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EFFECT OF SULPHUR ON DIFFERENT CROPS AND SOILS [1]

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INTRODUCTION

There has recently been some discussion as to the importance and supply for plant growth of sulphur in its various compounds in soils, and whether or not it may be a limiting element in crop production. While it is one of the essential elements, the amounts found by the old method of ashing plants were so low in most cases that it was generally assumed there was an abundant supply of its compounds in soils for all crop requirements. More recently, however, it has been demonstrated by improved methods of analysis that most plants contain much more sulphur than was formerly thought to be the case, owing to the fact that in many instances by the old method the bulk of the sulphur was lost on ashing the plant, and therefore was overlooked. The question then arose as to whether there is an ample supply of sulphur compounds in soils for crop needs and especially for the best growth of those which are now known to have a high sulphur content.

Hart and Peterson (4),[3] of Wisconsin, later the writer (5), and afterwards Brown and Kellogg (2), of Iowa, Ames and Boltz (1), of Ohio, and others have found that the sulphur content of many soils is low and that there has been a decided loss of sulphur in some soils which have been cultivated for a long term of years when compared with the corresponding virgin soils.

Some investigators contend that, although some soils are low in sulphur, lower in many cases than in phosphorus, this is compensated for by the amount brought down in the rainfall; and as a result it will never be a limiting element in crop production. There are others, however,

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[2] The writer desires to express his thanks to Dr. Peter, for his helpful suggestions in the preparation of the manuscript, and to the county agents who assisted in the collection of the soils.

[3] Reference is made by number to "Literature cited," p. 103.

who maintain that the sulphur brought down in the rainfall will not equal the loss of this element in the drainage, and their point seems to be established by the limited work that has been done along this line. They contend that the application of sulphur compounds may be beneficial for the maximum production of crops high in sulphur when they are grown on soils that are low in this element.

To establish this point, numerous experiments have been carried on, at first abroad and later in this country; and many of these have been mentioned in former publications (1–6). Since then other work has been published or started along this line, but it is not thought necessary to describe these experiments here further than to state that in some cases decidedly beneficial results have been obtained by applying sulphur or its compounds to some soils and crops; in other instances no benefits were obtained; and in still other experiments an injury was noted. These variations are to be expected when different soils and crops are employed in experiments.

In demonstrating the effect of a given element on plant growth it is sometimes extremely difficult to arrange the experiment so as to prove the desired point, for the reason that the element is generally applied in combination with other elements; consequently the results are not always easy of interpretation.

EXPERIMENTAL WORK

In an effort to avoid the above difficulty the writer used flowers of sulphur mixed with soil to which the necessary fertilizing ingredients were added, together with calcium carbonate. For this purpose eight surface soils, taken to a depth of 6⅔ inches, each representing a distinct type in Kentucky, were selected; and on these were grown five different crops. These soils had been in cultivation for a number of years and, with one or two exceptions, had had little manure or fertilizer added. Their locations and descriptions are as follows:

No. 892.—Eastern coal-field area, Lawrence County, from the farm of Ernest Shannon, 3 miles west of Louisa and 20 rods north of the Louisa-Bussyville road. This land had been cultivated over 60 years; no fertilizer used; produced about 20 bushels of corn per acre. The land appeared to be somewhat worn.

No. 893.—St. Louis-Chester area, Warren County, from the Alderson farm, 1 mile west of Bowling Green. This land had been cultivated for 60 years; no fertilizer used; produced about 20 bushels of corn and 15 bushels of wheat per acre.

No. 894.—Cincinnatian area, Mason County, from the farm of John M. Chambers, about 2½ miles northwest of Washington. This land had been continuously cropped for nearly 100 years; very little fertilizer added; was worn out and produced very poor crops.

No. 895.—Western coal-field area, Muhlenburg County, from the Station experiment field, 2½ miles southwest of Greenville. This land had been cultivated for 40 years, and some fertilizer and manure used. It produced 30 bushels of corn, 12 bushels of wheat, and 1 ton of hay per acre.

No. 896.—Keokuk-Waverly area, Barren County, from the Underwood farm near Roseville. The land had been long in cultivation; was worn out; had little fertilizer used and produced 20 bushels corn, 8 bushels wheat, and 12 bushels oats per acre.

No. 897.—Quaternary area, McCracken County, from the Station experiment field, about 3 miles southwest of Paducah, at Lone Oak. A part of this land had been cultivated for 15 years, the remainder for 30 years. Some stable manure had been added. It produced about 15 bushels of corn, 8 bushels of wheat, and 1 ton of hay per acre.

No. 898.—Devonian area, Madison County, from the farm of Mark Settle, northwest of Big Hill. This land had been cultivated for 50 years; was much worn; no fertilizers used. It produced 15 bushels of corn, 10 bushels of wheat, and ½ ton of hay per acre.

No. 899.—Silurian area, Jefferson County, from a farm adjoining the Fair Grounds woods at Fern Creek. The land had been cultivated for many years; was much worn; no commercial fertilizers and little stable manure used. It produced light crops.

Before the experiments were started the soils were partially analyzed and found to have the following composition, in pounds per acre, on assuming that the surface 6⅔ inches weighs 2,000,000 pounds (Table I):

TABLE I.—*Composition of experimental Kentucky soils*

Soil number.	Total phosphorus.[a]	Total sulphur.[b]	Sulphate sulphur.[c]	Calcium carbonate requirement.[d]
892	360	180	160	393
893	540	400	140	129
894	1,540	520	180	3,176
895	520	420	200	107
896	400	700	240	143
897	520	400	200	36
898	400	240	200	1,335
899	600	380	200	107

[a] Magnesium-nitrate method (Wiley, H. W., ed. Official and provisional methods of analysis, Association of Official Agricultural Chemists. As compiled by the Committee on Revision of Methods. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 2. 1908.)
[b] Sodium-peroxid method (5).
[c] Hydrochloric-acid (sp. gr. 1.115) digestion (Wiley, H. W. Idem, p. 14).
[d] Hopkins method (Wiley, H. W. Idem, p. 20).

These soils were air-dried, put through a coarse sieve, and 15 pounds (in triplicate) were placed in 2-gallon glazed earthenware jars, supplied with drainage and thoroughly mixed with the following materials, added at the rate of pounds per acre of soil on the above assumption of soil weight:

500 pounds of tricalcium phosphate, C. P., precipitated.
200 pounds of potassimum nitrate, C. P.
8,000 pounds of calcium carbonate, C. P.
100 pounds of flowers of sulphur; or
200 pounds of flowers of sulphur.

Triplicate jars like the above were also prepared of each soil, except that the sulphur was omitted; and these were used as controls.

SERIES I: SOYBEANS.—Fifteen uninoculated soybean seeds (*Soja max*) were planted in each jar in the greenhouse on November 2, 1914, and

watered in all cases with the same amount of distilled water. When the plants were about 3 inches in height, they were thinned to 6 plants of average size in each jar. After the pods had matured, which took place at different times, according to the soil, the plants were cut close to the ground, air-dried, and weighed. They were cut on the following dates: No. 894 and 895 on December 31; No. 892 and 893 on January 9; and the remainder on January 19, 1915.

SERIES II: CLOVER.—After the plants in Series I had been cut, the soil in each jar was sifted, and 25 inoculated red-clover seeds (*Trifolium pratense*) planted. After germinating, these were thinned to 15 average-sized plants in each jar. The plants were allowed to grow until they had attained a height of about 10 inches. Four cuttings were made at a distance of about 2 inches from the crown. When cut in this manner and not allowed to blossom, the plants grew faster, and this procedure was followed until July 14, when the weather became too warm for greenhouse experiments.

SERIES III: OATS.—The soil in each jar of Series II was pulverized and stirred to a depth of 6 inches, and on December 23, 1915, 36 Burt oat seeds (*Avena sativa*) were planted in each. Two weeks later they were thinned to 25 average-sized plants in each jar, and potassium nitrate was then added in solution at the rate of 100 pounds per acre and repeated on February 15. On May 12, 1916, after the seed had matured, the plants were cut close to the ground, air-dried, and weighed.

SERIES IV: ALFALFA.—Similar jars of the same soils used in Series I to III were prepared, and, in addition, jars representing 200 pounds of sulphur per acre were included in triplicate. Thirty-five inoculated alfalfa seeds (*Medicago sativa*) were planted on October 14, 1914, in each of the jars containing soil from Warren, Mason, Muhlenburg, and McCracken Counties, and a like number on November 6 in the remainder. On November 17 the plants were thinned to 15 average-sized plants, and cuttings were made at intervals—whenever the plants attained a height of about 10 inches—just as was done in Series II. Five cuttings were made from the Lawrence, Barren, Madison, and Jefferson County soils, and six from the remainder. Final cuttings on all were made on July 9, 1915, when the experiments were stopped.

SERIES V: WHEAT.—The soils in Series IV were stirred and pulverized to a depth of 6 inches and on December 23, 1915, were planted with 36 Jersey Fultz wheat seeds (*Triticum aestivum*) in each jar. The plants were thinned to 25 average-sized plants, and potassium nitrate was added in the same amounts and at the same time as in Series III. On June 13, 1916, after the seeds had matured, the plants were cut close to the ground, air-dried, and weighed.

The weight in grams of the total air-dry materials in Series I–V, together with the percentage gains or losses are given in Table II.

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*

LAWRENCE COUNTY SOIL, EASTERN COAL-FIELD AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	6.9	0.5	24.1	28.7	11.3	23.1	26.6	1.5
Do	4.7	1.3	15.4	30.8	12.3	22.6	23.4	1.6
Do	4.9	1.1	17.3	25.3	12.7	21.0	24.2	1.9
Total	16.5	2.9	56.8	84.8	36.3	66.7	74.2	5.0
100 pounds	6.0	.9	25.4	29.6	13.4	22.5	29.9	3.2
Do	6.4	1.1	18.6	28.8	13.2	17.3	25.4	1.6
Do	5.2	1.0	23.6	30.3	12.7	21.5	25.1	1.9
Total	17.6	3.0	67.6	88.7	39.3	61.3	80.4	6.7
200 pounds						21.0	28.6	2.4
Do						23.6	24.3	1.7
Do						22.7	32.0	2.0
Total						67.3	84.9	6.1

WARREN COUNTY SOIL, ST. LOUIS-CHESTER AREA

Control	8.7	.8	33.0	20.9	9.1	34.1	23.6	4.4
Do	7.6	.8	27.8	26.1	8.9	40.2	24.7	5.3
Do	7.2	1.6	26.0	22.5	9.6	38.9	21.9	3.1
Total	23.5	3.2	86.8	69.5	27.6	113.2	70.2	12.8
100 pounds	5.2	1.0	27.2	25.5	9.5	39.8	22.2	2.9
Do	6.5	1.2	24.1	28.9	9.1	41.1	28.0	4.0
Do	7.3	1.1	28.1	22.6	8.4	39.1	25.0	5.0
Total	19.0	3.3	79.4	77.0	27.0	120.0	75.2	11.9
200 pounds						40.3	32.8	6.2
Do						41.2	26.5	5.5
Do						41.4	26.4	4.6
Total						122.9	85.7	16.3

MASON COUNTY SOIL, CINCINNATIAN AREA

Control	9.5	4.6	27.7	17.5	6.5	36.1	24.0	5.0
Do	8.5	4.4	19.0	17.3	7.7	39.0	26.5	3.5
Do	8.2	4.1	19.5	23.3	8.7	37.9	27.0	4.0
Total	26.2	13.1	66.2	58.1	22.9	113.0	77.5	12.5
100 pounds	9.1	4.8	15.4	18.6	8.4	43.0	26.0	4.0
Do	8.2	4.1	13.9	19.8	8.2	47.1	29.0	5.0
Do	9.2	4.9	17.2	23.8	7.2	40.2	25.3	4.7
Total	26.5	13.8	46.5	62.2	23.8	130.3	80.3	13.7
200 pounds						36.2	31.4	5.6

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued

MUHLENBURG COUNTY SOIL, WESTERN COAL-FIELD AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	11.8	7.7	27.2	23.7	10.3	38.3	30.0	7.0
Do	11.6	6.3	29.0	21.7	9.3	39.2	30.2	6.8
Do	12.2	6.8	26.0	25.9	9.2	40.1	27.0	5.0
Total	35.6	20.8	82.2	71.3	28.8	117.6	87.2	18.8
100 pounds	11.0	6.8	24.6	25.3	10.7	42.5	31.3	5.7
Do	9.4	3.8	22.5	24.3	9.7	41.1	25 6	6.4
Do	12.5	5.6	20.5	24.7	8.3	39.7	29.7	7.3
Total	32.9	16.2	67.6	74.3	28.7	123.3	86.6	19.4
200 pounds	.....	.....	.....	.....	.....	29.9	26.0	5.0
Do	.....	.....	.....	.....	.....	44.1	27.3	2.7
Do	.....	.....	.....	.....	.....	39.2	26.9	5.1
Total	.....	.....	.....	.....	.....	113.2	80.2	12.8

BARREN COUNTY SOIL, KEOKUK-WAVERLY AREA

Control	8.0	1.0	28.7	31.2	12.9	27.8	31.6	5.4
Do	5.4	2.4	28.1	27.4	14.6	26.4	31.5	6.5
Do	7.1	2.3	17.9	29.5	13.5	28.0	33.2	5.8
Total	20.5	5.7	74.7	88.1	41.0	82.2	96.3	17.7
100 pounds	7.4	2.4	28.9	28.6	12.4	24.0	30.8	6.2
Do	5.0	1.8	20.5	25.8	12.3	30.9	33.7	6.3
Do	6.4	3.3	22.6	31.3	12.7	28.4	33.9	6.1
Total	18.8	7.5	72.0	85.7	37.4	83.3	98.4	18.6
200 pounds	.....	.....	.....	.....	.....	25.1	32.5	6.5
Do	.....	.....	.....	.....	.....	25.6	28.7	3.3
Do	.....	.....	.....	.....	.....	27.4	34.2	6.8
Total	.....	.....	.....	.....	.....	78.1	95.4	16.6

MCCRACKEN COUNTY SOIL, QUATERNARY AREA

Control	9.9	2.5	28.4	21.9	12.1	45.8	29.5	6.5
Do	9.1	2.7	32.3	32.9	14.1	46.5	32.1	6.9
Do	8.6	3.0	14.8	29.1	13.9	49.3	32.7	6.3
Total	27.6	8.2	75.5	83.9	40.1	141.6	94.3	19.7
100 pounds	9.5	2.4	18.8	32.1	15.9	48.4	30.6	5.4
Do	8.6	2.4	22.7	32.9	14.1	50.8	29.1	5.9
Do	10.2	2.2	23.6	28.3	12.7	51.4	28.9	7.1
Total	28.3	7.0	65.1	93.3	42.7	150.6	88.6	18.4
200 pounds	.....	.....	.....	.....	.....	46.9	30.7	8.3
Do	.....	.....	.....	.....	.....	49.8	32.9	7.1
Do	.....	.....	.....	.....	.....	53.2	31.6	6.4
Total	.....	.....	.....	.....	.....	149.9	95.2	21.8

TABLE II.— *Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued

MADISON COUNTY SOIL, DEVONIAN AREA

Quantity of sulphur per acre.	Soybeans.		Clover.	Oats.		Alfalfa.	Wheat.	
	Hay.	Grain.	Hay.	Straw.	Grain.	Hay.	Straw.	Grain.
Control	7.0	2.3	27.2	23.0	13.0	19.9	33.4	8.6
Do	6.8	2.2	27.1	26.8	12.2	30.2	23.0	3.1
Do	6.7	2.4	24.8	22.3	12.7	16.9	33.3	5.7
Total	20.5	6.9	79.1	72.1	37.9	67.0	89.7	17.4
100 pounds	9.2	2.6	24.1	23.5	12.5	18.8	26.8	3.3
Do	7.6	1.7	30.0	25.4	13.6	30.7	25.1	4.9
Do	8.6	3.1	24.0	23.1	15.0	28.7	26.4	5.6
Total	25.4	7.4	78.1	72.0	41.1	78.2	78.3	13.8
200 pounds	.....	.....	.....	.....	.....	27.4	30.7	7.3
Do	.....	.....	.....	.....	.....	28.3	19.5	2.5
Do	.....	.....	.....	.....	.....	30.5	32.3	6.7
Total	.....	.....	.....	.....	.....	86.2	82.5	16.5

JEFFERSON COUNTY SOIL, SILURIAN AREA

Control	10.4	2.6	13.6	24.5	11.5	35.7	33.4	8.6
Do	8.8	2.8	21.3	26.7	13.3	34.9	33.8	8.2
Do	9.4	3.1	13.6	25.9	13.1	38.2	34.5	7.5
Total	28.6	8.5	48.5	77.1	37.9	108.8	101.7	24.3
100 pounds	10.9	3.2	16.1	24.9	13.1	37.1	34.3	8.7
Do	11.8	3.4	19.0	22.7	13.3	41.0	32.6	8.4
Do	10.5	3.5	15.7	24.0	13.0	38.9	33.4	7.6
Total	33.2	10.1	50.8	71.6	39.4	117.0	100.3	24.7
200 pounds	.....	.....	.....	.....	.....	34.8	32.0	7.0
Do	.....	.....	.....	.....	.....	33.8	31.4	8.6
Do	.....	.....	.....	.....	.....	35.1	31.7	8.3
Total	.....	.....	.....	.....	.....	103.7	95.1	23.9

TABLE II.—*Weight (in grams) and percentage gains or losses of the total air-dried material of Series I to V*—Continued.

PERCENTAGE GAIN OR LOSS

County.	Quantity of sulphur added per acre.	Soybeans.		Clover hay.	Oats.		Alfalfa hay.	Wheat.	
		Hay.	Grain.		Straw.	Grain.		Straw.	Grain.
	Pounds.								
Lawrence	100	+ 6.9	+ 3.4	+19.0	+ 4.6	+8.3	− 8.1	+ 8.4	+34.0
Do	200	.....	.....	.....	.....	.....	+ .9	+14.4	+22.0
Warren	100	−19.1	+ 3.1	− 8.5	+10.8	−2.2	+ 6.0	+ 7.1	− 7.0
Do	200	.....	.....	.....	.....	.....	+ 8.6	+22.1	+27.3
Mason	100	+ 1.1	+ 5.3	−29.8	+ 7.1	+3.9	+15.3	+ 3.6	+ 9.6
Do	200	.....	.....	.....	.....	.....	− 4.0	+21.7	+33.3
Muhlenburg	100	− 7.6	−22.1	−17.3	+ 4.2	− .03	+ 4.8	− .7	+ 3.2
Do	200	.....	.....	.....	.....	.....	− 3.7	− 8.0	−31.9
Barren	100	− 8.3	+31.6	− 3.6	− 2.7	−8.8	+ 1.3	+ 2.2	+ 5.1
Do	200	.....	.....	.....	.....	.....	− 5.0	− .9	− 6.2
McCracken	100	+ 2.5	−14.6	−13.7	+11.2	+6.5	+ 6.4	− 6.0	− 6.6
Do	200	.....	.....	.....	.....	.....	+ 5.9	+ .9	+10.7
Madison	100	+23.9	+ 7.2	− 1.3	− .1	+8.4	+16.7	−12.7	−20.7
Do	200	.....	.....	.....	.....	.....	+28.7	− 8.0	− 5.2
Jefferson	100	+16.1	+18.8	+ 4.7	− 7.1	+4.0	+ 7.5	− 1.4	+ 1.6
Do	200	.....	.....	.....	.....	.....	− 4.7	− 6.5	− 1.6

EFFECT OF SULPHUR ON THE TOTAL AND SULPHATE-SULPHUR CONTENT OF SOYBEANS, CLOVER, AND ALFALFA

The air-dried plants in Series I, II, and IV, were finely ground for this work, a composite sample being made of the triplicates in each case, and the soybean seeds were ground with the corresponding sample of hay.

The total sulphur determinations were made by the sodium-peroxid method [1] and the sulphate sulphur was determined by the following procedure:

Ten gm. of material were digested in 400 c. c. of water on the water bath for several hours, with frequent stirring. It stood overnight, and was made to 500 c. c. volume, first deducting the volume occupied by the sample. This was then filtered, and a 5-gm. aliquot used, to which was added 1 c. c. of hydrochloric acid (1:1) to precipitate the protein and organic matter. The whole was then heated on the water bath several hours longer, allowed to stand overnight, filtered, and washed. The filtrate was made slightly acid with hydrochloric acid, heated, and barium sulphate precipitated by adding, hot, 10 per cent barium-chlorid solution, and letting it stand overnight.

The results obtained on the above samples are given in Table III.

[1] A slight modification was used, which is now the official method of the Association of Official Agricultural Chemists (Wiley, H. W., ed. Op. cit., p. 23.)

TABLE III.—*Percentage of total and sulphate sulphur in air-dry soybeans, clover, and alfalfa*

SOYBEANS

Quantity of sulphur to the acre.	Lawrence County.	Warren County.	Mason County.	Muhlenburg County.	Barren County.	McCracken County.	Madison County.	Jefferson County.
Control:								
Total sulphur	0.207	0.301	0.252	0.260	0.209	0.223	0.198	0.202
Sulphate sulphur	.025	.038	.079	.068	.039	.049	.042	.056
Residual sulphur	.182	.263	.173	.192	.170	.174	.156	.146
100 pounds:								
Total sulphur	.302	.376	.298	.278	.229	.247	.237	.254
Sulphate sulphur	.037	.044	.096	.086	.035	.054	.056	.083
Residual sulphur	.265	.332	.202	.192	.194	.193	.181	.171

CLOVER

Control:								
Total sulphur	0.238	0.276	0.275	0.304	0.219	0.213	0.279	0.231
Sulphate sulphur	.097	.140	.125	.143	.084	.081	.148	.071
Residual sulphur	.141	.136	.159	.161	.135	.132	.131	.160
100 pounds:								
Total sulphur	.267	.281	.321	.379	.248	.291	.340	.351
Sulphate sulphur	.130	.152	.178	.218	.100	.107	.198	.195
Residual sulphur	.137	.129	.143	.161	.148	.184	.142	.156

ALFALFA

Control:								
Total sulphur	0.410	0.457	0.352	0.409	0.334	0.306	0.387	0.284
Sulphate sulphur	.168	.223	.142	.209	.152	.123	.204	.093
Residual sulphur	.242	.234	.210	.200	.182	.183	.183	.191
100 pounds:								
Total sulphur	.511	.480	.425	.451	.397	.398	.467	.435
Sulphate sulphur	.265	.256	.205	.265	.206	.166	.267	.248
Residual sulphur	.246	.224	.220	.186	.191	.232	.200	.187
200 pounds:								
Total sulphur	.517	.503	.528	.462	.422	.409	.474	.412
Sulphate sulphur	.286	.301	.349	.295	.213	.212	.298	.218
Residual sulphur	.231	.202	.179	.167	.209	.197	.176	.194

FORMATION OF SULPHATE IN SEEDS ON GERMINATION

As the results in Table III indicate that the excess of sulphur in those plants which have been grown in soil to which this element has been added exists in the form of sulphate, it was thought that it might be of interest to ascertain whether sulphate is formed in seeds from their sulphur compounds when they are allowed to germinate.

As a control the sulphate was determined in the finely ground ungerminated seed by the same method used for the work in Table III, and about the same weight of the seeds were then allowed to germinate in covered dishes between cheesecloth kept moistened with distilled water, after which the sample was ground in a mortar and the sulphate determined. As a precaution all precipitates of barium sulphate were fused with sodium carbonate and reprecipitated and blanks made on the reagents.

The results of these experiments are given in Table IV.

TABLE IV.—*Percentage of sulphur existing as sulphate in seeds before and after germination*

Variety.	Before germination.	After germination.	Increase during germination.	Period of germination.
				Days.
Corn	None.	None.	None.	6
Beans	None.	0.0003	0.0003	6
Cowpeas	None.	.0079	.0079	6
Alfalfa	None.	.0144	.0144	6
Millet	None.	.0223	.0223	6
Oats	None.	.0312	.0312	6
Soybeans	0.0007	.0034	.0027	6
Wheat	.0007	.0219	.0212	6
Hemp	.0014	.0107	.0093	6
Timothy	.0034	.0316	.0282	6
Rye	.0048	.0168	.0120	6
Tobacco	.0072	.0261	.0189	13
Peas	.0117	.0212	.0095	6
Onion	.0220	.0566	.0346	6
Bluegrass	.0258	.0309	.0051	13
Clover	.0483	.0447	[a] .0006	6

[a] Loss.

GENERAL DISCUSSION

While a few of the duplicates in Table II vary widely, yet on the whole they agree fairly well, considering work of this character. If an allowance of 10 per cent, compared with the controls, which is a safe amount, is made for unavoidable factors, then we find from an examination of Table II that applications of sulphur have affected the crops grown on the soils from the different counties as follows:

LAWRENCE.—Beneficial, clover from the smaller application and wheat grain and straw from the larger application. Injurious, none.

WARREN.—Beneficial, oat straw from the smaller application, and wheat, both in grain and straw, from the larger application. Injurious, soybean hay.

MASON.—Beneficial, alfalfa and wheat, both in grain and straw, from the larger application. Injurious, clover.

MUHLENBURG.—Beneficial, none. Injurious, soybean grain, clover, and wheat grain from larger application.

BARREN.—Beneficial, soybean grain. Injurious, none.

MCCRACKEN.—Beneficial, oat straw and wheat grain from larger application. Injurious, soybean grain and clover.

MADISON.—Beneficial, soybean hay and alfalfa. Injurious, wheat, both in grain and straw, from smaller application.

JEFFERSON.—Beneficial, soybeans, both in hay and grain. Injurious, none.

From the foregoing we find that the sulphur has affected the crops differently, depending on the soil. Some undoubtedly were benefited, others were injured, while in many cases no effect was apparent. On the whole, there is a preponderance of gains from the sulphur, although generally small.

Some observers have found that sulphur had a more marked effect on certain crops when applied to soils fairly well supplied with organic matter. What the effect would have been if such had been the case here or if the other fertilizing ingredients had been omitted is not easy to forecast, for, as stated before, it is difficult to have all soil conditions ideal in order to prove a certain point. Soil fertility involves so many factors that its study is very complicated. The question of mineral plant food has occupied considerable attention, and rightly so, but oftentimes another important side has been overlooked—namely, the organic matter, involving, as it does, all bacterial activities of the soil. If a bacterial study was carried on in mineral-nutrition work, probably different deductions would be drawn then where each is considered alone. In this connection it might be of interest to state that Fred and Hart (3) have been found that soluble phosphates have a more marked effect on promoting the bacterial activity of a soil than sulphates; and for this reason, while sulphates are important and as low in amount in most soils as phosphates, they will not in all probability have the same crop-producing power as the phosphates.

From an examination of Tables III, it will be found that applications of sulphur increased the total and sulphate-sulphur content of the plant; and the larger the application, the greater the increase. Furthermore, it will also be observed that in the clover and alfalfa, the sulphur marked "residual" more nearly approaches a constant figure, regardless of whether sulphur was applied or not. This does not hold true with respect to the soybeans in most cases, however, and this indicates that the excess sulphur in the clover and alfalfa plants exists as

sulphate, while part of the excess in the soybeans is in a form other than sulphate.

As sulphur is combined with the protein of plants, it was thought that in the soybeans protein determinations might show that where an increased sulphur content is shown, owing to the sulphur applied, a correspondingly larger protein content might be found; but such is not always the case, as will be seen in Table V. For these determinations the same materials used for the sulphur work in Table III were employed.

TABLE V.—*Protein in air-dry soybeans, tops and seed*

County.	Protein.			
	Controls.		Sulphur, 100 pounds per acre.	
	Per cent.	Weight (in grams).	Per cent.	Weight (in grams).
Lawrence	24.3	4.7	24.5	5.0
Warren	25.5	6.8	24.9	5.6
Mason	23.6	9.3	21.0	8.5
Muhlenburg	23.2	13.1	21.5	10.6
Barren	26.5	6.9	26.9	7.1
McCracken	25.1	9.0	26.5	9.4
Madison	29.8	8.2	28.5	9.3
Jefferson	25.7	9.5	23.6	10.2

The results in Table IV are interesting in showing that some seeds contain no sulphate soluble in water; others contain small amounts; while some are fairly well supplied. Furthermore, these results show that in most cases more or less sulphate is formed from the reserve sulphur compounds in the seed on germinating, but there are exceptions—namely, corn and clover—and the latter is of particular interest, since it possessed the highest sulphate content and seemed to show a slight loss on germination.

SUMMARY

(1) Soybeans, clover, oats, alfalfa, and wheat were grown in the greenhouse on eight soils, each taken from a different county and representing a distinct type in Kentucky. They were more or less impoverished by cultivation. To these soils applications of flowers of sulphur at the rate of 100 and 200 pounds per acre, together with the calcium carbonate and other fertilizing ingredients, were added.

(2) The results show that the sulphur increased the production of some crops, had no effect on others, and on some was injurious, depending on the crop and the soil on which it was grown. There was a preponderance of gains, however, from the sulphur application, but these were generally small.

(3) Analyses of some of the crops show that the sulphur increased the total and sulphate-sulphur content of the plant, and the greater the application, the greater the increase.

(4) Where sulphur wasa pplied to clover and alfalfa, the excess sulphur in those plants was in the form of sulphate, while in soybeans part of the excess was in another form.

(5) In the soybeans which showed an increased sulphur content, no corresponding increased protein content was always found. In five instances out of eight, however, soybeans grown in soil where sulphur was added show an increase in the total weight of protein.

(6) It was found that, of the 16 varieties of field and garden seeds examined, some contain sulphates, while others do not, but that, on germinating, all except two form a greater or less amount of sulphate. The highest sulphate content obtained in the ungerminated seed was 0.048 per cent, in clover, and the increase due to germination varied from none, in corn, to 0.035 per cent, in the onion. There was a slight loss in only one sample, clover.

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