric acid for the production of cotton, as indicated by the results of fertilizer experiments on these soils at Substation No. 3, Angleton. The use of 100 pounds of superphosphate, or 200 to 600 pounds of a 4-8-0 fertilizer per acre is suggested for the Lake Charles soils. Some potash may be beneficial where larger amounts of nitrogen and phosphoric acid are supplied. Some of the higher-analysis fertilizers, such as the ammonium phosphates, in quantities to supply the above amounts and ratios of nitrogen and phosphoric acid also should give satisfactory results on the soils.

The Lake Charles soils occupy extensive areas in the humid part of the Gulf Coast Prairie. They are black to dark-gray in color, with dark-gray heavy clay subsoils. These soils are very hard when dry although they crumble to fairly good tilth when plowed and cultivated at the proper moisture content. The topography is almost flat and drainage is slow. When the soils are adequately drained, however, they are rather productive. The fertilizer work has been conducted on the Lake Charles clay. According to analyses made by the Division of Chemistry, the surface soil contains .117 per cent of nitrogen, .028 per cent of phosphoric acid, 20 parts per million of active phosphoric acid, and 210 parts per million of active potash.

These experiments have been conducted in a three-year rotation of cotton, corn, and cowpeas, and in a three-year rotation of cotton, cotton, and corn. The cotton and corn were fertilized, while the cowpeas were not fertilized but received the residual effects of the fertilizer.

The average rainfall at Angleton for the 18 years, 1914 to 1931, inclusive, was 45.31 inches. The rainfall in 1930 and in 1931 was 43.16 and 40.18 inches, respectively.

The fertilizer work at Angleton was started in 1925. The work conducted during the five-year period, 1925 to 1929, inclusive, was not very comprehensive; the main object was to determine what element or elements are deficient in the soil. Sulphate of ammonia, superphosphate, and muriate of potash were used alone and in combination at two different rates. The treatments used (expressed in terms of nitrogen, phosphoric acid, and potash) and the results obtained during the five years are given in Table 5. The results show rather definitely that the soil responded readily to applications of superphosphate alone and in combination with nitrogen or potash.

TABLE 5.—Yield of cotton in pounds of lint per acre at Angleton, Texas, 1925 to 1929, where fertilizers of different analyses were used at 400 and 800 pounds per acre

Fertilizer used	1925	1926	1927	1928	1929	Average	Average increase produced by fertilizers
None	282	173	508	289	70	264	....
At 400 pounds per acre:							
5-0-0	231	200	530	317	81	272	8
0-8-0	287	222	609	366	85	314	50
0-0-5	234	162	442	303	44	237	—27
5-8-0	283	216	591	318	56	293	29
5-0-5	268	180	490	308	77	265	1
0-8-5	349	191	575	327	77	304	40
5-8-5	351	187	648	364	45	319	55
At 800 pounds per acre:							
5-0-0	310	222	498	261	158	290	26
0-8-0	412	202	540	298	127	316	52
0-0-5	364	176	497	293	130	292	28
5-8-0	459	231	657	317	124	358	94
5-0-5	369	192	551	348	159	324	60
0-8-5	399	196	566	327	155	329	65
5-8-5	400	321	703	373	132	386	122

For instance, the use of 400 pounds per acre of the 0-8-0 fertilizer (the same as 200 pounds of 16 per cent superphosphate) made an average yield of 314 pounds of lint per acre, or 50 pounds more than the unfertilized soil. In all cases, the analyses used at the rate of 800 pounds per acre made larger average yields than the same analyses applied at the rate of 400 pounds per acre.

Apparently the use of commercial nitrogen in this test did not produce as large increases in yield as did similar amounts of nitrogen in the test during 1930 and 1931. This difference may be due to the fact that cowpeas were plowed under every third year on the soil used in the test from 1925 to 1929 and supplied part of the nitrogen required by the crop.

While the results obtained during the five years, 1925 to 1929, inclusive, indicated that phosphoric acid is the first limiting element in the production of cotton on the Lake Charles soil, they gave no definite information on the proper ratio of plant food and rate of application of fertilizer for cotton under the particular conditions.

In view of this fact, the experiment was revised and expanded considerably in 1930 to determine definitely the fertilizer requirements of the soil for the production of cotton. The several treatments used and the results obtained in 1930 and 1931 are shown in Table 6.

Phosphoric Acid: All applications of phosphoric acid increased the yield of cotton. The 0-4-0 fertilizer (100 pounds of 16 per cent superphosphate) produced an average yield of 330 pounds of lint per acre, or 60 pounds more

TABLE 6.—Yield of lint cotton in pounds per acre at Angleton, Texas, 1930 and 1931, where 400 pounds of fertilizers of different analyses were used and where a 4-12-4 fertilizer was used at different rates per acre

Fertilizer used	1930	1931	Average	Average increase produced by fertilizers
None	249	290	270	----
Nitrogen varied:				
0-12-4	372	376	374	104
4-12-4	390	421	406	136
6-12-4	394	448	421	151
8-12-4	409	476	443	173
Phosphoric acid varied:				
0-4-0	347	312	330	60
0-8-0	319	368	344	74
4-0-4	283	329	306	36
4-6-4	381	392	387	117
4-8-4	388	409	399	129
4-12-4	390	421	406	136
4-16-4	401	419	410	140
Potash varied:				
4-12-0	384	386	385	115
4-12-4	390	421	406	136
4-12-6	387	358	373	103
At 800 lbs. per acre:				
4-12-4	457	503	480	210
6-12-4	466	550	508	238
8-12-4	522	561	542	272
10-12-4	521	624	573	303
8-12-4	522	561	542	272
8-12-6	524	579	552	282
8-12-8	530	576	553	283
Rates of 4-12-4:				
200	351	383	367	97
400	390	421	406	136
600	412	461	437	167
800	457	503	480	210
1000	476	548	512	242

than the unfertilized soil, for the two years, 1930 and 1931 (Table 6). The 4-6-4 fertilizer made an average yield of 387 pounds of lint per acre, which was a gain of 81 pounds over the yield of the fertilizer which contained no phosphoric acid (the 4-0-4 analysis). The yield of cotton increased as the percentage of phosphoric acid was increased from 6 to 16 per cent. Where the fertilizer was used at the rate of 400 pounds per acre the yields indicate that 8 per cent of phosphoric acid is sufficient where only 4 per cent of nitrogen is used, as additional amounts of phosphoric acid produced only small increases in yield.

Nitrogen: The yield of cotton increased as the percentage of nitrogen was increased from 0 to 8 per cent. The 4-12-4 fertilizer produced an average yield of 406 pounds of lint per acre, or 32 pounds more than the 0-12-4 fertilizer. The use of 6 per cent of nitrogen increased the yield 47 pounds, and 8 per cent of nitrogen, 69 pounds of lint. The results indicate that the soil will respond to even larger applications of nitrogen. For instance, where 800 pounds of fertilizer was used and the percentage of nitro-

gen ranged from 4 per cent to 10 per cent, the yield of cotton increased with each additional increment of nitrogen.

Potash: In general, applications of potash did not produce consistent increases in the yield of cotton. The 4-12-0 fertilizer, however, made an average yield of 385 pounds of lint and the 4-12-4 fertilizer 406 pounds, for the two years, 1930 and 1931, which is a gain of 21 pounds attributable to the 4 per cent of potash (Table 6). The 4-12-6 fertilizer yielded only 373 pounds of lint, or slightly less than the 4-12-0 fertilizer. Increasing the potash from 4 per cent to 8 per cent where 800 pounds of fertilizer was used did not produce significant increases in yield.

Rates of Application of Fertilizer: The 4-12-4 fertilizer was applied at rates of 200, 400, 600, 800, and 1,000 pounds per acre. The yield of cotton increased from 367 pounds to 512 pounds of lint as the rate of application was raised from 200 to 1,000 pounds per acre (Table 6). The first increment of 200 pounds of fertilizer produced an increase of 97 pounds of lint; the second 200 pounds of fertilizer, 39 pounds of lint; the third increment of 200 pounds of fertilizer, 31 pounds of lint; the fourth 200 pounds of fertilizer, 43 pounds of lint; and the fifth increment of 200 pounds

TABLE 7.—Average increase in yield of lint produced by the 4-12-4 fertilizer applied at different rates and increase per 100 pounds of fertilizer used at Angleton, Texas, 1930 and 1931

Rate per acre pounds	Average yield per acre	Increase over unfertilized soil	Increase in yield produced by 100 pounds of fertilizer
	Lbs. lint	Lbs. lint	Lbs. lint
None	270	----	----
200	367	97	48.5
400	406	136	34.0
600	437	167	27.8
800	480	210	26.2
1000	512	242	24.2

of fertilizer, 32 pounds of lint. The amount of lint produced by each 100 pounds of fertilizer decreased rather sharply as the rate of application increased, as shown in Table 7. The yield per 100 pounds of fertilizer decreased from 48.5 pounds of lint to 24.2 pounds of lint when the rate of application was increased from 200 to 1,000 pounds per acre.

Fertilizers Suggested for the Lake Charles Soils: The results of the fertilizer experiments at Angleton indicate that the use of 100 pounds of superphosphate, or 200 to 600 pounds of a 4-8-0 fertilizer, is good fertilizer practice for cotton on the Lake Charles soils. Where larger amounts of nitrogen and phosphoric acid are used, the addition of potash may be beneficial, especially on the lighter soils. The use of some of the commercial ammonium phosphates in quantities to supply the above amounts and ratios of plant food also should be satisfactory.

Results Obtained on Lufkin Fine Sandy Loam at College Station

The Lufkin fine sandy loam at College Station gave better response to applications of phosphoric acid and potash than to applications of nitrogen. The results obtained during the five years, 1927 to 1931, inclusive, indicate that the use of 200 to 400 pounds per acre of an 0-12-4 or 4-12-4 fertilizer or a fertilizer furnishing similar ratios and amounts of plant food is good fertilizer practice for cotton on the Lufkin soils.

The Lufkin fine sandy loam soil is one of the most extensive soil types of the region. The surface soil is gray in color and is underlain by a gray or mottled grayish and yellowish dense plastic clay subsoil. The Lufkin soils, on account of the dense subsoil, have slow under-drainage and on the smooth flat areas the soils may remain wet for a long time after rains. They are only moderately productive. The soil on which the fertilizer work is conducted contains .065 per cent of nitrogen, .024 per cent of phosphoric acid, 49 parts per million of active phosphoric acid (equivalent to 98 pounds in the 2,000,000 pounds of soil in the upper 6 2-3 inches of soil

TABLE 8.—Yield of cotton in pounds of lint per acre at College Station, 1927 to 1931, when 400 pounds of fertilizers of different analyses were applied, and where a 4-12-4 fertilizer was used at different rates per acre.

Fertilizer used	1927	1928	1929	1930	1931	Average	Average increase produced by fertilizers
None	206	315	122	219	287	230	
8-12-8 (800 lbs.)	288	391	187	303	301	294	64
Nitrogen varied:							
0-12-4	218	375	210	293	364	292	62
4-12-4	236	397	191	295	367	297	67
4*-12-4	254	371	126	280	423	291	61
6-12-4	229	375	199	310	345	292	62
8-12-4	228	352	164	280	354	276	46
Phosphoric acid varied:							
4-0-4	203	341	106	241	342	247	17
4-6-4	228	365	150	296	365	281	51
4-8-4	240	382	140	282	285	286	56
4-12-4	236	397	191	295	367	297	67
Potash varied:							
4-12-0	194	359	141	258	278	246	16
4-12-2	221	378	152	290	346	277	47
4-12-4	236	397	191	295	367	297	67
Rates of 4-12-4:							
200 lbs.	223	382	126	273	373	275	45
400 lbs.	236	397	191	295	367	297	67
600 lbs.	236	381	188	305	351	292	62
800 lbs.	266	408	184	313	353	305	75
Manure:							
8 tons	237	366	190	281	402	295	65
12 tons	297	394	169	311	391	312	82
12 tons and 400 lbs. superphosphate	282	439	223	343	433	344	114

*One-third of nitrogen supplied in cottonseed meal and two-thirds in sulphate of ammonia.

per acre), and 48 parts per million of active potash in the surface soil, according to analyses made by the Division of Chemistry.

The fertilizer work was conducted in a three-year rotation of cotton, corn, and oats, the fertilizer being applied to each crop in the rotation.

The average yearly rainfall at College Station for the 43 years 1889 to 1931, inclusive, was 38.33 inches. The rainfall in 1927, 1928, 1929, 1930, and 1931, during which time the experiment was conducted, was 41.28, 34.34, 48.40, 44.27, and 34.79 inches, respectively. The average yearly rainfall would appear to be sufficient for satisfactory yields of crops, but the distribution of the rainfall during the growing season and from year to year is not always favorable for the production of satisfactory yields of cotton and other crops. Periods of deficient rainfall frequently occur in July and August, resulting in low yields.

The yields of cotton obtained in the experiment during the five years 1927 to 1931, inclusive, are given in Table 8.

Phosphoric Acid: The Lufkin soil responded readily to applications of phosphoric acid. For example, the plats treated with the 4-12-4 fertilizer produced an average yield of 297 pounds of lint per acre during the five years of the experiment, which was 50 pounds more than the average yield of the plats which received the 4-0-4 fertilizer (Table 8). Or stated in another way, the 12 per cent of phosphoric acid in the fertilizer was responsible for the average increase of 50 pounds of lint per acre.

Potash: The yield of cotton increased as the amount of potash was increased, as shown by the results presented in Table 8. The 4-12-4 fertilizer made an average yield of 297 pounds, or an increase of 51 pounds over the yield of the plats which received the 4-12-0 fertilizer. This gain of 51 pounds is attributed to the 4 per cent of potash.

Nitrogen: The soil responded slightly to applications of nitrogen but the use of 4 per cent, or 16 pounds, of nitrogen in the 400 pounds of fertilizer was sufficient since larger amounts did not produce additional increases in yield (Table 8).

Rates of Application of Fertilizer: The yield of cotton increased as the rate of application of the 4-12-4 fertilizer was increased from 200 pounds to 800 pounds per acre (Table 8). The application of 200 pounds per acre made an average yield of 275 pounds of lint per acre for the five years of

TABLE 9.—Average increase in yield of lint produced by the 4-12-4 fertilizer used at different rates and average increase per 100 pounds of fertilizer at College Station, 1927 to 1931

Rate per acre pounds	Average yield per acre	Increase over unfertilized soil	Increase in yield produced by 100 pounds of fertilizer
	Lbs. lint	Lbs. lint	Lbs. lint
None	230	---	---
200	275	45	22.5
400	297	67	16.7
600	292	62	10.3
800	305	75	9.4

the experiment, or 45 pounds per acre more than the yield of the soil which received no fertilizer. While larger amounts of fertilizer produced further increases in yield, the increases were not profitable. The increase

produced per 100 pounds of fertilizer used gradually decreased from 22.5 pounds to 9.4 pounds as the rate was increased from 200 to 800 pounds per acre, as shown in Table 9.

Manure: Manure was used alone at rates of 8 tons and 12 tons per acre and at 12 tons per acre in combination with 400 pounds of superphosphate. The application of 8 tons of manure made an average yield of 295 pounds of lint, or 65 pounds per acre more than the yield of the unfertilized soil, as reported in Table 8. The treatment of 12 tons of manure and 400 pounds of superphosphate produced an average yield of 344 pounds of lint per acre while the use of 12 tons of manure alone produced 312 pounds, a difference of 32 pounds. This gain, while indicating the value of superphosphate in balancing the plant-food content of manure, was not profitable.

Fertilizers Suggested for Cotton on Lufkin Soil: On the basis of the results obtained in the fertilizer work at College Station, the use of 200 to 400 pounds per acre of an 0-12-4 or a 4-12-4 fertilizer, or a fertilizer with equivalent amounts and ratios of plant food is suggested for the Lufkin fine sandy loam soil.

Results Obtained on the Goliad Soils at Beeville

The results of experiments with fertilizers on the Goliad fine sandy clay loam at Substation No. 1, Beeville, indicate that the soil is somewhat deficient in available phosphoric acid. In general, however, the use of fertilizers has not been profitable on this soil.

The soils on the experiment station farm at Substation No. 1, Beeville, consist mostly of the Goliad series, which are dark calcareous soils. The fertilizer work has been conducted on the Goliad fine sandy clay loam. The surface soil contains .093 per cent of nitrogen, .032 per cent of phosphoric acid, 56 parts per million of active phosphoric acid, and 435 parts per million of potash, according to chemical anaylses made by the Division of Chemistry. These soils are naturally productive.

The average yearly rainfall at Beeville was 30.56 inches for the 28 years, 1904 to 1931. The rainfall during the active growing season was 15.50 inches in 1927, 19.38 inches in 1928, 23.02 inches in 1929, 14.99 inches in 1930, and 21.53 inches in 1931.

The experiment has been conducted in a three-year rotation of cotton, corn, and cowpeas. The fertilizers were applied in the drill to the cotton and corn. The cowpeas were grown for seed and the vines were plowed under for soil improvement.

Studies with fertilizers on cotton have been conducted at Beeville since 1925. The experiments conducted in 1925 and 1926, however, were preliminary and were designed to indicate the elements deficient in the soil. Sulphate of ammonia, superphosphate, and muriate of potash were used alone and in combination at two different rates. The treatments used expressed in terms of nitrogen, phosphoric acid, and potash, and the yields of cotton obtained are shown in Table 10. The results obtained during these two years indicate that the soil is deficient in phosphoric acid and slightly deficient in nitrogen. The use of 200 pounds of 16 per cent superphosphate

(equivalent to 400 pounds of an 0-8-0 fertilizer) produced an average yield of 263 pounds of lint per acre, or 74 pounds more than the yield of the soil which received no fertilizer. Further, all treatments which included phosphoric acid increased the yield of cotton.

While the work conducted in 1925 and 1926 showed that the soil responded to application of phosphoric acid, it did not indicate the ratio of plant food needed in the fertilizer or a desirable rate of application. For this reason,

TABLE 10.—Yield of cotton in pounds of lint per acre at Beeville, Texas, 1925 and 1926, where fertilizers of various analyses were applied at rates of 400 and 800 pounds per acre

Fertilizer used	1925	1926	Average	Gain produced by fertilizer
None	131	247	189	----
At 400 pounds per acre:				
5-0-0	145	293	219	30
0-8-0	162	364	263	74
0-0-5	190	240	215	26
5-8-0	205	390	298	109
5-0-5	139	261	200	11
0-8-5	187	217	202	13
5-8-5	172	374	273	84
At 800 pounds per acre:				
5-0-0	211	235	223	34
0-8-0	141	285	213	24
0-0-5	137	213	175	—14
5-8-0	157	372	265	76
5-0-5	157	272	215	26
0-8-5	135	409	272	83
5-8-5	181	464	323	134

the work was revised and expanded in the spring of 1927 with the view of determining definitely the fertilizer requirements of the soil for cotton.

The results obtained with the several fertilizer treatments during the five years, 1927 to 1931, inclusive, are shown in Table 11. The effects of nitrogen, of phosphoric acid, of potash, and of rates of application of fertilizer on the yield of cotton are discussed separately in order to show the proper amount of each element and the most suitable rate of application.

Phosphoric Acid: The Goliad sandy clay loam has given some response to applications of phosphoric acid. For instance, the 4-6-4 fertilizer produced an average yield of 348 pounds of lint per acre, or 54 pounds more than the fertilizer which contained no phosphoric acid (the 4-0-4 fertilizer). The 24 pounds of phosphoric acid, in combination with the nitrogen and potash, was responsible for the gain of 54 pounds of lint, which is equivalent to two and one-fourth pounds of lint for each pound of phosphoric acid used. These results indicate that 6 to 8 per cent is enough phosphoric acid for the soil. Apparently the addition of nitrogen and potash without phosphoric acid reduced the yield of cotton, since the 4-0-4 fertilizer made an average yield of 294 pounds of lint while the soil which received no fertilizer produced 322 pounds per acre.

Nitrogen: The application of 4 per cent of nitrogen (16 pounds in the 400 pounds of 4-12-4 fertilizer) made an average yield of 330 pounds of lint, or 34 pounds more than the yield of the 0-12-4 fertilizer (Table 11).

This is an increase of about 2 pounds of lint cotton for each pound of nitrogen used. Apparently the 4 per cent of nitrogen was sufficient, for larger amounts made only slight increases in yield, which were probably not significant.

TABLE 11.—Yield of cotton in pounds of lint per acre at Beeville, Texas, 1927 to 1931, where 400 pounds of fertilizers of different analyses were used and where a 4-12-4 fertilizer was used at different rates per acre

Fertilizer used	1927	1928	1929	1930	1931	Average	Average increase produced by fertilizers
None	146	127	445	655	236	322	----
8-12-8 (800 lbs.)	108	113	503	679	272	335	13
Nitrogen varied:							
0-12-4	125	116	466	521	254	296	—26
4-12-4	146	132	476	616	278	330	8
4*-12-4	178	140	490	630	272	342	20
6-12-4	121	100	429	584	299	307	—15
8-12-4	157	135	484	682	293	350	28
Phosphoric acid varied:							
4-0-4	129	167	364	586	222	294	—28
4-6-4	191	128	481	662	277	348	26
4-8-4	135	143	501	626	239	329	7
4-12-4	146	132	476	616	278	330	8
Potash varied:							
4-12-0	80	159	456	514	297	301	—21
4-12-2	105	146	496	571	306	325	3
4-12-4	146	132	476	616	278	330	8
Rates of 4-12-4:							
200 lbs.	131	137	453	663	271	331	9
400 lbs.	146	132	476	616	278	330	8
600 lbs.	132	119	451	705	296	341	19
800 lbs.	105	123	504	692	279	341	19
Manure:							
8 tons	----	----	----	671	299	485**	----
2 tons	----	----	----	725	304	515**	----
12 tons and 400 lbs. superphosphate	----	----	----	658	333	495**	----

*One-third of nitrogen supplied in cottonseed meal; two-thirds in sulphate of ammonia.
**Average for two years, 1930 and 1931.

Potash: The application of nitrogen and phosphoric acid without potash apparently reduced the yield as compared with the yield of the unfertilized soil or with the yield of the soil which received the 4-12-4 fertilizer, as shown in Table 11. The 4-12-4 fertilizer, however, made an average yield of 330 pounds per acre, or only 8 pounds more than the yield of the unfertilized soil, which probably was not significant.

TABLE 12.—Average increase in yield of lint produced by the 4-12-4 fertilizer used at different rates and average increase of lint per 100 pounds of fertilizer at Beeville, 1927 to 1931

Rate per acre pounds	Average yield per acre	Increase over unfertilized soil	Increase in yield produced by 100 pounds of fertilizer
	Lbs. lint	Lbs. lint	Lbs. lint
None	322	----	----
200	331	9	4.5
400	330	8	2.0
600	341	19	3.2
800	341	19	2.4

Rates of Application of Fertilizer: The yield of cotton increased as the rate of application of fertilizer was increased, although the increases were not profitable. The gain produced by the various rates ranged from 9 pounds of lint for the 200 pounds of fertilizer to 19 pounds of lint for the 800 pounds of fertilizer, as shown in Table 12.

Manure: Manure was used in 1930 and 1931. The application of 8 tons of manure produced 485 pounds of lint, or 39 pounds more than the unferlized soil, which is a gain of nearly 5 pounds of lint for each ton of manure used. The 12 tons of manure made an average yield of 515 pounds of lint, which was 69 pounds more than the yield of the untreated soil and 30 pounds more than the yield of the 8 tons of manure.

Results Obtained on the Houston Soils at Temple

All of the fertilizers used increased the average yield of cotton on the Houston black clay and Houston clay at Temple during the four years, 1928 to 1931. In general, however, the increases in yield were not sufficient to pay for the fertilizers used. The results indicate that the soil gives better response to applications of phosphoric acid than to applications of nitrogen or potash. Chemical analysis also indicates that the soil is defi-

TABLE 13.—Yield in pounds of lint cotton per acre at Temple, Texas, 1928 to 1931, where 400 pounds of fertilizers of different analyses were applied and where a 4-12-4 fertilizer was used at different rates per acre

Fertilizer used	1928	1929	1930	1931	Average	Average increase produced by fertilizer
None	183	162	99	303	187	
8-12-8 (800 lbs.)	189	212	123	356	220	33
Nitrogen varied:						
0-12-4	206	188	155	327	219	32
4-12-4	205	173	173	355	227	40
4*-12-4	198	193	119	338	212	25
6-12-4	267	194	144	351	239	52
8-12-4	268	198	132	322	230	43
Phosphoric acid varied:						
4-0-4	220	142	114	311	197	10
4-6-4	222	188	128	339	219	32
4-8-4	222	171	117	335	211	24
4-12-4	205	173	173	355	227	40
Potash varied:						
4-12-0	214	187	146	310	214	27
4-12-2	217	164	141	363	221	34
4-12-4	205	173	173	355	227	40
Rates of 4-12-4:						
200 lbs.	190	179	99	328	199	12
400 lbs.	205	173	173	355	227	40
600 lbs.	214	198	113	383	227	40
800 lbs.	215	174	131	374	224	37

*One-third of nitrogen supplied in cottonseed meal; two-thirds in sulphate of ammonia.

cient in active (available) phosphoric acid, although it contains an abundance of total phosphoric acid.

The fertilizer work at Substation No. 5, Temple, is located on Houston clay and Houston black clay, which are the principal soil types in the Blackland Prairie in central Texas. The Houston soils, the well-known

"black waxy" soils, have been noted for their productiveness, as indicated by their high yield of good-quality cotton. The surface soil contains .101 per cent of nitrogen, .105 per cent of phosphoric acid, 7 parts per million of active phosphoric acid, and 67 parts per million of active potash, as shown by the analyses made by the Division of Chemistry.

The average yearly rainfall at Temple for the 19 years, 1913 to 1931, inclusive, was 33.70 inches. The rainfall during each of the four years of the experiment was: 29.74 inches in 1928, 31.86 inches in 1929, 34.75 inches in 1930, and 23.93 inches in 1931.

The experiment has been conducted in a three-year rotation of cotton, corn, and oats in which the fertilizer has been applied to each crop. The work was begun in 1928 and the results of four years are now available and are presented in Table 13.

As mentioned above, all of the fertilizers used produced larger average yields than the unfertilized soil during the four years, 1928 to 1931, as shown in Table 13. The results indicate that probably phosphoric acid is needed before either nitrogen or potash. For example, the 4-12-4 fertilizer made an average yield of 227 pounds of lint, which was 30 pounds more than the yield of the fertilizer which contained no phosphoric acid (the 4-0-4 fertilizer).

While the use of nitrogen made some increases in yield, as shown in Table 13, it is doubtful if they were significant. Somewhat similar results were obtained with potash.

Although some increases in yield of cotton were obtained from the application of fertilizers on the Houston soils at Temple, the fertilizers were, as a rule, not profitable.

Results Obtained on the San Saba Soils at Denton

Fertilizers have increased the yield of cotton to some extent on the San Saba clay at Substation No. 6, Denton, Texas. In general, however, the fertilizers used have not been profitable and consequently fertilizers are not recommended for cotton on this soil.

The soils at Substation No. 6, Denton, belong to the Denton and San Saba series of soils, which are important and extensive soils of the Grand Prairie. The fertilizer work has been conducted on the San Saba clay, which has a black to dark-brown surface soil underlain by a dark-brown or yellowish-brown, or in places, by very dark-gray clay subsoil. The San Saba clay is a rather productive soil. According to a chemical analysis made by the Division of Chemistry, the surface soil contains .140 per cent of nitrogen, .076 per cent of phosphoric acid, 34 parts per million of active phosphoric acid, and 285 parts per million of active potash.

The work with fertilizers has been conducted in a three-year rotation of cotton, corn, and wheat and in a three-year rotation of cotton, corn, and oats.

These studies have been in progress since 1926. The work in 1926 and 1927, however, was rather limited in scope and the main object was to determine the elements deficient in the soil. Sulphate of ammonia, super-

phosphate, and muriate of potash were used alone and in all possible combinations at two different rates. The treatments used, expressed in percentages of nitrogen, phosphoric acid, and potash (N-P-K), and the results obtained are presented in Table 14. The average yields of cotton for the two years indicate that phosphoric acid is deficient in this soil. For ex-

TABLE 14.—Yield of cotton in pounds of lint per acre at Denton, Texas, 1926 and 1927, where fertilizers of various analyses were used at 400 and 800 pounds per acre

Fertilizer used	1926	1927	Average	Average increase produced by fertilizers
None	262	277	270	----
At 400 lbs. per acre:				
6-0-0	242	280	261	—9
0-8-0	223	351	287	17
0-0-5	225	284	255	—15
6-8-0	266	385	326	56
6-0-5	177	347	262	—8
0-8-5	237	395	316	46
6-8-5	291	372	332	62
At 800 lbs. per acre:				
6-0-0	206	268	237	—33
0-8-0	315	428	372	102
0-0-5	292	363	328	58
6-8-0	300	464	382	112
6-0-5	225	330	278	8
0-8-5	316	413	365	95
6-8-5	285	485	385	115

TABLE 15.—Yield of cotton in pounds of lint per acre at Denton, Texas, 1928 to 1931, where 400 pounds of fertilizers of different analyses were applied and where a 4-12-4 fertilizer was used at different rates per acre.

Fertilizer used	1928	1929	1930	1931	Average	Average increase produced by fertilizer
None	341	229	224	387	295	
8-12-8 (800 lbs.)	381	249	242	410	321	26
Nitrogen varied:						
0-12-4	339	262	232	442	319	24
4-12-4	356	287	228	426	324	29
4*-12-4	347	300	247	404	325	30
6-12-4	354	291	226	425	324	29
8-12-4	369	292	216	432	327	32
Phosphoric acid varied:						
4-0-4	332	276	231	381	305	10
4-6-4	354	281	225	409	317	22
4-8-4	353	328	237	444	341	46
4-12-4	356	287	228	426	324	29
Potash varied:						
4-12-0	338	267	212	407	306	11
4-12-2	339	261	216	422	310	15
4-12-4	356	287	228	426	324	29
Rates of 4-12-4:						
200 lbs.	331	288	235	431	321	26
400 lbs.	356	287	228	426	324	29
600 lbs.	387	305	239	455	347	52
800 lbs.	357	288	232	390	317	22
Manure:						
8 tons	383	266	251	490	348	53
12 tons	377	292	247	437	338	43
12 tons and 400 lbs. superphosphate	366	295	252	409	331	36

*One-third of nitrogen supplied in cottonseed meal and two-thirds in sulphate of ammonia.

ample, applications of phosphoric acid either alone or with nitrogen or potash made somewhat larger average yields than the unfertilized soil.

The fertilizer studies were revised and enlarged in 1928 with the view of determining the most suitable analyses of fertilizer and the most practicable rate of application of fertilizer for cotton under the conditions prevailing in the region. The results of the revised work during the four years, 1928, 1929, 1930, and 1931, are given in Table 15.

All of the fertilizer treatments used made larger average yields of cotton than the soil which received no fertilizer. Applications of nitrogen, of phosphoric acid, and of potash have produced small increases in yield. The results obtained so far indicate that the 4-8-4 fertilizer furnishes about the right proportion of nitrogen, phosphoric acid, and potash. In general, however, the fertilizers have not been profitable when applied to cotton on the San Saba clay.

PROFITS OBTAINED FROM THE USE OF FERTILIZERS

The profits resulting from the use of fertilizers on any crop will depend upon (1) the cost of the fertilizer, including the purchase price, interest on the money invested in fertilizer, the cost of applying the fertilizer, and the harvesting and preparing the increase in yield of crop produced by fertilizer; (2) the increase in yield and improvement in quality resulting from the fertilizer; and (3) the selling price of the crop. It is obvious from these considerations that the fertilizer which makes the largest yield may not be the most profitable fertilizer. In general, however, the best fertilizer to use will be the one that gives the largest and most consistent profit over a period of years.

In order to arrive at the most profitable fertilizer practice for cotton, the profits or losses resulting from the use of the different fertilizers at the substations were computed. The profits and losses were obtained by deducting the cost of the fertilizer from the value of the increase in yield of cotton produced by the fertilizer. The figures on profit and loss do not include any interest on the money invested in fertilizer or the expense involved in applying the fertilizer to the land and picking and harvesting the increase produced by the fertilizer. The cost of the fertilizer during each year of the experiment was based on the average selling price of the materials used in making up the various analyses. The average price of spot cotton, middling basis for ⅞-inch staple, for the month of October on the Houston market each year of the experiment was used in estimating the value of the increase produced by the fertilizer.

The average profits obtained from the fertilizer used during the years of the experiment are given in Table 16. The reader should not get the impression that he would obtain similar results if he were to use the same or similar fertilizers, because the cost of fertilizers and the selling price of cotton in all probability would be different from the ones used here. These figures are given merely to interpret to the fertilizer consumer the

results of the fertilizers in dollars and cents, which in the final analysis, determines the proper practices to follow in any locality. If, however, the increase in yield caused by the fertilizer, the selling price of the crop,

TABLE 16.—Average profits and losses obtained from use of fertilizers at Troup, Nacogdoches, Angleton, College Station, Beeville, Temple, and Denton, Texas

Fertilizer used	Troup 1927-1930	Nacogdoches 1927-1931	Angleton 1930-1931	College Station 1927-1931	Beeville 1927-1931	Temple 1928-1931	Denton 1928-1931
	$	$	$	$	$	$	$
8-12-8 (800 lbs.)		—5.67**	5.67	—9.68	—16.90	—15.48	—15.93
Nitrogen varied:							
0-12-4	—2.77	1.65	5.52	4.47	—2.92	0.22	—1.33
4-12-4	2.92	4.06	5.58	2.74	—4.71	—2.13	—2.39
4*-12-4	2.47	5.08		—0.12	—3.37	—3.95	—2.77
6-12-4	1.43	3.57	5.49	0.69	—7.07	—0.42	—3.63
8-12-4	1.66	3.38	6.01	—3.30	—5.75	—2.21	—4.10
Phosphoric acid varied:							
0-4-0			4.95				
0-8-0			4.21				
4-0-4	—2.35	—3.23	—0.08	—1.34	—1.98	—1.13	—1.03
4-6-4	5.40	5.27	5.65	1.31	—1.26	—0.57	—1.56
4-8-4	4.49	5.01	6.06	1.55	—2.85	—2.22	0.86
4-12-4	2.92	4.06	5.58	2.74	—4.71	—2.13	—2.39
4-16-4			5.14				
Potash varied:							
4-12-0	—0.22	4.05	4.98	—2.58	—3.39	—1.67	—3.57
4-12-2	0.54	4.17		0.10	—2.72	—2.31	—4.01
4-12-4	2.92	4.06	5.58	2.74	—4.71	—2.13	—2.39
4-12-6			3.07				
Rates of 4-12-4:							
200 lbs.	2.48	6.72	5.32	2.20	—2.01	—1.72	0.43
400 lbs.	2.92	4.06	5.58	2.74	—4.71	—2.13	—2.39
600 lbs.	2.61	2.92	4.99	—1.21	—7.78	—4.93	—2.62
800 lbs.	—1.09	—1.00	5.70	—2.27	—9.61	—8.86	—9.15
1000 lbs.			5.11				
Manure:							
8 tons		**17.08		8.27	†2.80		5.91
12 tons		**22.63		11.36	†5.83		5.89
12 tons, 400 lbs. superphosphate		**19.24		11.08	†—1.67		0.65
At 800 lbs:							
4-12-4			5.70				
6-12-4			5.35				
8-12-4			6.39				
10-12-4			5.99				
8-12-4			6.39				
8-12-6			6.24				
8-12-8			5.67				

*One-third of nitrogen in cottonseed meal; two-thirds in sulphate of ammonia.
**Average for 1927, 1928, and 1929.
†Average for 1930 and 1931.

and the cost of the fertilizer are known, the reader can calculate for himself the profits or losses obtained from the use of fertilizers under his particular conditions.

At Troup the 4-6-4 and 4-8-4 fertilizers were the most profitable treatments used, resulting in average profits of $5.40 and $4.49 per acre, respectively, for the four years, 1927 to 1930 (Table 16). Those fertilizers that

did not contain all three elements—nitrogen, phosphoric acid, and potash—were used at a loss. The 0-12-4 fertilizer resulted in a loss of $2.77 per acre; the 4-0-4, a loss of $2.35; and the 4-12-0, a loss of $0.22.

The use of 200 pounds per acre of a 4-12-4 fertilizer made the largest average profit, $6.72 per acre, at Nacogdoches. Manure on the average increased the value of the crop about two dollars per acre for each ton of manure used.

At Angleton, superphosphate at the rate of 100 pounds per acre (0-4-0 analysis) returned an average profit of $4.95 per acre and the largest profit per dollar invested in fertilizer. Probably the use of 100 pounds of superphosphate per acre or moderate applications of 4-8-0 fertilizer, 200 to 600 pounds per acre, will be the most profitable fertilizer practice for cotton on the Lake Charles soils.

The 0-12-4 and 4-12-4 fertilizers were the most profitable treatments used at College Station, and returned average profits of $4.47 and $2.74 per acre, respectively, for the five years of the experiment. On the average, manure was worth about a dollar per ton.

In general, fertilizers have been unprofitable on the Goliad soil at Beeville, on the Houston soil at Temple, and on the San Saba soil at Denton.

DISCUSSION OF RESULTS

The results of the fertilizer work with cotton have been discussed separately for each section. Now, in order to get a better idea of the results of all the work, the average yields of cotton at each station are brought together in Table 17.

The results of these fertilizer experiments show that the sandy soils in the eastern part of the State are deficient in nitrogen and phosphoric acid and to a lesser extent in potash, that the Lake Charles soils in the Gulf Coast Prairie are markedly deficient in phosphoric acid, and that the soils in the Blackland Prairie do not, as a rule, respond readily or profitably to applications of fertilizers.

It will be noted from Table 17 that the sandy soils at Nacogdoches and Troup need a complete fertilizer for best results. The use of a 4-8-4 or 4-6-4 fertilizer at the rate of 200 to 400 pounds per acre is suggested for cotton on these soils. The use of manure at the rates of 8 and 12 tons per acre has been worth about two dollars per ton a year at Nacogdoches.

The dark-colored prairie soils of the Lake Charles series in the humid part of the Gulf Coast Prairie are deficient in phosphoric acid. The use of 100 pounds of superphosphate or 200 to 600 pounds per acre of a 4-8-0 fertilizer or a fertilizer furnishing similar amounts and proportions of nitrogen and phosphoric acid should give good results when applied to cotton on these soils.

The Lufkin fine sandy loam at College Station appears to be more deficient in phosphoric acid and potash than in nitrogen. The application of the 0-12-4 fertilizer made the largest average profit per acre, which, however, was due largely to the good results obtained in 1929. Considering both yield and profit, the use of 200 to 400 pounds per acre of 0-12-4 or

TABLE 17.—Average yield and average gain in pounds of lint per acre produced by fertilizers at Troup, Nacogdoches, Angleton, College Station, Beeville, Temple, and Denton, Texas

Fertilizers used		Troup 1927-1930		Nacogdoches 1927-1931		Angleton 1930-1931		College Station 1927-1931		Beeville 1927-1931		Temple 1928-1931		Denton 1928-1931	
Analysis	Lbs. per acre	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.	Yield Lbs.	Gain Lbs.
None		190	----	120	----	270	----	230	----	322	----	187	----	295	----
8-12-8	800	----	----	----	----	553	283	294	64	335	13	220	33	321	26
Nitrogen varied:															
0-12-4	400	200	10	163	43	374	104	292	62	296	—26	219	32	319	24
4-12-4	400	248	58	194	74	406	136	297	67	330	8	227	40	324	29
4*-12-4	400	247	57	201	81	----	----	291	61	342	20	212	25	325	30
6-12-4	400	247	57	202	82	421	151	292	62	307	—15	239	52	324	29
8-12-4	400	255	65	207	87	443	173	276	46	350	28	230	43	327	32
Phosphoric acid varied:															
4-0-4	400	199	9	101	—19	306	36	247	17	294	—28	197	10	305	10
4-6-4	400	254	64	191	71	387	117	281	51	348	26	219	32	317	22
4-8-4	400	250	60	202	82	399	129	286	56	329	7	211	24	341	46
4-12-4	400	248	58	194	74	406	136	297	67	330	8	227	40	324	29
Potash varied:															
4-12-0	400	224	34	200	80	385	115	246	16	301	—21	214	27	306	11
4-12-2	400	231	41	194	74	----	----	277	47	325	3	221	34	310	15
4-12-4	400	248	58	194	74	406	136	297	67	330	8	227	40	324	29
Rates of:															
4-12-4	200	226	36	187	67	367	97	275	45	331	9	199	12	321	26
4-12-4	400	248	58	194	74	406	136	297	67	330	8	227	40	324	29
4-12-4	600	266	76	213	93	437	167	292	62	341	19	227	40	347	52
4-12-4	800	262	72	212	92	480	210	305	75	341	19	224	37	317	22

*One-third of nitrogen supplied in cottonseed meal and two-thirds in sulphate of ammonia.

4-12-4 fertilizer or an analysis supplying equivalent amounts and proportions of plant food is suggested for cotton on the Lufkin soils. Manure when used at the rates of 8 and 12 tons per acre increased the value of the cotton crop about one dollar per acre for each ton of manure used.

The dark-colored soils of the Goliad series at Beeville have responded to some extent to applications of nitrogen, of phosphoric acid, and of potash. As a rule, however, none of the fertilizers used was profitable. Somewhat similar results have been obtained on the Houston black clay at Temple and on the San Saba clay at Denton.

SUMMARY

The results obtained in the experiments with fertilizers on cotton at the several substations lead to the following conclusions:

The sandy soils in the eastern part of the State are deficient in nitrogen, phosphoric acid, and potash. The application of 200 to 400 pounds per acre of a 4-6-4 or 4-8-4 fertilizer or a fertilizer supplying similar ratios and amounts of plant food is recommended for cotton on these soils.

The Lake Charles soils in the Gulf Coast Prairie are first in need of phosphate. The use of 100 pounds of superphosphate or 200 to 600 pounds of a 4-8-0 fertilizer per acre or a fertilizer with equivalent amounts and proportions of plant food is suggested for cotton on these soils.

The Lukfin fine sandy loam apparently needs phosphoric acid and potash before it does nitrogen. The 4-12-4 and 0-12-4 fertilizers gave better results on this soil than the other fertilizers used.

Although fertilizers gave some response on the Goliad fine sandy clay loam at Beeville, on the Houston clay and Houston black clay at Temple, and on the San Saba clay at Denton, in general the use of fertilizers was not profitable on these soils.