A6-130-8,000-L180

TEXAS AGRICULTURAL EXPERIMENT STATION

A. B. CONNER, DIRECTOR
College Station, Brazos County, Texas

BULLETIN NO. 408 FEBRUARY, 1930

DIVISION OF AGRONOMY

THE EFFECT OF SULPHUR ON YIELD OF CERTAIN CROPS

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†As of February 1, 1930.

The use of sulphur in amounts ranging from 50 to 10,000 pounds per acre on soils at Temple, Angleton, Beeville, College Station, Nacogdoches, and Troup, Texas, did not produce significant or profitable increases in the yield of cotton, corn, cowpeas, or oats. The work was conducted over a period of six years at Temple, four years at Angleton and Troup, three years at Nacogdoches, and two years at Beeville and College Station. The results indicate that the soils on which the experiments were conducted are not deficient in sulphur and consequently the use of sulphur alone as a fertilizer would not be profitable in farm practice.

Sulphur applied at rates ranging from 50 to 10,000 pounds per acre each year to the dark calcareous soil at Temple did not bring about an acid condition in the soil during the six years of the experiment. The rate of application of sulphur apparently had no appreciable effect on the development or control of root-rot disease of cotton on this soil, indicating that sulphur would be of little practical value in controlling the disease on highly calcareous soils, such as the black waxy soils in the Blackland region of Central Texas.

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BULLETIN NO. 408 FEBRUARY, 1930

THE EFFECT OF SULPHUR ON YIELD OF CERTAIN CROPS

E. B. REYNOLDS

In 1921 the Texas Agricultural Experiment Station began field experiments with sulphur as a fertilizer to determine the needs of some of the more important soils in Texas for sulphur. The results obtained in these experiments from 1921 to 1928 are reported in this Bulletin. These and other experiments with sulphur were made possible through the generous cooperation of the Freeport Sulphur Company.

It has been known for a long time that several elements are necessary for the growth and normal development of plants. Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, iron, and sulphur are the ten elements usually regarded as being necessary for the complete development of plants. Manganese, silicon, chlorine, and boron may possibly function as nutrient elements. Of the essential elements, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and iron are used in large amounts by plants. Small amounts or traces of manganese, chlorine, and boron are beneficial to some species of plants.

It has been found by practical farm experience and field experiments that nitrogen, phosphorus, and potassium are more likely to be deficient in cultivated soils than the other essential elements. This is the reason why these elements are used in commercial fertilizers.

While sulphur is necessary for plant growth, until recent years this element has been assumed to be present in the soil in amounts sufficient for normal plant growth. Accordingly sulphur has not been regarded as being a limiting factor in the production of crops and has not been used extensively as a fertilizer. Investigations during the last thirty or forty years, however, have shown the importance of sulphur in the nutrition of plants and its relation to the fertility of the soil.

REVIEW OF OTHER WORK WITH SULPHUR

An extensive review of the work done with sulphur as a fertilizer need not be given here for the reason that rather complete reviews have been made by other workers, especially Joffe (4), Olson and St. John (8), Reimer and Tartar (10), and Shedd (11). A brief discussion, however, will be given to show in a general way the development of the research work with sulphur as a fertilizer.

Apparently the first work reported on the use of sulphur in agriculture in this country was done primarily as control measures on plant diseases, especially potato scab. Halsted at the New Jersey Agricultural

Experiment Station conducted several field experiments with sulphur for the purpose of controlling potato scab. In some of these experiments (2) the use of sulphur reduced the infestation of potato scab from 100 per cent to 5 per cent. The increase in yield of potatoes obtained by using sulphur in these and similar experiments elsewhere suggested the use of sulphur as a fertilizer. Subsequently, numerous experiments with sulphur as a fertilizer have been conducted in Europe and America. A large amount of work with sulphur has been carried on in the United States since 1910.

Hart and Peterson (3) in Wisconsin were perhaps the first workers to study sulphur in its relation to soil fertility in a comprehensive and fundamental manner. They determined the amount of sulphur in different soils, the amount removed by different crops, the amount lost by leaching, and the amount added to the soil by rainfall. These workers found that soils which had been in cultivation 50 to 60 years without the addition of manures had lost 40 per cent of their sulphur, in comparison with the sulphur content of adjacent virgin soils.

Shedd (11) determined the amount of sulphur in some of the soils in Kentucky and conducted experiments with sulphur as a fertilizer for several crops. He found that sulphur increased the yield of tobacco, soybeans, mustard, radishes, and turnips. Application of 7,000 pounds of sulphur per acre caused cabbage to die and prevented the germination of mustard seed.

Reimer and Tartar (10) made a rather extensive study of sulphur as a fertilizer for alfalfa on soils in southern Oregon. They found that sulphur and fertilizers containing sulphur increased the yield of alfalfa 50 per cent to 1000 per cent on some soils. These workers recommended the use of 40 to 50 pounds of sulphur along with 200 pounds of rock phosphate per acre, or 200 pounds of gypsum alone per acre, or 250 pounds of superphosphate per acre for alfalfa on the soils of southern Oregon.

Olson and St. John (8) in Washington recently made an exhaustive study of sulphur as a plant food.

Lomanitz (5) found by chemical analyses of soils and pot experiments with crops, that the soils of Brazos and Jefferson counties, Texas, are not deficient in sulphur.

Reynolds and Leidigh (9) at the Texas Agricultural Experiment Station reported that sulphur produced slight increases in the yield of cotton on a dark calcareous soil in central Texas.

In experiments conducted by the Montana Agricultural Experiment Station (7) sulphur increased the yield of alfalfa 1.92 tons per acre, while gypsum gave an increase of 1.35 tons.

Cross (1) reported that applications of sulphur to sugar cane in Argentine produced small but distinct increases in the yield of cane and sugar.

McKibbin (6) in Maryland studied the effect of sulphur on soils and on yield of crops. He used thirteen different crops, including cotton, corn, wheat, potatoes, and alfalfa, and seven different soils. Sulphur was used at the rates of 50, 100, and 300 pounds per acre. In twenty-one trials where sulphur was used alone, increases in yield were obtained in eleven cases; decreases in yield resulted in seven cases; and in the other three trials sulphur had no effect on yield. The use of sulphur in mixtures with superphosphate (acid phosphate) had a tendency to lower the yield of crops grown on Maryland soils, while sulphur in mixtures with raw rock phosphate tended to increase the yield. McKibbin stated that light applications of sulphur for specific crops may increase yields but he recommended that not more than 100 pounds of elemental sulphur per acre be applied to Maryland soils.

OBJECT AND PLAN OF THE EXPERIMENT

When the work with sulphur was begun in 1921 at Substation No. 5 Temple, Bell County, the two main objects in mind were to determine by the use of field experiments (1) the need of the soils for sulphur and (2) if the use of sulphur in various amounts would control root rot, a disease of cotton especially destructive in the Blackland Region of Central Texas. Later the work was extended to the following points in the State:

Main Station, College Station, Brazos County,
Substation No. 1, Beeville, Bee County,
Substation No. 2, Troup, Smith County,
Substation No. 3, Angleton, Brazoria County,
Substation No. 11, Nacogdoches, Nacogdoches County.

At these five places the principal object has been to determine the needs of the soils for sulphur, since the root-rot disease is not present or is not of major importance at these stations. (See cut on back page.)

Time and Method of Applying the Sulphur

Ground commercial sulphur was used in all of these studies. In the work at Angleton, College Station, and Temple the sulphur was applied broadcast to the land two to three weeks before the crops were planted and disked in thoroughly to mix the sulphur with the surface soil. At Beeville, Nacogdoches, and Troup the sulphur was applied in the drill at the time the seed bed was prepared.

Rate of Applying the Sulphur

The rate of applying sulphur has not been uniform at all the stations. At Temple the work has included light and heavy applications, ranging from 50 pounds to 10,000 pounds per acre. Only two rates of application, 100 pounds and 200 pounds per acre, were used in the experiment at Beeville and College Station. The sulphur was applied at the rates of 250 and 500 pounds per acre at Angleton, Nacogdoches, and Troup.

EXPERIMENTAL DATA

The data obtained in conducting the experiment with sulphur are discussed separately for each station as a matter of convenience. The general results at the several stations are then brought together and compared in order that the experiment may be considered as a whole.

Results Obtained with Cotton, Corn, and Oats at Temple

Since the object of the experiment at Substation No. 5, Temple, was to determine the need of the soil for sulphur and to ascertain if sulphur could be used effectively to control the root rot of cotton, the sulphur was used at several rates of application, ranging from 50 to 4,000 pounds per acre on cotton, corn, and oats in a three-year rotation (Table 1). Sulphur also was applied at the rates of 500, 2,500, 5,000, and 10,000 pounds per acre on cotton grown on the same land every year (Table 2). In the three-year rotation the sulphur was applied to the cotton only in 1922 and 1923, but in 1924, 1925, and 1926, the sulphur was applied to the three crops each year. Belton cotton, Mosshart Yellow Dent corn, and Texas Red Rust-Proof oats were the crops grown in the experiment. The work was conducted on Bell clay, which is a dark or black calcareous soil, previously correlated as Simmons clay.

Yield of Rotated Cotton: The rate of applying sulphur appeared to have no consistent effect on the yield of cotton grown in rotation in 1922 and 1923 (Table 1). In 1926, however, the rates of 400, 500, 1,000, and 1,500 pounds of sulphur made considerably larger yields than the other rates of application, or the soil which did not receive sulphur. The application of 1,000 pounds of sulphur per acre produced the largest yield, 655 pounds of lint per acre in 1926, which was 120 pounds

Table 1. Yield of rotated cotton in pounds of lint per acre in experiment with sulphur at Temple, Texas

Pounds of sulphur per acre	1921	1922	1923	1924	1925	1926	Average	
							1922-1926	1921-1926
None	269	207	303	247	157	535	290	286
50	....	188	319	220	172	512	282	....
100	....	204	297	203	149	523	275	....
200	....	204	302	234	142	454	267	....
300	....	216	291	216	152	502	275	....
400	....	195	317	219	142	625	300	....
500	249	221	332	238	140	593	305	296
1000	....	211	316	225	147	655	311	....
1500	....	209	323	221	149	628	306	....
2000	....	228	304	202	158	516	282	....
2500	223	199	270	270	137	472	270	262
3000	....	188	278	223	122	477	258	....
4000	....	195	320	179	135	445	255	....

more than the yield of the soil which received no sulphur. The 1000-pound treatment of sulphur also made the largest average yield, 311 pounds per acre, during the five years, 1922 to 1926, inclusive. This high average yield is due to the large yield of 655 pounds in 1926, since the treatment actually made a smaller average yield than the untreated soil from 1922 to 1925, inclusive. The average yield of cotton decreased as the amount of sulphur increased from 1,500 to 4,000 pounds per acre. For the six years, 1921 to 1926, inclusive, the treatment of 500 pounds of sulphur per acre made an average yield of 296 pounds of lint per acre, which was only 10 pounds more than the yield of soil which received no sulphur. While sulphur used at the rates of 400, 500, 1,000, and 1,500 pounds per acre made slightly larger average yields than the soil receiving no sulphur, the increases in yield were not large enough to pay for the cost of the sulphur used. The results indicate, therefore, that sulphur is not needed on this soil for the production of cotton.

Yield of Continuous Cotton: During the six years of the experiment the yields of cotton resulting from the various treatments were rather erratic, showing no consistent relation to the amount of sulphur used, Table 2. The treatment of 500 pounds of sulphur made the largest average yield, 151 pounds of lint per acre, for the four years, 1923, 1924, 1925, and 1926, as compared with 141 pounds for the untreated soil and 147 pounds for the soil which received 10,000 pounds per acre. These data indicate that sulphur would not be profitable when used as a fertilizer on this soil.

Table 2. Yield of continuous cotton in pounds of lint per acre in experiment with sulphur at Temple, Texas

Pounds of sulphur per acre	1921	1922	1923	1924	1925	1926	Average	
							1921-1926	1923-1926
None	174	127	160	169	23	212	144	141
500	152	123	162	191	42	210	147	151
2500	....	....	189	112	47	209	....	139
5000	....	....	151	113	79	200	....	136
10000	147	118	164	125	53	246	142	147

Yield of Corn: As mentioned above, sulphur was applied to corn in 1924, 1925, and 1926. In 1922 and 1923 the corn received the residual effects, if any, of the sulphur applied to the previous crop of cotton. In 1924 and 1926 apparently the heavier applications of sulphur, 2,000 to 4,000 pounds per acre, caused some reduction in the yield of corn (Table 3). The untreated soil and the soil to which 500 pounds of sulphur were applied made the same average yield, 38.1 bushels per acre, for the four years, 1922, 1923, 1924, and 1926. The use of 50 pounds of sulphur per acre resulted in the largest average yield, 40.1 bushels per acre during the three years, 1923, 1924, and 1926, which was 2.3 bushels more than the yield of the soil which received no sulphur. The heavier applications, 2,000 to 4,000 pounds per acre, reduced the yield of corn about five bushels per acre in comparison with the yield of corn on the untreated soil.

Table 3. Yield of corn in bushels per acre in experiment with sulphur at Temple, Texas

Pounds of sulphur per acre	1922	1923	1924	1926	Average	
					1922-23-24-26	1923-24-26
None	38.8	44.0	31.9	37.5	38.1	37.8
50	....	47.1	36.9	36.4	....	40.1
100	....	44.2	36.9	35.6	....	38.9
200	....	43.6	32.9	39.9	....	38.8
300	....	44.1	30.7	37.9	....	37.6
400	....	44.0	34.1	33.5	....	37.2
500	36.5	43.0	36.0	36.9	38.1	38.6
1000	....	42.5	30.8	35.0	....	36.1
1500	....	43.9	25.5	36.2	....	35.2
2000	....	39.6	24.9	32.2	....	32.2
2500	36.6	40.6	23.8	33.8	33.7	32.7
3000	....	44.1	22.8	28.6	....	31.8
4000	....	42.7	23.0	31.6	....	32.4

Yield of Oats: Satisfactory yields of oats were obtained in 1923, 1924, and 1926. The oats in the experiment were practically a failure in 1925 on account of being replanted in February after being killed by freezing and on account of drouth later in the season, the yields ranging from 3.7 to 10.8 bushels per acre, as shown in Table 4. The average yields for the three years, 1924, 1925, and 1926 show that sulphur had very little effect on the yield of oats.

Table 4. Yield of oats in bushels per acre in experiment with sulphur at Temple, Texas

Pounds of sulphur per acre	1923	1924	1925	1926	Average	
					1924-26	1923-26
None	73.9	72.5	8.6	70.1	50.4	56.3
50	....	61.7	10.8	84.6	52.4	....
100	....	62.8	10.8	72.2	48.6	....
200	....	68.1	6.0	56.4	43.5	....
300	....	71.0	9.3	66.7	49.0	....
400	....	69.0	9.3	71.0	49.7	....
500	70.9	78.7	8.7	65.3	50.9	55.9
1000	....	83.0	7.3	69.4	53.2	....
1500	....	75.5	8.6	65.7	49.9	....
2000	....	77.1	7.7	64.2	49.7	....
2500	69.4	73.4	6.7	66.5	48.9	54.0
3000	....	71.3	3.9	69.9	48.4	....
4000	....	71.9	3.7	85.6	53.7	....

Effect of Sulphur on the Reaction of the Soil

Bell clay, on which the work with sulphur at Temple was conducted, is a dark or black calcareous soil. The soil contains about 100,000 pounds of lime in 2,000,000 pounds of soil (the weight of the upper $6\frac{2}{3}$ inches of soil on an acre), as reported in Texas Agricultural Experiment Station Bulletin No. 301. It is slightly alkaline or basic in reaction, having a pH of 7.8 to 8.0. When the experiment with sulphur was begun in 1921, it was thought that sulphur might be used on this soil and similar soils to control root rot of cotton, by changing the reaction of the soil.

Sulphur was applied to the soil at rates ranging from 50 to 10,000 pounds per acre, as mentioned previously. The reaction of the soil receiving different amounts of sulphur was determined by the colorimetric method at monthly intervals during the growing season of cotton in 1922 and 1923. The small applications of sulphur, 50 to 400 pounds per acre, did not have much effect on the reaction (pH value) of the soil, as shown in Table 5. It may be explained here that a soil having a reaction of pH 7.0 is neutral (neither acid nor alkaline); while a soil having a value higher than pH 7.0, such as 7.3, 7.8, 8.5, etc., is alkaline in reaction; and a soil having a value lower than pH 7.0, such as 6.3, 5.4, 4.5, etc., is acid in reaction. The largest applications of sulphur, 4,000 to 10,000 pounds per acre, reduced the reaction of the soil from pH 7.8 or 8.0 to pH 7.1 in several instances, September 15, 1922, and July 15 and August 16, 1923. An acid reaction, however, was never observed at any time in the soil on any of the plats in the experiment.

The soil which received sulphur at the rate of 10,000 pounds per acre has received a total of 60,000 pounds of sulphur per acre during the six years of the experiment. This amount of sulphur when completely oxidized to sulphuric acid is equivalent to approximately 180,000 pounds of sulphuric acid. One pound of sulphuric acid will neutralize or use up about one pound of lime. It follows, therefore, that the 60,000 pounds of sulphur if completely oxidized to sulphuric acid would be more than sufficient to use up all of the lime in the surface soil. As pointed out above, however, the soil has not become acid, but it appears to be just a matter of time until enough of the sulphur is oxidized to sulphuric acid to neutralize the lime and other bases in the soil, thus producing an acid reaction. Theoretically, that is what would be expected to occur eventually, but so far the soil has not become acid.

Effect of Sulphur on Root Rot

It will be recalled that one of the objects of the experiment with sulphur at Temple was to determine if sulphur in various amounts would control root rot of cotton. The percentage of cotton plants that died from root rot on each plat in the experiment was obtained in 1922, 1925, and 1926. The sulphur appeared to have no effect on the development of the disease in cotton grown in rotation, as shown in Table 6. The percentage of root rot, however, varied from one plat to another, but the variation did not appear to have any consistent relation to the amounts of sulphur used. For example, in 1926 the percentage of root rot was about the same on the plats which received 50, 1,000, 2,000, 2,500, 3,000, and 4,000 pounds of sulphur per acre, respectively. Similar results were obtained on cotton grown on the same land every year (Table 6a). The variation in the prevalence of the disease on the several plats seemed to be due to causes other than the treatments of sulphur.

Table 5. Reaction of soil treated with various amounts of sulphur at Temple, Texas, in 1922 and 1923

Pounds of sulphur per acre	During 1922					During 1923				
	July 5	July 25	Aug. 16	Sept. 15	Oct. 15	June 15	July 15	Aug. 16	Sept. 15	Oct. 25
	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
None	7.9	7.6	7.8	7.9	7.9	7.9	8.0	7.9	8.0	7.6
50	7.7	7.6	7.8	7.9	7.6	7.8	8.0	7.9	8.0	7.5
100	7.7	7.7	7.6	7.8	7.7	7.8	7.8	7.9	8.0	7.5
200	7.8	7.5	7.6	7.9	7.6	7.8	7.8	7.9	8.0	7.6
300	7.9	7.5	7.6	7.9	7.6	7.6	7.7	7.9	8.0	7.6
None	7.9	7.9	7.8	7.9	7.7	7.9	8.0	7.9	8.0	7.5
400	7.7	7.4	7.7	7.8	7.6	7.6	7.7	7.9	8.0	7.6
500	7.7	7.4	7.5	7.8	7.4	7.6	7.7	7.9	7.9	7.6
1000	7.6	7.4	7.4	7.7	7.4	7.6	7.7	7.7	7.9	7.4
1500	7.4	7.3	7.4	7.7	7.4	7.6	7.6	7.7	7.9	7.4
None	7.8	7.9	7.7	7.9	7.6	7.8	8.0	7.9	8.0	7.6
2000	7.4	7.3	7.4	7.4	7.5	7.5	7.5	7.5	7.6	7.4
2500	7.4	7.3	7.4	7.5	7.4	7.5	7.5	7.4	7.7	7.3
3000	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.3
4000	7.4	7.3	7.3	7.1	7.2	7.4	7.6	7.5	7.6	7.3
None	7.8	7.8	7.7	7.4	7.6	7.9	7.8	7.9	7.9	7.6
5000	...	...	...	...	...	7.3	7.5	7.3	7.3	7.2
10000	...	...	...	...	...	7.2	7.1	7.1	7.2	7.3
None	...	...	...	...	...	7.9	7.8	8.0	8.0	7.6

Table 6.—Percentage of root rot in rotated cotton on soil treated with various amounts of sulphur at Temple, Texas

Pounds of sulphur per acre	1922	1925	1926
None	20.6	60.9	59.2
50	27.6	53.1	69.6
100	20.3	58.4	65.0
200	19.7	51.9	51.3
300	11.5	34.7	35.4
None	8.3	13.2	11.5
400	4.0	6.7	16.6
500	3.0	7.6	59.5
1000	1.3	8.0	70.8
1500	7.4	9.5	40.8
None	2.2	6.7	75.3
2000	2.3	8.5	74.5
2500	2.9	10.1	76.0
3000	4.8	20.1	72.3
4000	1.4	14.8	70.3
None	3.6	39.4	63.0

Recent investigations on the root rot of cotton by the Division of Plant Pathology and Physiology of this Station (Texas Agr. Exp. Sta. Bul. No. 389) have shown that the growth of the root-rot fungus in artificial media is inhibited at an acidity of pH 4.1 and at an alkalinity of pH 8.9; that is, the fungus does not grow in a strongly acid or alkaline medium. It was found also that the root-rot disease did not occur in very acid soils and seldom in strongly alkaline soils.

Table 6a. Percentage of root rot in continuous cotton on soil treated with sulphur at Temple, Texas

Pounds of sulphur per acre	1922	1925	1926
None	8.3	21.7	99.0
None	9.1	33.5	99.0
500	16.3	35.8	98.7
500	32.6	27.8	98.9
None	19.8	28.8	98.4
None	10.5	23.1	86.5
2500	21.4	24.4	68.6
2500	16.1	33.6	65.9
None	24.0	21.7	51.2
5000	22.4	50.4	53.0
None	23.9	36.8	47.4
5000	20.9	32.2	18.6
None	4.7	16.4	14.7
10000	1.0	39.7	30.0
10000	1.5	40.7	11.5
None	0.9	33.2	37.5

As stated above, the soil on which the sulphur work was conducted at Temple was highly calcareous, having a pH of 7.8 to 8.0, a reaction at which the root-rot fungus thrives. The treatments of sulphur did not cause acidity in the soil, although the larger applications of sulphur reduced the reaction from pH 8.0 to 7.4, and in a few cases to pH 7.1, a condition approaching neutrality (Table 5).

Since the root-rot fungus thrives in either slightly acid or basic soils, that is, soils ranging from pH 6.5 to pH 8.0 in reaction, and since large amounts of sulphur aggregating 60,000 pounds per acre have not yet brought about an acid condition in the highly calcareous soil at Temple, it would seem impracticable to attempt to control the disease on soils containing large amounts of lime by the use of sulphur. While theoretically the use of sulphur in sufficient amounts would eventually bring about an acid condition in strongly calcareous soils, the procedure would be impracticable in farm practice on account of the expense and time involved. On such soils other methods of control, such as rotation of crops and clean cultivation, should be used until more effective measures of control are perfected (Texas Agr. Exp. Sta. Bul. No. 365). On neutral or slightly acid soils on which root rot occurs, however, sulphur in suitable amounts might possibly be used as an aid in controlling the disease, but this phase of the matter needs further study before definite conclusions should be drawn.

Results Obtained with Cotton, Corn, and Cowpeas at Angleton

The experiment with sulphur at Substation No. 3, Angleton, was conducted four years, 1925, 1926, 1927, and 1928. The work included cotton, corn, and cowpeas. The sulphur was applied broadcast at the rates of 250 and 500 pounds per acre to the land before planting the crops. The work was located on a light-colored phase of Lake Charles clay and Lake Charles clay loam soils. The surface soil of these types is dark gray in color and is underlain by a dense, heavy, gray subsoil. These soils are rather heavy, crust, and become hard on drying. If, however, they are plowed and cultivated at the right moisture content they crumble to a good tilth. The surface of these soils is rather flat and this, together with dense subsoils, results in poor or slow drainage on the surface and through the soil. These soils are productive but not quite as productive as the typical Lake Charles clay.

Yield of Cotton: The soil treated with 500 pounds of sulphur per acre made a yield of 318 pounds of lint per acre, or only 12 pounds more than the yield of the untreated land in 1925 (Table 7). This difference in yield does not appear to be significant. In 1926, the application of 500 pounds of sulphur again produced the largest yield, 196 pounds of lint per acre, which was 23 pounds more than the yield of the land which received no sulphur. Large yields resulted in 1927, the untreated land producing the highest yield, 508 pounds of lint per acre, which is significantly larger than the yield of 451 pounds produced by the treatment of 500 pounds of sulphur per acre. In 1928 the untreated land also made decidedly larger yields than the land treated with sulphur. During the four years, the untreated land made an average yield of 325 pounds of lint per acre, which is 19 pounds more than the yield resulting from the application of 500 pounds of sulphur per acre. These small differences in yield are probably not significant. The results indicate that sulphur is not needed on the Lake Charles soils for the production of cotton.

Table 7. Yield per acre of lint cotton in experiment with sulphur at Angleton, Texas

Pounds of sulphur per acre	1925	1926	1927	1928	Average 1925-1928
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
None	306	173	508	314	325
250	282	130	481	274	292
500	318	196	451	259	306

Yield of Corn: In 1925 the largest yield of corn, 37.4 bushels per acre, resulted from the application of 500 pounds of sulphur (Table 8). In 1926, the treatment of 250 pounds of sulphur made the largest yield, 25.2 bushels, which was only 1.7 bushels more than the yield of the plat which received no sulphur. Yields below the average resulted in 1927 and 1928. During the four years of the experiment the untreated land made an average yield of 25.2 bushels per acre, which was 1.8 bushels and 1.2 bushels per acre more than the yield of the treatments of 250 and 500 pounds of sulphur, respectively. These small differences in yield are not regarded as significant. Sulphur did not increase the yield of corn, which would indicate that the Lake Charles soils are not at present deficient in sulphur.

Table 8. Yield per acre of corn and cowpeas in experiment with sulphur at Angleton, Texas

Pounds of sulphur per acre	Bushels of corn					Pounds of cowpea hay
	1925	1926	1927	1928	Average	
None	34.3	23.5	18.6	24.5	25.2	1754
250	33.8	25.2	16.0	18.6	23.4	1870
500	37.4	21.7	20.0	17.0	24.0	1552

Yield of Cowpeas: The application of 250 pounds of sulphur per acre in 1926 made the largest yield of hay, 1,870 pounds per acre, while the untreated soil produced 1,754 pounds and the soil treated with 500 pounds of sulphur per acre produced 1,552 pounds of hay per acre (Table 8).

Results with Cotton and Cowpeas at College Station

The experiment with sulphur at the Main Station, College Station, was conducted in 1926 and 1927. The sulphur was used at the rates of 100 pounds and 200 pounds per acre on Lufkin fine sandy loam soil, which is an important soil type of the region. There were 12 plats of each of the sulphur treatments and 13 untreated soil check plats for cotton and for cowpeas, which were the only crops used in the experiment at College Station.

Yield of Cotton: In 1926 the yield of cotton on the untreated plats was slightly greater than the yield of cotton on the plats receiving 100 pounds or 200 pounds of sulphur per acre (Table 9). In 1927 the application of 100 pounds of sulphur produced the highest yield of cotton, 221 pounds of lint per acre, or only 19 pounds more than the yield of the untreated soil. During the two years the untreated soil and the soil receiving 100 pounds and 200 pounds of sulphur per acre made about the same average yields, indicating that sulphur is not needed as a fertilizer on the Lufkin fine sandy loam soil.

Table 9. Yield per acre of cotton and cowpeas at College Station, 1926 and 1927

Pounds of sulphur per acre	Pounds of lint cotton			Cowpeas, pounds of hay		
	1926	1927	Average	1926	1927	Average
None	364	202	283	3227	3359	3318
100	351	221	286	3122	3479	3301
200	355	208	282	3266	3545	3406

Yield of Cowpeas: In 1926 the application of 200 pounds of sulphur per acre gave the largest yield of hay, 3,266 pounds per acre, which, however, was not significantly greater than the yield of the untreated plats or the yield of the plats treated with 100 pounds of sulphur per acre (Table 9). During the season of 1927 the 200-pound application of sulphur again produced the largest yield, 3,545 pounds of hay per acre, or only 186 pounds more than the yield of the plats which received no sulphur. The average yields of hay on the plats receiving sulphur and on the plats which received no sulphur were not significantly different, indicating that sulphur had no significant effect on the yield of cowpeas on the particular soil.

Results with Cotton and Cowpeas at Beeville

At Substation No. 1, Beeville, the sulphur was applied at the rates of 100 pounds and 200 pounds per acre to cotton and cowpeas. The sulphur was distributed in the row at planting time or previous to planting. The work was done on dark-colored soils mapped as Goliad fine sandy clay loam and Bee fine sandy clay loam. These soils are productive and are well adapted to the general farm crops of the region.

Yield of Cotton: It would appear from the data in Table 10 that sulphur had no appreciable influence on the yield of cotton. In 1926 the soil which received no sulphur made a yield of 123 pounds of lint per acre; the soil receiving sulphur at the rate of 100 pounds per acre produced 125 pounds of lint; and the soil receiving 200 pounds of sulphur per acre yielded 120 pounds of lint. During the two years, 1926 and 1927, the treatment of 100 pounds of sulphur made the largest average yield, 128 pounds of lint per acre, which was only 9 pounds more than the yield of the untreated soil and 10 pounds more than the yield of the soil treated with sulphur at the rate of 200 pounds per acre. These results indicate that sulphur is not needed on these soils.

Table 10. Yield per acre of cotton and cowpeas in experiment with sulphur at Beeville, Texas

Pounds of sulphur per acre	Pounds of lint cotton			Bushels of cowpeas		
	1926	1927	Average	1926	1927	Average
None	123	114	119	6.1	5.2	5.7
100	125	130	128	6.3	5.6	6.0
200	120	116	118	6.7	5.5	6.1

Yield of Cowpeas: Sulphur apparently had very little effect on the yield of cowpeas at Beeville, as shown in Table 10. There was not very much difference in the yield of the three treatments in 1926 or 1927, and consequently the average yields for the two years, indicating that sulphur is not needed on the soil for the production of cowpeas.

Results with Cowpeas at Troup

In the experiments at Substation No. 2, Troup, the sulphur was applied at the rates of 250 and 500 pounds per acre in the row before planting. The work was conducted on Kirvin fine sandy loam, originally correlated as Susquehanna fine sandy loam, which usually responds readily to applications of commercial fertilizers. Cowpeas were the only crop included in the work at Troup, the Groit variety being used. Yields of seed and hay were obtained.

Yield of Seed: The treatments of sulphur apparently had little influence on the yield of seed in 1925 and 1926 (Table 11). In 1928, however, the sulphur appeared to reduce the stand and consequently the yield of cowpeas. The cowpeas on all plats came up to a good stand, but some of the plants on the plats which received sulphur died soon after emergence. Considering the stand of cowpeas on the untreated soil as 100 per cent, the plats treated with 250 pounds of sulphur had 70 per cent of a stand and the plats receiving 500 pounds per acre had 23 per cent. The average yield of seed of the three treatments for the four years, 1925 to 1928, inclusive, are substantially the same.

Table 11. Yield in bushels per acre of cowpeas in experiment with sulphur at Troup, Texas

Pounds of sulphur per acre	1925	1926	1927	1928	Average
None	5.9	8.7	9.2	7.5	7.8
250	7.0	7.6	9.4	7.0	7.8
500	6.9	8.6	11.0	3.4	7.5

Yield of Hay: During the three years, 1925, 1927, and 1928, the untreated soil made an average yield of 2,508 pounds of hay per acre, which was only 104 pounds and 270 pounds more than the yield of the soil receiving 250 and 500 pounds of sulphur per acre, respectively (Table 12). These results indicate that the sulphur might have caused a slight, but perhaps not significant, reduction in the yield of hay.

Table 12. Yield of cowpea hay in pounds per acre in experiment with sulphur at Troup, Texas

Pounds of sulphur per acre	1925	1927	1928	Average
None	3442	1882	2200	2508
250	3275	2050	1888	2404
500	3394	1999	1320	2238

Results Obtained with Cowpeas at Nacogdoches

At Substation No. 11, Nacogdoches, the sulphur was applied at the rates of 250 and 500 pounds per acre in the row before planting the cowpeas. The experiment was located on Orangeburg fine sandy loam and Nacogdoches fine sandy loam, both of which respond readily to applications of commercial fertilizers. Chinese Red was the variety of cowpeas used and yield of seed only was obtained.

Table 13. Yield per acre of cowpeas in experiments with sulphur at Nacogdoches, Texas

Pounds of sulphur per acre	1925	1926	1927	Average
	Bus.	Bus.	Bus.	Bus.
None	2.0	11.7	4.0	5.9
250	3.9	8.5	3.7	5.4
500	4.5	8.8	4.0	5.8

In 1925 the yields were small, as shown in Table 13. The soil treated with sulphur at the rate of 500 pounds per acre made 4.5 bushels of cowpeas per acre, as compared with 3.9 bushels for the 250 pounds of sulphur and 2 bushels per acre for the untreated soil. During the season of 1926, the untreated soil produced 11.7 bushels per acre, or about three bushels more than the soil which received 500 pounds of sulphur per acre. The three treatments produced about equal average yields, 5.9, 5.4, and 5.8 bushels per acre, for the untreated soil and the soil receiving 250 and 500 pounds, respectively, for the three years of the experiment.

Comparison of Results at Different Stations

The foregoing discussion treats of the results obtained at each station separately. At this point it is desirable to bring the average results of the stations together in order that they may be more easily compared.

Yield of Cotton: The treatments of sulphur were not the same at all of the stations, but the rates of 100 and 200 pounds were used at Temple, Beeville, and College Station. The treatment of 500 pounds of sulphur per acre was used at Temple and Angleton; so the yields of cotton resulting from the treatment at the two places may be compared. It will be observed that sulphur gave no significant increases in yield at either of the four stations (Table 14). At Angleton both treatments of sulphur caused a slight reduction in yield. These data indicate that the use of sulphur would not be profitable on the soils at the several places for the production of cotton.

Table 14. **Yield per acre of cotton in pounds of lint in the experiment with sulphur at Temple, Angleton, Beeville, and College Station**

Pounds of sulphur per acre	Temple, 5 years	Angleton, 4 years	Beeville, 2 years	College Station, 2 years
None	290	325	119	283
100	275	....	128	286
200	267	....	118	282
250	....	292	....	....
500	305	306	....	....

Yield of Corn: Corn was included in the experiments only at Temple and Angleton. The yields of corn on the untreated soil and on soil treated with 500 pounds of sulphur per acre are the only comparisons possible at the two stations, as shown in Table 15. There was no significant difference in the yield of corn on the untreated soil and the yield of corn on the soil treated with 500 pounds of sulphur per acre at either station, indicating that the soils are not deficient in sulphur.

Table 15. **Yield of corn in bushels per acre in experiment with sulphur at Angleton and Temple**

Pounds of sulphur per acre	Temple, 4 years	Angleton, 4 years
None	38.1	25.2
250	....	23.4
500	38.1	24.0

Yield of Cowpeas: Cowpeas were used in the experiment at Angleton, Beeville, College Station, Nacogdoches, and Troup. Sulphur was applied at the rates of 250 and 500 pounds per acre at Angleton, Troup, and Nacogdoches, while the rates of 100 and 200 pounds per acre were included in the experiment at College Station and Beeville. At Angleton sulphur used at the rate of 250 pounds per acre produced 1,870 pounds of hay per acre, as compared with 1,754 pounds for the soil which received no sulphur and 1,552 for the soil receiving 500 pounds of sulphur per acre, as shown in Table 16. The sulphur apparently reduced slightly the yield of hay at Troup, but had little effect on the yield of seed at Nacogdoches. Sulphur made a slight increase in yield at College Station and Beeville. The results at these points indicate that the use of sulphur on the soils would not be profitable.

Table 16. Yield per acre of cowpeas in the experiment with sulphur at Angleton, Troup, Nacogdoches, College Station, and Beeville

Pounds of sulphur per acre	Angleton, 1 year, pounds forage	Troup, 4 years, pounds forage	Nacogdoches 3 years, bushels seed	College Station, 2 years, pounds forage	Beeville, 2 years, bushels seed
None	1754	2508	5.9	3318	5.7
100	....	....	....	3301	6.0
200	....	....	....	3406	6.1
250	1870	2404	5.4	....	....
500	1552	2238	5.8	....	....

While the results obtained in these experiments indicate that the soils are not now deficient in sulphur as shown by the yield of crops, it should be recognized that there is a possibility of sulphur becoming deficient in the soil after long continued cultivation on account of the removal of sulphur in crops and in drainage water. In this connection it will be recalled that Hart and Peterson (3) found that soils in Wisconsin that had been under cultivation 50 to 60 years without the addition of manures had lost 40 per cent of their sulphur as compared with the amount of sulphur in the adjacent virgin soils.

SUMMARY

Experiments with sulphur as a fertilizer were conducted over a period of six years at Temple; four years at Angleton and Troup; three years at Nacogdoches; and two years at Beeville and College Station. The sulphur was applied at rates ranging from 50 to 10,000 pounds per acre at Temple; at the rates of 100 and 200 pounds per acre at College Station and Beeville; and 250 and 500 pounds at Angleton, Nacogdoches, and Troup. Cotton, corn, and oats were used in the work at Temple; cotton, corn, and cowpeas at Angleton; cotton, and cowpeas at Beeville and College Station; and cowpeas at Nacogdoches and Troup.

The use of sulphur made no significant or profitable increases in the yield of cotton, corn, or oats on the Bell clay, which is a dark calcareous soil, at Temple. The applications of sulphur ranging from 2,000 to 4,000 pounds per acre, however, caused a slight reduction in the yield of corn. None of the treatments made the soil acid. Apparently sulphur had little or no effect on the development of root rot of cotton.

The yield of cotton, corn, or cowpeas was not appreciably affected by applications of sulphur on the Lake Charles clay, a dark-colored prairie soil, at Angleton in the Gulf Coastal Plains.

Sulphur applied at the rates of 100 and 200 pounds per acre had no significant effect on the yield of cotton and cowpeas on Lufkin fine sandy loam soil at College Station. Similar results were obtained with these crops on the dark-colored Goliad fine sandy clay loam at Beeville.

Sulphur did not have much effect on the yield of cowpea seed on

Kirvin fine sandy loam at Troup, but the use of 500 pounds per acre caused a slight reduction in the yield of hay.

On the Nacogdoches fine sandy loam soil at Nacogdoches, apparently sulphur had little effect on the yield of cowpeas.

The results obtained at these six different places in Texas indicate that sulphur would not increase the yield of crops in general and consequently its use as a fertilizer would not be profitable.

ACKNOWLEDGMENTS

The field work in these experiments with sulphur was conducted by the following members of the Experiment Station Staff: Mr. G. T. McNess, Superintendent, Main Station Farm, College Station; Mr. R. A. Hall, Superintendent, Substation No. 1, Beeville; Mr. W. S. Hotchkiss, former superintendent, and Mr. P. R. Johnson, Superintendent, Substation No. 2, Troup; Mr. R. H. Stansel, Superintendent, Substation No. 3, Angleton; Mr. D. T. Killough and Mr. H. E. Rea, former superintendents, Substation No. 5, Temple; and Mr. H. F. Morris, Superintendent, Substation No. 11, Nacogdoches.

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SOIL REGIONS OF TEXAS: PRINCIPAL SURFACE FEATURES, SOIL SERIES, AND CROPS.

Humid Region

(30 inches or more average annual rainfall)

1. Gulf Coast Prairie: Flat, heavy growth of coarse grasses; heavy dark soils, some sandy light colored soils. Soil series: Lake Charles, Edna, Katy, Hockley, Acadia, Harris. Rice, cotton, corn, figs, truck crops, cattle.

2a, 2b, 2c, 2d. East Texas Timber Country: Timbered sandy soils with clay subsoils.

2a. Northeastern division: Rolling to hilly; pine and some hardwood timber. Principal soil series: Kirvin, Bowie, Norfolk, Ruston, Susquehanna, Caddo, Ochlockonee, Leaf, Myatt, Kalmia, Bibb. Cotton, corn, lumber, truck crops, fruits, livestock.

2b. Western division: Undulating to rolling; timbered with oak mainly. Principal soil series: Kirvin, Susquehanna, Lufkin, Tabor, Crockett, Ochlockonee. Cotton, corn, truck crops, fruits, livestock.

2c. Southeastern: Flat to rolling; longleaf, shortleaf, and loblolly pine. Principal soil series: Bowie, Lufkin, Susquehanna, Caddo, Bibb. Lumber, cotton, livestock.

2d. Central division: Rolling to hilly; pine and some hardwood timber. Soil series same as 2a except that Nacogdoches series—"East Texas Redlands"—are confined mainly to this area. Cotton, corn, truck crops, fruits, livestock.

3. East Texas Cross Timbers: Rolling; sandy soils; oak timber. Soil series: Kirvin, Tabor, Ochlockonee. Cotton, corn, truck crops, fruits.

4. Blackland Prairie: Rolling; grassland; dark, heavy soils. Soil series: Houston, Wilson, Crockett, Ellis, Bell, Irving, Trinity, Catalpa. Cotton, corn, small grain.

5. Blackland interior prairies: Rolling; grassland; dark, heavy soils. Soil series: Wilson, Houston, Crockett. Cotton, corn, livestock.

6. Grand Prairie: Rolling to hilly; grassland; dark, heavy soils that are shallow in many places. Stony and rough areas in southern part. Soil series: Denton, San Saba, Crawford, Trinity, Catalpa, Rough stony land. Cotton, small grain, livestock.

7. Central Basin: Rolling valleys, hills and rough lands; sandy and stony soils, some small oak timber and some small mesquite timber. Soil series: Pontotoc, Lancaster, Tishomingo, Harley, Pedernales. Rough stony land. Range livestock, cotton, small grain.

8. West Cross Timbers and interior prairies: Rolling to hilly; timbered with small oaks in places, small mesquite trees in places and some prairies; sandy and heavy soils. Soil series: Windthorst, Nimrod, Denton. Small grain, cotton, range livestock, truck crops.

Subhumid Region

(15 to 30 inches average annual rainfall)

9. Gulf Coast Plain: Flat to undulating; grassland and abundant small trees (mainly mesquite) and shrubs in places, dark and light colored soils. Soil series: Victoria, Hidalgo, Willacy, Nueces, Laredo, Harlingen, Lomalto, Rio Grande. Cotton, range livestock, citrus fruits, truck crops.

10. Interior Blackland Plains: Flat to undulating; grassland and much shrub and small tree growth, largely mesquite; dark, heavy and sandy soils. Soil series: Goliad, Zapata, and others. Cotton, range livestock.

11. Rio Grande Plain: Undulating to rolling; small trees and shrubs in scattering growth over grassland; mostly sandy soils, though some heavy soils. Soil series: Duval, Webb, Brennan, Maverick, San Antonio, Uvalde, Frio. Range livestock, cotton, truck crops.
12. Edwards Plateau: Rolling and hilly; small oak and mesquite trees and shrubs in scattered growth over grassland; soils mostly dark, heavy, very shallow and stony. Soil series: Rough stony land, Valera, Reagan. Range livestock, sheep, cattle, goats.
13. Northwest Texas Rolling Plains: Undulating to rolling; grassland; brown and reddish sandy and clay loam soils. Soil series: Abilene, Miles, Roscoe, Spur, Rough broken land on western margin. Cotton, grain sorghums, range cattle, small grain.
14. Northwest Texas Redland Plains: Undulating to rolling; some rough, eroded areas; grassland; mostly red sandy and clay loam soils, though some dark soils. Soil series: Vernon, Fowlkes, Wichita, Calumet, Foard, Enterprise, Miller, Yahola, Rough broken land. Range cattle, cotton, small grain, grain sorghums.

15a, 15b. High Plains (Llano Estacado): High flat to undulating; grassland. Soils brown and reddish sandy and clay loams. Soil series: Amarillo, Richfield.
- 15a. North Plains Division: Soils mostly clay loams. Small grain, grain sorghums, range cattle.
- 15b. South Plains Division: Soils mostly sandy and of Amarillo series. Cotton, grain sorghums, range cattle.

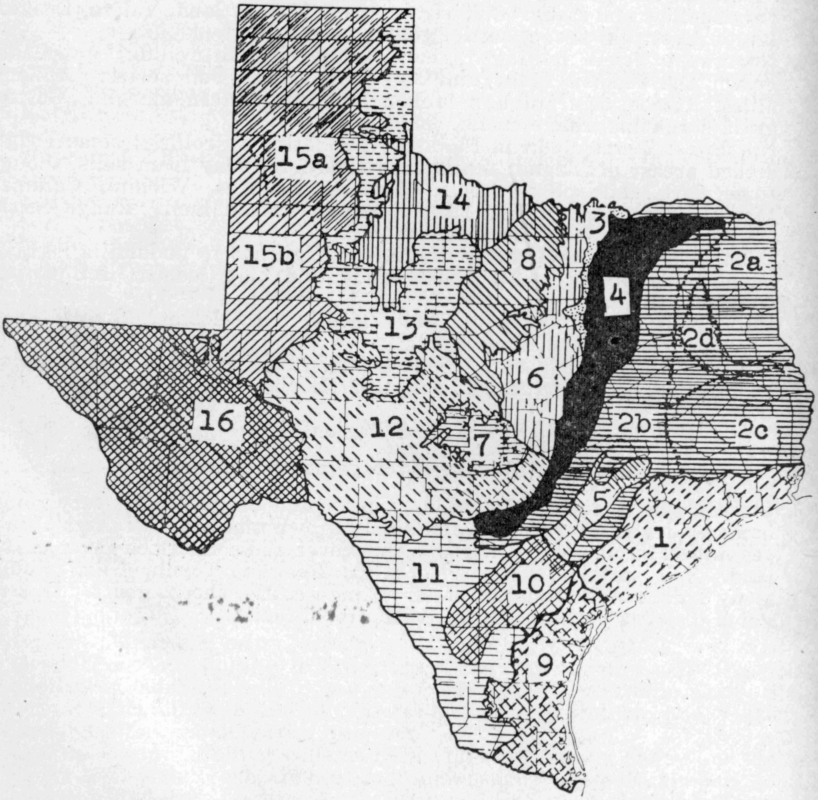
Semiarid Region

(Less than 15 inches average annual rainfall)

16. Trans-Pecos Region: Mountains, plains, and basins; much very rough land; no dryland farming; soils mostly brown and gray. Desert shrubs vegetation in places; considerable thin cover and some thick cover grassland. Soil series: Reeves, Verhalen, Reagan, Toyah, Gila. Rough stony land, rough mountain land. Range cattle, sheep, goats. In irrigated districts cotton, alfalfa, truck crops, fruits.

SOIL REGIONS OF TEXAS

(Prepared by W. T. Carter)



Humid Region

1. Gulf Coast Prairie.
2a, 2b, 2c, 2d. East Texas Timber Country:
   2a. Northeastern division,
   2b. Western division,
   2c. Southeastern division,
   2d. Central division.
3. East Cross Timbers.
4. Blackland Prairie.
5. Blackland Interior Prairies.
6. Grand Prairie.
7. Central Basin.
8. West Cross Timbers and Interior Prairies.

Subhumid Region

9. Gulf Coast Plain.
10. Interior Blackland Plains.
11. Rio Grande Plain.
12. Edwards Plateau.
13. Northwest Texas Rolling Plains.
14. Northwest Texas Redland Plains.
15a, 15b. High Plains (Llano Estacado):
   15a. North Plains division,
   15b. South Plains division.

Semiarid Region

16. Trans-Pecos Region.

(For more detailed information concerning soil regions, see pages 22 and 23.)