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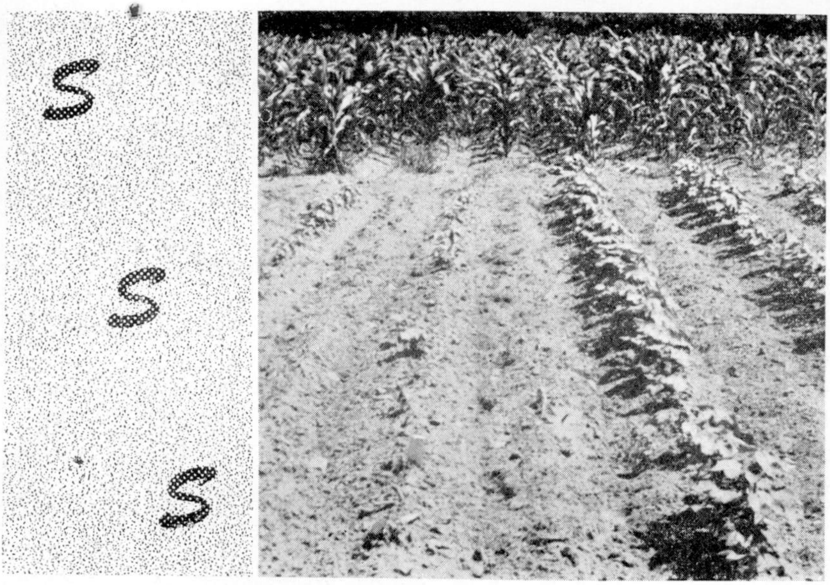
SULFUR



in relation to SOIL FERTILITY

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SULFUR

in relation to SOIL FERTILITY

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SULFUR WAS RECOGNIZED as an essential element for plant growth as early as about 1860. Yet, it has received relatively little attention in soil fertility studies.

There are probably two reasons why sulfur has been neglected. First, superphosphate has long been used as the main source of phosphorus and it has supplied much of the sulfur needed by crops. Second, the amount needed by plants was underestimated because much of the sulfur was lost in the ashing procedure used in early work.

Soils of the United States have been found to contain between 140 and 980 pounds of sulfur per acre *(9)*. Sulfur in the surface layer of soils is largely in organic form, which becomes available by microbial decomposition. Sulfates added to the soil or released from organic form are subject to crop removal and loss by leaching. Cropping some Wisconsin soils for 50 to 60 years caused a 40 per cent reduction in sulfur content *(10)*. Kentucky workers *(14)* estimated that the Ohio River carried away sulfur equivalent to 35 pounds per acre annually from its basin. Results from lysimeter studies in New York *(13)* showed that 3 to 6 times as much sulfur was lost by leaching as was removed by crops. Sulfur brought down in rain *(1, 3, 7, 22)* will supply only a portion of that lost by leaching and crop removal.

Sulfur deficiency has been found in arid and semi-arid regions *(5, 11, 15, 17)* as well as humid regions *(3, 4, 7, 16)*. Much of the work in the arid and semi-arid regions was done with alfalfa, which often gave a striking response to elemental sulfur or sulfate. Workers in the humid region have obtained response in the field with such crops as cotton and clovers.

The need of sulfur for crop production in Alabama was suspected some 20 years ago, when numerous cooperative tests were conducted to determine the response of cotton to calcium sulfate. More recently the sulfur status of Alabama soils has been studied. With the trend toward higher analysis fertilizers, some of which may contain little or no sulfur, the need for information on sulfur in relation to soil fertility will become more acute.

This bulletin summarizes all of the pertinent data obtained in Alabama on the role of sulfur in soil fertility.

RESULTS OF EXPERIMENTS

SULFUR BROUGHT DOWN IN RAIN

The problem of sulfur fertility is complicated by the fact that variable amounts of sulfur gases are present in the atmosphere and may be returned to the soil in rain. Also, plants are able to utilize atmospheric sulfur dioxide (SO_2) to some extent directly through the leaves *(3, 18, 20, 21)*.

Considerable data have been collected and published showing the quantity of sulfur brought down in rain. In rural districts of Alabama, sulfur brought down in rain ranged from 3 to 6 pounds per acre annually *(22)*. However, rain in the vicinity of Birmingham added about 31 pounds of sulfur per acre annually. Data from other states also show that the amount of sulfur brought down is closely related to distance from cities or industry. Alway *(1)* summarized the available data on the subject in 1940 for 53 stations outside Minnesota. According to his summary, over one-half of the stations showed more than 25 pounds of sulfur per acre in rainwater. Alway believed that many of the results were high because of the use of gauges that reacted with SO_2 in the atmosphere. The data reported for Alabama *(22)* show relatively low sulfur content in comparison to other areas. This may be partially because Alabama data were from samples collected by containers resistant to gaseous sulfur. Recent data by Jordan[1] show sulfur accretions from rain of 4 to 6 pounds per acre in areas south of Kentucky and Virginia and removed from industrial activity.

A cooperative project between the Agricultural Experiment Station of The Alabama Polytechnic Institute and the Tennessee

[1]Personal communication.

Valley Authority was begun in 1951 to study the effects of steam plant effluents. Rainwater samples were collected for 3 years before the steam plant near Tuscumbia was put into operation to obtain baseline data on atmospheric SO_2. Samples were also collected during the time the units of the steam plant were being put in use and for one year after the four units were in operation. The data in Table 1 show effects of the steam plant on amount of sulfur brought down in rain. Effluents from the steam plant about doubled the amount of SO_2 brought down in rain. The highest amount measured for any period was 14.3 pounds per acre per year, which is relatively small as compared with amounts reported for certain industrial areas of the United States *(1)*. The plant's high smoke stacks (300 feet) permitted a wide diffusion of the gases.

TABLE 1. EFFECT OF STEAM PLANT EFFLUENTS ON SULFUR IN RAINWATER AND SO_2 ADSORBED BY LEAD PEROXIDE CYLINDERS

Distance and direction from steam plant	Sulfur brought down in rain, per acre			Sulfur adsorbed as SO_2 by lead peroxide cylinder, 100 sq. cm surface				
	Before steam plant operation	Transition period	After steam plant operation	March through May	June through Aug.	Sept. through Nov.	Dec. through Feb.	Total
	Lb.	*Lb.*	*Lb.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
15 miles SE	5.9	10.1	10.0					
13 miles E	4.1	14.5	7.7					
5 miles SE	5.7	11.7	12.0	1.90	3.35	4.19	2.51	11.95
3 miles SE	—	5.7	9.9	0.92	4.55	2.59	2.87	10.93
6 miles S	3.4	10.5	9.1					
3 miles S	—	13.7	11.6					
2 miles W	4.3	11.6	9.9	0.17	0.05	4.01	1.30	5.53
4 miles SW	4.4	10.2	8.4	1.33	5.05	7.11	2.94	16.43
3 miles W	4.8	—	11.4					
4 miles NW	6.0	8.2	10.0					
7 miles W	4.6	—	7.5					
6 miles NW	5.6	12.8	9.2					
13 miles W	4.6	8.6	6.7					
25 miles NE	6.1	11.4	9.1					
25 miles NE	—	12.2	8.2					
20 miles NE	5.4	10.9	5.8					
12 miles N	4.4	9.3	7.3					
11 miles N	4.6	9.0	9.6					
6 miles NE	5.3	9.2	8.0					
3 miles NE	2.8	—	12.1	6.32	6.85	6.65	7.14	26.96
2 miles N	—	10.3	14.3	6.08	0.94	5.51	2.84	15.37
7 miles N	5.4	9.7	12.5					
2 miles N	4.3	11.9	14.8	9.05	3.30	6.07	7.88	26.30
AVERAGES	4.89	10.57	9.79					

[1]From Dec. 1, 1953 to Nov. 30, 1954.
[2]From Dec. 1, 1954 to Nov. 30, 1956; Units being put into operation.
[3]From Dec. 1, 1955 to Nov. 30, 1956; All four units in operation.

During the last year of study on effects of steam plant effluents on atmospheric SO_2, lead peroxide cylinders were used to measure SO_2 in the atmosphere. The SO_2 reacts with the lead peroxide and is held on the cylinder. The data are reported in Table 1 in addition to the data for sulfur in rainwater. Sulfur dioxide adsorption by lead peroxide varied with location and season. Totals for the year ranged from 5.53 to as much as 26.96 mg. of sulfur adsorbed per 100 sq. cm. of exposed surface. If the surface of a soil were as active in adsorbing SO_2 as lead peroxide, as much as 32 pounds per acre per year of sulfur could be added in this manner. However, it is doubtful if soil would adsorb this much. Since plants can take up SO_2 through the stomatal openings in leaves, atmospheric SO_2 could be a supplemental source of sulfur for growing plants. It should be pointed out that SO_2 concentrations can become high enough to be toxic to plants.

Sulfur Status of Alabama Soils

In humid regions most of the sulfur in surface layers is in organic form *(19)*. Since soils of Alabama are inherently low in organic matter, it would be expected that their total sulfur content would also be low.

Most of the inorganic fraction of sulfur occurs as sulfate in well aerated soils. Factors affecting the movement of sulfates in soils have received only slight attention. Results from recent studies *(6, 12)* show that sulfate is adsorbed by soils and that this is an important consideration in sulfur fertility studies. The author *(6)* found that sulfate is retained to a certain extent by most Alabama soils. His work revealed that subsurface layers usually contained more sulfate and were capable of adsorbing more sulfate than surface layers. The surface layers of most of the light textured soils did not contain sulfate or show a capacity to adsorb sulfate from solution.

The distribution of sulfate with depths extracted from nine soils by sodium acetate solution is given in Table 2. The sandy soils have little or no sulfate in the surface 6 inches, but have appreciable quantities at lower depths. The surface layer of the Dewey silt loam contained considerable sulfate. A number of similar soils from the Tennessee Valley Area have been analyzed and many of them were found to be relatively high in soluble sulfate.

TABLE 2. SULFATE SULFUR EXTRACTED FROM VARIOUS SOILS BY SODIUM ACETATE AT pH 4.8

Depth of sample	Kalmia ls (Prattville)	Norfolk sl (Prattville)	Kalmia lfs (Brewton)	Kalmia lfs (Brewton)	Magnolia fsl (Monroe-ville)	Magnolia fsl (Monroe-ville)	Hartsells fsl (Cross-ville)	Dewey sil Tus-cumbia	Decatur cl Alex-andria
Inches	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
0-6	0	1	0	1	1	1	0	47	2
6-12	0	1	0	80	54	67	0	109	94
12-18	0	27	31	105	95	82	0	78	....
18-24	36	43	39	124	106	92	0	....	....
24-30	46	61	51	120	146	98	44	....	....
34-36	39	62	56	104	87	102	52	....	....

TABLE 3. SULFATE EXTRACTED FROM AND ADSORBED BY DIFFERENT HORIZONS OF 12 ALABAMA SOILS

Soil type	Sulfate-sulfur extracted by sodium acetate pH 4.8 from soil horizons			Sulfate-sulfur adsorbed from $CaSO_4$ solution containing 40 ppm sulfur			Calculated adsorption capacity-sum of extracted sulfate plus adsorbed sulfate		
	A	B	C	A	B	C	A	B	C
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Oktibbeha clay	0	25	1	0	16	5	0	41	6
Houston clay	0	1	0	0	16	26	0	17	26
Eutaw clay	0	0	0	16	84	132	16	84	132
Susquehanna fine sandy loam	0	0	0	0	174	142	0	174	142
Decatur silty clay loam	0	134	0	32	105	174	32	239	174
Cecil sandy loam	0	151	190	0	110	221	0	261	411
Davidson sandy clay loam	0	68	43	42	163	216	42	231	259
Ruston sandy loam	0	0	66	10	47	174	10	47	240
Orangeburg sandy loam	0	0	36	10	68	174	10	68	210
Norfolk sandy loam	0	80	149	0	32	68	0	112	217
Greenville fine sandy loam	0	0	18	21	42	68	21	42	86
Hartsells fine sandy loam	0	......	......	0	42	52	0	......	......

Most Alabama soils contain little or no sulfate extractable by water. Phosphate and acetate solutions are effective in extracting sulfate. This suggests that sulfate is adsorbed as an anion. Data presented in Table 3 show the calculated adsorption capacity of 12 soils by horizons. Calculated adsorption capacity is simply the sum of sulfate extracted by sodium acetate plus that adsorbed from $CaSO_4$ solution. The data show that the A horizon of some soils will adsorb sulfate, but that the B and C horizons have a much greater adsorption capacity. The higher capacity of the lower horizons is probably associated to a certain extent with their higher clay content. It has been shown *(6, 12)* that the adsorption capacity for sulfate decreases with increasing amounts of phosphate and lime.

The amount of sulfate in soils is influenced to some extent by past fertilization. Data given in Table 4 show the effect of applied sulfate on extractable sulfate at various depths, at three locations. In the alfalfa test on Hartsells very fine sandy loam, 48 pounds of sulfate-S annually for 4 years increased the sulfate content of the soil only below the 18-inch depth. Data from a cotton test on the same soil type show that a difference in applied sulfate-S of 40 pounds per acre per year (28 vs. 68) for 24 years resulted in only a small increase in soluble sulfate below 18 inches and none above 12 inches. Enough sulfate was added to increase all zones to a considerable degree, but evidently the capacity to adsorb sulfate was not great enough in any soil horizon to retain much of the added sulfate.

Sulfate moves downward rather rapidly in sandy soils, as shown by the data, Table 4, for a Kalmia loamy sand. Sulfate

TABLE 4. EFFECT OF PAST APPLICATIONS OF SULFATE ON SULFATE-SULFUR EXTRACTED BY SODIUM ACETATE AT pH 4.8

Depth of Sample	Alfalfa on Hartsells fine sandy loam		Cotton on Hartsells fine sandy loam		Kalmia loamy sand sampled through fertilizer band		
	No sulfur 1949-52	48 lb. S. annually 1949-52	28 lb. S. annually 1930-53	68 lb. S. annually 1930-53	Before S. applied	21 days after S. applied	100 days after S. applied
Inches	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
0-6	0	0	0	0	0	210	30
6-12	0	0	0	0	0	33	30
12-18	0	0	60	74	0	32	33
18-24	0	43	76	87	36	53	51
24-30	44	63	74	90	46	58	67
30-36	52	78	....	....	39	58	53

was applied in bands at the rate of 36 pounds of sulfur per acre. Soil samples were taken through the band at 6-inch intervals to a depth of 36 inches. Considerable sulfate had moved out of the surface layer into the deeper layers by 21 days after application. After 100 days the quantity of sulfate in the surface had decreased considerably. This decrease was due to both leaching and plant uptake.

SULFUR CONTENT OF PLANTS

The total sulfur content of plants tends to approach or may exceed that of phosphorus *(2)*. Part of the total sulfur in plants is contained in the proteins and part occurs as inorganic sulfur. It has been shown that chloroplasts contain about 70 per cent of the protein sulfur in cotton leaves *(8)*.

The percentages of sulfur in plants varies with the available sulfur supply. The sulfur content of cotton plants at 3 weeks of age as influenced by various rates of sulfate is given in Table 5. At this stage of growth, the sulfur content of cotton plants was more than doubled by sulfate fertilization. It is also evident that cotton can obtain more sulfur from certain soils than from others.

As is true for other elements, the sulfur content of plants changes with age. The percentage of sulfur in cotton at 3 stages of growth is given in Table 6. Although the sulfur content decreased with age, the total uptake of sulfur per acre increased with age.

TABLE 5. SULFUR CONTENT OF YOUNG COTTON PLANTS AS INFLUENCED BY SULFUR TREATMENTS

Sulfur applied per acre		Percentage of sulfur in cotton plants[1] grown on various soils						
Gyp-sum	Elemen-tal sulfur	Dickson silt loam 1954	Dickson silt loam 1955	Magnolia fine sandy loam	Dewey silt loam	Tilsit silt loam 1953	Tilsit silt loam 1955	Tilsit silt loam 1956
Lb.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
0	0	0.35	0.54	0.33	0.55	0.75	0.37	0.24
4	0	0.51	....	....	....	0.87	0.60	0.32
8	0	0.58	0.69	0.36	....	0.88	0.70	0.45
16	0	0.68	....	....	....	0.94	0.79	0.46
32	0	0.77	0.79	0.48	0.68	1.00	0.86	0.58
0	8	0.42	....	....	....	....	....	....
0	16	0.48	....	....	....	....	....	....
0	32	0.49	0.79	0.61	....	....	....	....

[1]Above ground portion of cotton plants at about 3 weeks of age.

It has been well established that the chemical composition of plants with respect to most essential elements varies with species. The sulfur content of 17 species given in Table 7 vary as much as 10 fold. For example, alfalfa contained 0.41 per cent sulfur, which means that 4 tons of alfalfa hay would remove about 33 pounds of sulfur per acre per year, whereas 4 tons of Johnsongrass hay would remove only 8 pounds. For alfalfa the removal is equivalent to the sulfur content of about 400 pounds of ordinary superphosphate.

All crops studied were fertilized with fertilizer containing sulfate, which means that plants differ in their capacity to take up available sulfate. The grasses contained only a small amount of sulfur, whereas such crops as cotton, tomatoes, radishes, and turnips were considerably higher in sulfur.

TABLE 6. SULFUR COMPOSITION AND TOTAL SULFUR UPTAKE OF COTTON AS INFLUENCED BY SULFUR TREATMENT AND AGE

Sulfate—S applied per acre	Sulfur concentration at 3 dates after emergence			Total sulfur uptake per acre at 3 dates after emergence		
	21 days	58 days	80 days	21 days	58 days	80 days
Lb.	*Pct.*	*Pct.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*
0	0.32	0.33	0.19	0.54	1.69	6.96
12	0.49	0.44	0.23	0.71	2.17	8.76
36	0.66	0.63	0.31	1.11	3.49	10.98

Note: Above ground portion of plants harvested for analysis.

TABLE 7. SULFUR CONTENT OF VARIOUS PLANT SPECIES FROM LOCATIONS IN COLBERT AND LAUDERDALE COUNTIES

Crop	Sulfur content of plants—averages for years grown			
	Howard farm 1954-56	Darby farm 1955-56	Gilbert farm 1954-56	Foster farm 1956
	Pct.	*Pct.*	*Pct.*	*Pct.*
Johnsongrass	0.16	0.05	0.15	0.09
Oats—forage	0.17	0.13	0.11	
Wheat—forage	0.18	0.14	0.20	0.11
Ryegrass	0.22	0.16	0.20	0.20
Crimson clover	0.25	0.22		....
Ladino clover	0.24	0.19	0.18	....
Orchardgrass	0.23	0.30	0.27	....
Kentucky 31 fescue	0.30	0.44	0.23	....
Kentucky bluegrass	0.32	0.30	0.25	....
Soybean leaves	0.35	0.28	0.18	....
Hairy vetch	0.41	0.32	0.25	0.26
Alfalfa	0.41			...
Potato leaves	0.44	0.55	0.47	0.51
Cotton leaves	0.85	0.49	0.77	0.69
Tomato leaves	0.75	0.84	0.60	0.89
Radish tubers	0.84	1.02	0.63	....
Radish tops	1.18	1.35	1.08	1.13
Turnip tops	0.98	1.15	0.93	0.89

Response of Crops to Sulfur

Cotton. An experiment was conducted from 1939 to 1943 at 420 locations to determine the response of cotton to sulfate under a wide range of conditions. Results of this experiment are reported in Table 8. The use of gypsum (calcium sulfate) increased seed cotton yields an average of 80 pounds per acre. Most of the increase resulted from the first increment of 22.5 pounds of gypsum. The Hartsells and Norfolk soil groups gave the greatest increase from gypsum.

More recently an experiment was conducted at 12 locations to

Table 8. Response of Cotton to Gypsum at 420 Locations, 1939-43

Soil type	Average per acre yield increases from gypsum applied[1] at:		
	22.5 lb. per a.	45 lb. per a.	90 lb. per a.
	Lb.	*Lb.*	*Lb.*
Clarksville, 41 experiments	25	46	57
Decatur, 76 experiments	30	36	16
Holston, 27 experiments	18	40	12
Hartsells, 57 experiments	88	109	132
Cecil, 53 experiments	38	49	46
Greenville, 64 experiments	63	94	103
Norfolk, 102 experiments	107	114	128
All soil groups, 420 expts.	62	77	80

[1]All plots received 36 pounds N from urea, 48 pounds P_2O_5 from concentrated superphosphate, and 36 pounds K_2O from muriate of potash. Enough dolomite was added to the fertilizer to neutralize the residual acidity of urea.

Table 9. Effect of Sulfate in High-Analysis Fertilizers on Yield of Seed Cotton, 12 Locations

Experiment sites		Acre yield of seed cotton		Yield increase per acre due to sulfate
Soil type[1]	County[2]	Sulfate-free fertilizer	Similar fertilizer containing sulfate	
		Lb.	*Lb.*	*Lb.*
Decatur c.l.	Calhoun (3)	1,367	1,597	230
Decatur c.l.	Calhoun (1)	1,020	1,163	143
Stough v.f.s.l.	Pickens (2)	935	1,080	145
Kalmia l.s.	Autauga (4)	993	1,149	156
Kalmia f.s.l.	Escambia (3)	671	833	162
Kalmia f.s.l.	Escambia (4)	1,024	1,239	215
Greenville f.s.l.	Autauga (3)	1,510	1,567	57
Magnolia f.s.l.	Monroe (3)	1,230	1,374	144
Magnolia f.s.l.	Monroe (4)	645	902	257
Boswell v.f.s.l.	Macon (2)	797	870	73
Boswell v.f.s.l.	Macon (1)	554	722	168
Norfolk l.s.	Macon (1)	1,008	972	-36
Weighted averages		1,001	1,162	161

[1]Key to abbreviations: c. l. = clay loam; v.f.s.l. = very fine sandy loam; l.s. = loamy sand; f.s.l. = fine sandy loam.

[2]Figures in parentheses indicate number of years experiment conducted at each location.

determine the value of sulfur in high analysis fertilizer for cotton. The data reported in Table 9 show that fertilizer containing sulfate produced 161 more pounds of seed cotton per acre than a similar one without sulfate. The test was conducted for periods of 1 to 4 years at each location.

Cotton plants may die in the seedling stage as a result of sulfur deficiency. Such loss is shown in the cover illustration. On the plot receiving no sulfate (left) many of the seedlings died after having come up to a good stand.

Most cultivated soils have received fertilizers containing sulfate and as a result may not show a response to sulfate the first year because of carry-over effects. This is illustrated by the data presented in Table 10. Five of the 6 locations showed little or no response of cotton to sulfate the first year, but in the second year 5 of the 6 locations showed a response. It should be pointed out in this connection that certain locations have not shown a response even after several years. This is illustrated by the data from the Dewey silt loam. Usually Dewey soils contain sulfate in or close to the surface.

An experiment was begun in 1953 on a Kalmia loamy sand near Prattville to study interactions of phosphate and sulfate on cotton.

TABLE 10. INCREASING NEED FOR SULFUR AS INDICATED BY YIELDS OF SEED COTTON GROWN ON FIVE ALABAMA SOILS

Soil types[1]	Average yield of seed cotton as index to need for sulfur	
	O lb. S. per acre	32 lb. S. per acre
	Lb.	*Lb.*
Kalmia sandy loam, Brewton		
First year	832	778
Second year	911	1,271
Decatur clay loam, Alexandria		
First year	1,215	1,245
Second year	1,482	1,791
Norfolk sandy loam, Brewton		
First year	1,233	1,404
Second year	753	1,042
Norfolk loamy sand, Auburn		
First year	1,528	1,475
Second year	1,439	2,017
Magnolia sandy loam, Monroeville		
First year	729	1,017
Second year	455	995
Dewey silt loam, Tuscumbia		
First year	1,339	1,233
Second year	1,766	1,847
Third year	1,791	1,692

[1]All plots received N, P_2O_5, and K_2O.

The experiment was continued 3 years and the results are reported in Table 11. Yield differences due to treatments were not significant the first year. The second year there was a response to 72 pounds of P_2O_5 when used without and with 12 pounds of sulfur, but there was no response to phosphorus when applied with 36 pounds of sulfur. There was a response to 36 pounds of sulfur without phosphorus but no response to sulfur with 24 or 72 pounds of P_2O_5. These data show an interaction of phosphate $\times$ sulfate on cotton. The effect is indicated by the fact that the response of cotton to 72 pounds of P_2O_5 plus 36 pounds sulfur (205 pounds of seed cotton) was less than the sum of the responses of each added separately (313 pounds of seed cotton). The 1955 data show the same effects but the differences were larger.

SERICEA. Tests were conducted from 1948 to 1956 to determine the response of alfalfa and sericea to sulfate. The location, soil type, and duration of the sericea tests follow.

Location	*Soil type*	*Duration*
Alexandria Experiment Field	Decatur clay loam	1948-53
Sand Mountain Substation	Hartsells fine sandy loam	1950-56
Piedmont Substation	Cecil sandy loam	1948-53
Tuskegee Experiment Field	Boswell very fine sandy loam	1948-56
Prattville Experiment Field	Greenville fine sandy loam	1948-52
Monroeville Experiment Field	Magnolia fine sandy loam	1948-55
Brewton Experiment Field	Kalmia loamy fine sand	1948-53

Sericea was usually cut twice annually for hay, producing about 3 tons per acre per year. Since the hay was removed from the plots, considerable sulfur was removed each year. Yet, sericea did not respond to applied sulfate at any location within the period of the experiment. Soil analysis showed that subsurface layers of soil at all locations contained considerable extractable sulfate. Evidently a deep-rooted crop such as sericea is able to obtain sufficient sulfur from the subsurface layers.

ALFALFA. The alfalfa test was also begun in 1948 and was continued at all locations as long as stands remained good. The location, soil type, and duration follow.

Location	*Soil type*	*Duration*
Alexandria Experiment Field	Decatur clay loam	1949-52
Sand Mountain Substation	Hartsells fine sandy loam	1949-52
Upper Coastal Plain Substation	Atwood fine sandy loam	1949-54
Prattville Experiment Field	Greenville fine sandy loam	1949-52
Monroeville Experiment Field	Magnolia fine sandy loam	1948-49
Brewton Experiment Field	Kalmia loamy fine sand	1948-49

TABLE 11. EFFECT OF PHOSPHATE AND SULFATE ON YIELDS OF SEED COTTON ON KALMIA LOAMY SAND NEAR PRATTVILLE, ALABAMA

Treatments[1]		1953			1954			1955		
P_2O_5 per acre	S per acre	Yield of seed cotton per acre	Per acre response to 72 lb. P_2O_5 at 3 S levels	Per acre response to 36 lb. S. at 3 P_2O_5 levels	Yield of seed cotton per acre	Per acre response to 72 lb. P_2O_5 at 3 S levels	Per acre response to 36 lb. S. at 3 P_2O_5 levels	Yield seed cotton per acre	Per acre response to 72 lb. P_2O_5 at 3 S levels	Per acre response to 36 lb. S. at 3 P_2O_5 levels
Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
0	0	1,602			920			1,645		
24	0	1,639			1,026			2,025		
72	0	1,783	181		1,071	151		2,161	548	
0	12	1,635			999			1,830		
24	12	1,573			1,048			2,151		
72	12	1,632	– 3		1,074	75		2,242	244	
0	36	1,623		21	1,082		162	2,193		516
24	36	1,611		– 28	1,083		57	2,269		412
72	36	1,609	– 14	– 174	1,125	43	54	2,265	104	72
L.S.D.	5%	N.S.			74.2			179.7		

[1]Phosphorus applied as concentrated superphosphate and sulfur as gypsum ($CaSO_4$). The area was limed at rate of 2,000 pounds per acre before planting in 1953.

Average yields of 4 tons of hay were produced at some locations. Based on a sulfur content of 0.4 per cent for alfalfa, 32 pounds of sulfur per acre per year were removed in hay. Nevertheless, alfalfa did not show a response to sulfate at any location. Like sericea, it must have obtained sufficient sulfate from the subsurface layers. Soil samples from alfalfa test areas showed that appreciable amounts of extractable sulfate were present in the subsurface layers at all locations.

OTHER CROPS. The response of other crops to sulfate has been studied to a limited extent. The response of white clover-Dallisgrass mixtures to sulfate at two locations is presented in Table 12. Differences in yield between concentrated superphosphate and ordinary superphosphate were attributed to the sulfate in the ordinary superphosphate. In case of the Sumter clay, differences in favor of the ordinary superphosphate did not occur until the second and third years. Although differences for the Vaiden clay were not significant at the 5 per cent level, the trend was toward higher yields for ordinary superphosphate.

Corn was used as a test crop at seven locations, but no response to sulfate was obtained. The test was conducted at 4 locations for 1 year only and at 3 locations for 2 years. The short duration of the test at any one location may explain the lack of response.

TABLE 12. INFLUENCE OF SULFATE ON FORAGE YIELDS OF WHITE CLOVER—DALLISGRASS MIXTURES ON SUMTER AND VAIDEN CLAYS

Annual phosphate treatments[1]		Yields dry matter per acre				
Source	P_2O_5 per acre	Vaiden clay		Sumter clay		
		1949	1950	1948	1949	1950
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
None	0	350	736	73	573	775
Concentrated superphosphate	80	2,379	1,540	1,224	2,298	2,767
Ordinary superphosphate	80	2,561	1,990	1,287	3,202	3,731
L.S.D. at 5%		574	520	264	534	938

[1]The concentrated superphosphate was sulfur-free while the ordinary superphosphate application supplied about 40 pounds per acre sulfate-S.

SUMMARY

A number of field tests has been conducted since 1939 to determine the response of cotton, alfalfa, sericea, and other crops to sulfate. The amount of sulfur brought down in rainwater was determined at 12 locations as early as 1940. More recently the sulfur status of soils has been investigated. In 1951 a cooperative project with TVA was begun in the Shoals area to study the effects of SO_2 and other steam plant effluents on soils and plants.

Results of the sulfur studies to date are summarized as follows:

1. Sulfur brought down in rainwater in the Shoals area averaged 5 pounds per acre per year prior to operation of a steam electric power plant near Tuscumbia. Operation of the steam plant approximately doubled the amount of sulfur in rainwater.

2. Sulfate is retained to a certain extent by most soils. Subsurface layers usually contain more sulfate and are capable of adsorbing more sulfate than surface layers.

3. Light textured surface soils usually do not contain sulfate or show a capacity to adsorb sulfate.

4. The sulfur content of cotton plants increased with increasing amounts of sulfate applied.

5. Plant species vary a great deal in sulfur content. Of the crop plants analyzed, the range in sulfur content was from about 0.1 per cent to over 1 per cent.

6. In tests conducted at 420 locations from 1939 to 1943 gypsum increased seed cotton yields an average of 80 pounds per acre. More recent data from 12 locations show that a high-analysis fertilizer containing sulfate produced an average of 161 pounds more seed cotton than a similar fertilizer without sulfate.

7. Alfalfa and sericea have not shown a response to sulfur at the locations tested. Evidently deep-rooted crops, such as these, can obtain sufficient sulfate from subsurface layers.

8. The trend is toward the use of fertilizers containing less sulfur. Continued use of fertilizers containing little or no sulfur will result in the need for a planned program of sulfur fertilization in Alabama.

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This report covers the sulfur data obtained by the Agricultural Experiment Station of Alabama Polytechnic Institute over a period of nearly 20 years. In preparing this bulletin the author compiled the results of many workers of this Station.

Summarized are results of cooperative field tests conducted by J. T. Williamson[1] from 1939 to 1942.

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Studies on and near the Experiment Fields were conducted by J. T. Cope, Jr., F. E. Bertram, Fred Glaze, J. W. Richardson, and J. T. Williamson[1].

Tests on the Substations were conducted by K. G. Baker[1], W. W. Cotney, S. E. Gissendanner, and E. L. Mayton.

[1]Deceased.

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