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CONTENTS

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RECLAMATION OF BLACK-ALKALI SOILS WITH VARIOUS KINDS OF SULFUR[1,2]

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INTRODUCTION

IN HARMONY with the suggestion of Lipman,[5] O'Gara[7] reported in 1917 that the application of elemental sulfur reduced the carbonate content of black-alkali soils. The results of laboratory and pot-culture tests by Hibbard[1] indicated that sulfur would be effective in the reclamation of such soils. Rudolfs,[8] and Waksman *et al.*[10] found that certain microörganisms produce active oxidation of sulfur in black-alkali soils. MacIntire, Gray, and Shaw[6] found that to a limited extent nonbiological oxidation of sulfur also takes place in soil. Kelley and Thomas[3] showed that elemental sulfur underwent oxidation in several black-alkali soils. The soils used contained soluble normal carbonate (CO_3) varying from 0.7 to 4.0 milliequivalents per 100 grams and chloride (Cl) varying from 0.3 to 12.6 milliequivalents per 100 grams. Kelley and Thomas[4] also obtained satisfactory practical results by applying elemental sulfur to the black-alkali soil near Fresno, California. Samuels[9] reported that the application of sulfur inoculated with a certain oxidizing bacterium (*Thiobacillus thioöxidans*) gave good results in alkali-reclamation experiments at Fresno.

KINDS OF SULFUR USED

Five different kinds of sulfur were used in the laboratory experiments and four in the field experiments here reported. These were: (1) sulfur inoculated with the oxidizing bacterium, *Thiobacillus thioöxidans;* (2) uninoculated, finely ground elemental sulfur; (3) uninoculated coarse sulfur; (4) uninoculated colloidal sulfur; (5) uninoculated sulfur concentrate.

The inoculated material contained 95 per cent pure sulfur, 80 per cent

[1] Received for publication March 30, 1936.

[2] Paper No. 344, University of California Citrus Experiment Station and Graduate School of Tropical Agriculture, Riverside, California.

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of which passed a 200-mesh screen. The elemental sulfur was 100 per cent sulfur, 80.07 per cent of which passed a 200-mesh screen. The particle size of the coarse sulfur ranged from 16 to 70 mesh; it was practically 100 per cent pure. The particle size of the colloidal sulfur did not exceed 25 microns. This material contained 94 per cent sulfur. The sulfur concentrate was finely ground and contained 85 per cent sulfur and about 15 per cent silica.

TABLE 1

WATER-SOLUBLE CONSTITUENTS PRESENT IN THE SOILS USED IN LABORATORY SULFOFICATION EXPERIMENTS
(In milliequivalents per 100 grams)

Constituent	Soil 7923	Soil 7924	Constituent	Soil 7923	Soil 7924
CO_3	1.60	2.60	Ca	0.12	0.08
HCO_3	1.30	1.25	Mg	0.16	0.16
Cl	1.97	2.40	Na	18.66	10.89
NO_3	0.67	1.19	K	0.20	0.10
SO_4	10.89	2.09			

TABLE 2

OXIDATION OF SULFUR AFTER TREATMENT AND INCUBATION

Amount and kinds of sulfur added, p.p.m.		Per cent oxidized after incubation for:				
		5 weeks	8 weeks	12 weeks	20 weeks	38 weeks
Soil 7923						
750	Inoculated sulfur	50.5	61.0	69.2	69.8	73.4
	Elemental sulfur	27.9	38.0	60.8	68.3	72.2
	Coarse sulfur	3.4	13.5	33.2	40.8	41.7
	Colloidal sulfur	34.5	43.6	65.5	68.0	72.7
	Sulfur concentrate	38.1	42.9	60.0	68.2	70.8
1,500	Inoculated sulfur	45.6	51.3	56.0	59.4	75.3
	Elemental sulfur	32.4	39.6	47.5	53.3	75.3
	Coarse sulfur	8.3	21.8	27.2	28.4	31.8
	Colloidal sulfur	37.2	42.8	48.7	52.7	65.6
	Sulfur concentrate	36.4	45.5	50.3	50.9	70.6
Soil 7924						
1,000	Inoculated sulfur	73.4	79.2	80.1	82.0	85.1
	Elemental sulfur	53.4	63.4	69.9	73.4	82.3
	Coarse sulfur	22.4	33.3	41.5	48.2	60.6
	Colloidal sulfur	58.4	65.1	68.9	70.8	72.8
	Sulfur concentrate	64.0	69.9	73.2	79.5	90.0
2,000	Inoculated sulfur	50.6	54.8	56.9	59.5	71.3
	Elemental sulfur	44.4	48.2	61.5	64.7	76.7
	Coarse sulfur	22.7	28.1	33.2	38.4	48.5
	Colloidal sulfur	39.7	52.7	61.4	66.1	73.6
	Sulfur concentrate	46.0	52.9	63.9	68.8	82.7

LABORATORY EXPERIMENTS

Soil No. 7923, a Hanford fine sandy loam, and soil No. 7924, a Fresno fine sandy loam, were used in the laboratory experiments. From the analyses given in table 1, it will be seen that both soils contained appreciable amounts of soluble salts.

To soil No. 7923, which contained 1.60 milliequivalents of soluble CO_3 per 100 grams, the sulfur was added at the rates of 750 and 1,500 parts per million (p.p.m.); and to soil No. 7924, which contained 2.60 milliequivalents of soluble CO_3 per 100 grams, at rates of 1,000 and 2,000 p.p.m. The sulfur-containing materials were thoroughly mixed with 3 kilograms of the dry soil, after which distilled water was added in amounts sufficient to bring the soil to optimum water content. The soils were then incubated at room temperature in large-mouth glass bottles and samples were withdrawn from time to time for analysis.

TABLE 3

CONTENT OF NORMAL CARBONATE AFTER TREATMENT AND INCUBATION

Amount and kinds of sulfur added, p.p.m.		CO_3 in milliequivalents per 100 grams found after incubation for:				
		5 weeks	8 weeks	12 weeks	20 weeks	38 weeks
		Soil 7923				
750	Inoculated sulfur	0.60	0.45	0.30	0.27	0.22
	Elemental sulfur	0.90	0.60	0.55	0.35	0.25
	Coarse sulfur	1.50	1.45	0.85	0.70	0.55
	Colloidal sulfur	0.85	0.55	0.45	0.42	0.40
	Sulfur concentrate	0.80	0.57	0.50	0.45	0.40
1,500	Inoculated sulfur	0.25	0.20	0.15	0.12	0.07
	Elemental sulfur	0.30	0.20	0.17	0.15	0.07
	Coarse sulfur	0.90	0.90	0.55	0.40	0.20
	Colloidal sulfur	0.35	0.27	0.20	0.15	0.10
	Sulfur concentrate	0.32	0.20	0.20	0.17	0.07
		Soil 7924				
1,000	Inoculated sulfur	0.20	0.17	0.15	0.12	0.10
	Elemental sulfur	0.60	0.45	0.15	0.10	0.05
	Coarse sulfur	1.60	1.37	0.95	0.85	0.35
	Colloidal sulfur	0.57	0.30	0.27	0.22	0.20
	Sulfur concentrate	0.42	0.32	0.20	0.15	0.03
2,000	Inoculated sulfur	0.05	0.00	0.00	0.00	0.00
	Elemental sulfur	0.15	0.05	0.00	0.00	0.00
	Coarse sulfur	0.52	0.47	0.30	0.22	0.10
	Colloidal sulfur	0.22	0.00	0.00	0.00	0.00
	Sulfur concentrate	0.10	Trace	0.00	0.00	0.00

Amount of Sulfur Oxidized.—Table 2 shows the amount of sulfur that had been oxidized at the various dates of sampling. During the first few weeks of the experiment the inoculated sulfur was oxidized more rapidly than the uninoculated forms. Later in the experiment the rates of oxidation became reversed, except in the case of the coarse sulfur.

TABLE 4

BICARBONATE CONTENT AFTER TREATMENT AND INCUBATION

Amount and kinds of sulfur added, p.p.m.		HCO_3 in milliequivalents per 100 grams found after incubation for:				
		5 weeks	8 weeks	12 weeks	20 weeks	38 weeks
		Soil 7923				
750	Inoculated sulfur	0.49	0.51	0.54	0.50	0.46
	Elemental sulfur	0.76	0.69	0.49	0.41	0.32
	Coarse sulfur	1.50	0.89	0.88	0.79	0.66
	Colloidal sulfur	0.60	0.56	0.55	0.56	0.56
	Sulfur concentrate	1.21	0.65	0.60	0.57	0.48
1,500	Inoculated sulfur	0.41	0.35	0.50	0.50	0.50
	Elemental sulfur	0.44	0.52	0.48	0.41	0.31
	Coarse sulfur	0.70	0.66	0.69	0.62	0.50
	Colloidal sulfur	0.61	0.51	0.50	0.50	0.51
	Sulfur concentrate	0.59	0.56	0.54	0.50	0.51
		Soil 7924				
1,000	Inoculated sulfur	0.51	0.57	0.32	0.34	0.39
	Elemental sulfur	0.70	0.56	0.49	0.46	0.45
	Coarse sulfur	0.95	0.66	0.62	0.59	0.54
	Colloidal sulfur	0.57	0.57	0.40	0.40	0.40
	Sulfur concentrate	0.59	0.59	0.32	0.32	0.34
2,000	Inoculated sulfur	0.36	0.34	0.30	0.29	0.25
	Elemental sulfur	0.42	0.45	0.29	0.26	0.22
	Coarse sulfur	1.12	0.70	0.49	0.45	0.31
	Colloidal sulfur	0.38	0.38	0.29	0.29	0.27
	Sulfur concentrate	0.39	0.38	0.27	0.29	0.27

With both soils the coarse sulfur underwent oxidation more slowly than any of the fine-grained materials, showing that small particles become oxidized more rapidly than large ones. This was to be expected because the rate of oxidation is a surface phenomenon and depends upon the amount of exposed surface.

It is interesting to note that with each soil the rate of oxidation was roughly proportional to the amount of sulfur added.

Effect of Sulfur on Soluble CO_3 and HCO_3.—Table 3 gives the amounts of soluble normal carbonate (CO_3) found at the various dates of sampling. The content of CO_3 was reduced in every case, but at markedly different rates. The decrease in soluble CO_3 was roughly proportional to the amount of sulfur that was oxidized. Since, as shown in table 2, the inoculated sulfur was oxidized more rapidly than the other forms during the first few weeks of the experiment, it is interesting to find that the soluble CO_3 decreased proportionately. Towards the close of

TABLE 5

WATER-SOLUBLE CALCIUM CONTENT AFTER TREATMENT AND INCUBATION

Amount and kinds of sulfur added, p.p.m.		Water-soluble Ca in milliequivalents per 100 grams found after incubation for:			
		5 weeks	8 weeks	12 weeks	38 weeks
Soil 7923					
750	Inoculated sulfur	Trace	0.22	0.23	0.31
	Elemental sulfur	Trace	Trace	0.27	0.33
	Coarse sulfur	Trace	Trace	Trace	0.23
	Colloidal sulfur	Trace	Trace	0.10	0.27
	Sulfur concentrate	Trace	Trace	0.05	0.32
1,500	Inoculated sulfur	0.15	0.40	0.51	2.36
	Elemental sulfur	0.12	0.37	0.47	1.01
	Coarse sulfur	Trace	Trace	0.22	0.27
	Colloidal sulfur	0.10	0.10	0.29	1.05
	Sulfur concentrate	Trace	Trace	0.35	1.62
Soil 7924					
1,000	Inoculated sulfur	0.12	0.15	0.10	0.21
	Elemental sulfur	Trace	Trace	0.05	0.14
	Coarse sulfur	Trace	Trace	Trace	0.02
	Colloidal sulfur	Trace	0.10	0.15	0.20
	Sulfur concentrate	Trace	0.09	0.20	0.27
2,000	Inoculated sulfur	0.58	1.02	2.37	3.45
	Elemental sulfur	0.35	0.39	1.07	2.49
	Coarse sulfur	Trace	0.13	0.06	0.37
	Colloidal sulfur	0.23	0.61	1.40	2.46
	Sulfur concentrate	0.40	0.70	1.35	3.24

the experiment, the finely ground elemental sulfur, the colloidal form, and the sulfur concentrate, none of which were inoculated, produced fully as great reduction in the soluble CO_3 as the inoculated sulfur. On the other hand, the coarse sulfur was less effective at all stages of the experiment. As shown in table 4, the soluble bicarbonate (HCO_3) was affected like the soluble normal carbonate (CO_3). (See table 3).

Effect of Sulfur on the Water-Soluble Calcium.—Table 5 gives the content of water-soluble calcium in the various samples. A comparison of the analyses in this table with those in table 3 shows that not more than a small amount of water-soluble calcium was found until practically all the CO_3 had been neutralized. After the CO_3 had been neutralized, however, appreciable amounts of water-soluble calcium were found in all of the samples.

FIELD EXPERIMENTS

The inoculated sulfur and three of the forms of uninoculated sulfur, namely, elemental, coarse, and colloidal sulfur, were used in replicated plot experiments. The sulfur materials were added at the rate of 1 ton of actual sulfur per acre to plots approximately ¼ acre in size. Two plots were left untreated as checks.

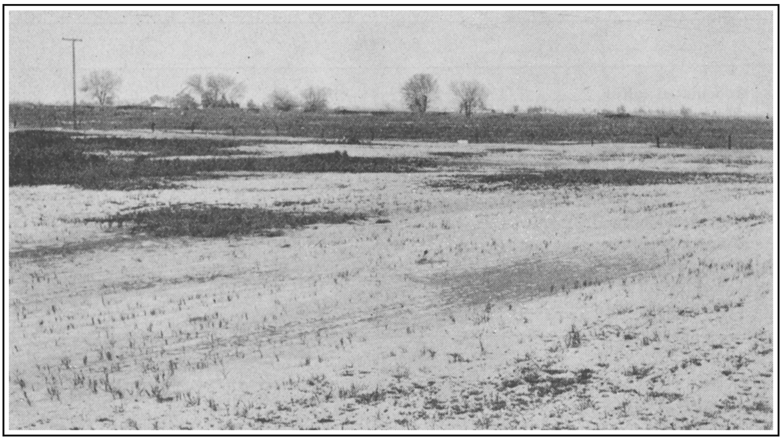

Fig. 1.—Condition of the field plots before the sulfur experiments were begun (photographed March, 1927). Note failure of the barley crop sown the previous fall.

The sulfur materials were applied in July, 1927, and were plowed under to a depth of 3 or 4 inches. The soil was irrigated and cultivated during the remainder of the summer and the fall of that year (fig. 1).

The flooding system of irrigation was used, the entire surface of each plot being covered with water at each application. This produced more or less leaching of the soil.

Soluble CO_3 and HCO_3 in Field-Plot Soils.—Table 6 gives the content of soluble CO_3 in samples of soil taken to a depth of one, two, three, and four feet respectively. One set of soil samples was taken before the sulfur treatments were applied, a second set 6 months later, and a third set 18 months after the sulfur was applied.

Within 6 months after the applications had been made, practically all of the soluble CO_3 had been removed from the surface foot of soil in each of the sulfur-treated plots. The irrigation water had also leached a part of the CO_3 from the surface foot of the untreated plot. The sulfur treatments caused considerable reduction in soluble CO_3 in the second foot also, but the effects were only slight in the third and fourth feet.

Table 7 shows that the soluble HCO_3 was only slightly affected by any of the sulfur materials.

Soluble SO_4 in Field-Plot Soils.—Table 8 gives the content of soluble

TABLE 6

CONTENT OF NORMAL CARBONATE (CO_3) IN FIELD-PLOT SOILS TREATED WITH DIFFERENT KINDS OF SULFUR

(In milliequivalents per 100 grams)

Time of analysis	0–12 inch depth	12–24 inch depth	24–36 inch depth	36–48 inch depth
Inoculated sulfur				
Before treatment	0.62	0.50	0.42	0.30
6 months after treatment	0.00	0.21	0.60	0.50
18 months after treatment	0.00	0.17	0.50	0.82
Elemental sulfur				
Before treatment	0.92	0.87	0.35	0.52
6 months after treatment	0.00	0.52	0.87	0.57
18 months after treatment	0.00	0.42	0.80	0.88
Coarse sulfur				
Before treatment	0.80	0.90	0.95	0.80
6 months after treatment	0.05	0.67	0.95	0.60
18 months after treatment	0.00	0.57	0.87	0.47
Colloidal sulfur				
Before treatment	0.67	1.27	1.25	0.85
6 months after treatment	0.05	0.75	1.12	0.80
18 months after treatment	0.00	0.57	1.22	1.02
Untreated				
Before time of treating the other plots	0.97	1.07	1.25	0.92
6 months later	0.75	0.92	1.12	0.87
18 months later	0.47	0.95	1.37	1.22

sulfate (SO_4) in the field-plot soils. Within 6 months after the sulfur applications, the SO_4 content of all of the treated plots had increased. Since these soils were irrigated by flooding, they must have been leached to some extent. This is indicated by the increase in the SO_4 content in the subsoil. In the untreated plots, on the other hand, the SO_4 content was reduced throughout the profile, an indication that more or less leaching took place.

Soluble Cl in Field-Plot Soils.—Table 9 gives the content of soluble chloride (Cl) in the field-plot soils. The chloride content was reduced substantially throughout the entire profile of each plot. This was fully as pronounced in the untreated as in the sulfur-treated plots.

TABLE 7

BICARBONATE (HCO_3) CONTENT OF FIELD-PLOT SOILS TREATED WITH DIFFERENT KINDS OF SULFUR

(In milliequivalents per 100 grams)

Time of analysis	0–12 inch depth	12–24 inch depth	24–36 inch depth	36–48 inch depth
Inoculated sulfur				
Before treatment	0.55	0.45	0.58	0.56
6 months after treatment	0.35	0.51	0.54	0.49
18 months after treatment	0.39	0.44	0.52	0.44
Elemental sulfur				
Before treatment	0.56	0.65	0.45	0.44
6 months after treatment	0.48	0.64	0.55	0.49
18 months after treatment	0.42	0.45	0.46	0.36
Coarse sulfur				
Before treatment	0.60	0.50	0.62	0.50
6 months after treatment	0.45	0.62	0.83	0.46
18 months after treatment	0.37	0.51	0.55	0.49
Colloidal sulfur				
Before treatment	0.50	0.57	0.46	0.53
6 months after treatment	0.44	0.55	0.64	0.53
18 months after treatment	0.44	0.56	0.53	0.55
Untreated				
Before time of treating the other plots	0.41	0.48	0.52	0.52
6 months later	0.52	0.56	0.67	0.57
18 months later	0.46	0.40	0.49	0.45

TABLE 8

SULFATE (SO_4) CONTENT OF FIELD-PLOT SOILS TREATED WITH DIFFERENT KINDS OF SULFUR

(In milliequivalents per 100 grams)

Time of analysis	0–12 inch depth	12–24 inch depth	24–36 inch depth	36–48 inch depth
Inoculated sulfur				
Before treatment	0.13	0.40	1.00	0.84
6 months after treatment	1.67	0.83	0.73	1.04
18 months after treatment	0.16	0.44	0.59	0.86
Elemental sulfur				
Before treatment	0.16	0.38	0.38	0.45
6 months after treatment	1.26	0.51	0.68	0.78
18 months after treatment	0.09	0.11	0.24	0.28
Coarse sulfur				
Before treatment	0.13	0.22	0.16	0.19
6 months after treatment	0.99	0.59	0.49	0.39
18 months after treatment	0.13	0.21	0.36	0.39
Colloidal sulfur				
Before treatment	0.12	0.31	0.44	0.22
6 months after treatment	1.21	0.71	0.65	0.50
18 months after treatment	0.29	0.32	0.48	0.41
Untreated				
Before time of treating the other plots	0.15	0.13	0.26	0.30
6 months later	0.06	0.07	0.11	0.24
18 months later	0.04	0.04	0.07	0.05

TABLE 9

CHLORINE (Cl) CONTENT OF FIELD-PLOT SOILS TREATED WITH DIFFERENT KINDS OF SULFUR

(In milliequivalents per 100 grams)

Time of analysis	0–12 inch depth	12–24 inch depth	24–36 inch depth	36–48 inch depth
Inoculated sulfur				
Before treatment	0.35	0.91	1.95	2.26
6 months after treatment	0.21	0.25	0.49	1.55
18 months after treatment	0.19	0.19	0.26	0.60
Elemental sulfur				
Before treatment	0.45	1.02	0.55	1.00
6 months after treatment	0.21	0.21	0.45	0.75
18 months after treatment	0.17	0.20	0.25	0.22
Coarse sulfur				
Before treatment	0.37	0.60	0.56	0.65
6 months after treatment	0.16	0.19	0.39	0.55
18 months after treatment	0.15	0.14	0.17	0.15
Colloidal sulfur				
Before treatment	0.36	0.81	1.15	0.80
6 months after treatment	0.20	0.24	0.51	0.65
18 months after treatment	0.17	0.25	0.27	0.29
Untreated				
Before time of treating the other plots	0.49	0.39	0.85	0.87
6 months later	0.12	0.12	0.25	0.26
18 months later	0.10	0.14	0.19	0.21

GROWTH OF CROPS ON FIELD PLOTS

Hubam clover was grown the first season after the sulfur materials were applied. The crop made good growth on all of the sulfur-treated plots. On the untreated plots the seed did not germinate in certain areas, and the soil remained bare, not even supporting the most alkali-resistant plants. The Hubam clover was plowed under as a green manure in September, 1928.

Alfalfa was sown on the plots the following spring. The seed germinated well, a complete stand being obtained on all of the treated plots

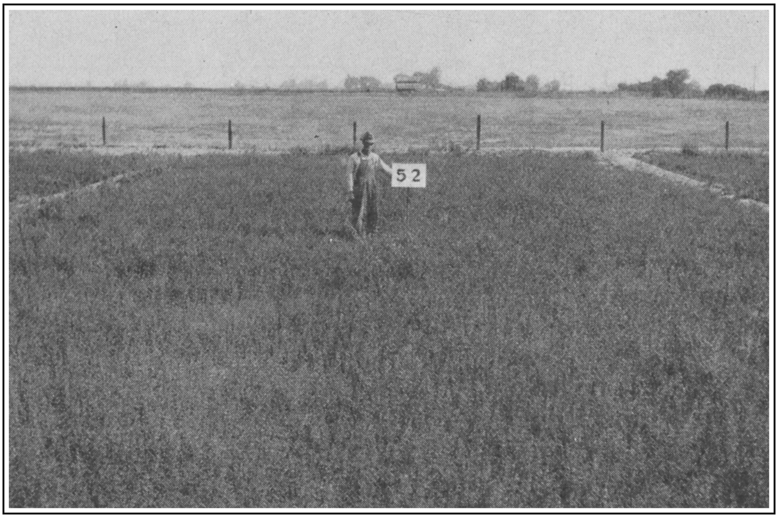

Fig. 2.—Alfalfa on the plot treated with coarse sulfur. The alfalfa was sown February 21, 1929, and photographed May 15, 1929.

(figs. 2, 3, 4, and 5). On the untreated plots the stand was uneven (fig. 6). Many of the young alfalfa plants died on the areas that had failed to support a good growth of Hubam clover the previous season.

As shown in the figures, good yields of alfalfa hay have been obtained on all of the sulfur-treated plots, no significant difference being found between the different kinds of sulfur. Every one of the sulfurs produced satisfactory results (table 10).

In 1933 oats were grown and an excellent yield of hay was produced on all the sulfur-treated plots. A good yield of oats was secured on certain parts of the check plots also. This may be attributed to the extreme variability of alkali soil in general as discussed by Kelley.[2] At the

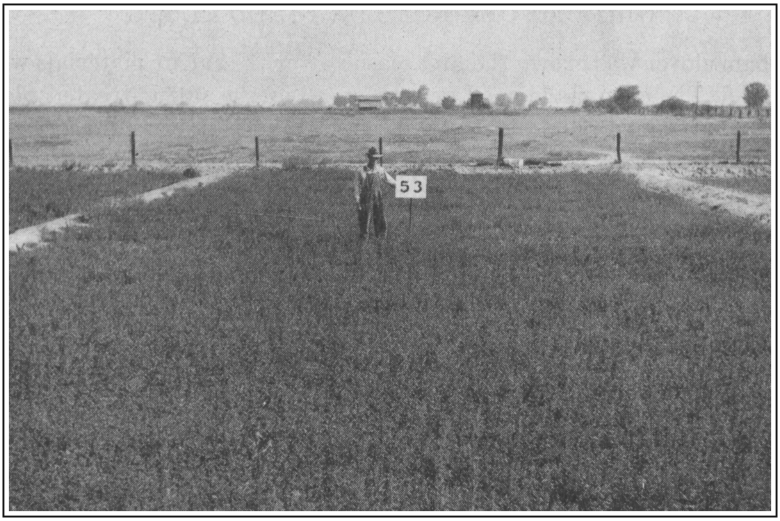

Fig. 3.—Alfalfa on plot treated with colloidal sulfur. The alfalfa was sown February 21, 1929, and photographed May 15, 1929.

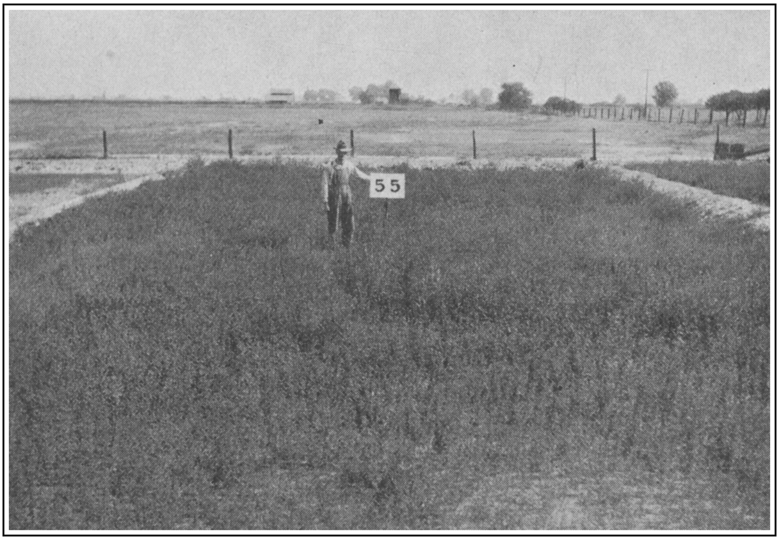

Fig. 4.—Alfalfa on the plot treated with inoculated sulfur. The alfalfa was sown February 21, 1929, and photographed May 15, 1929.

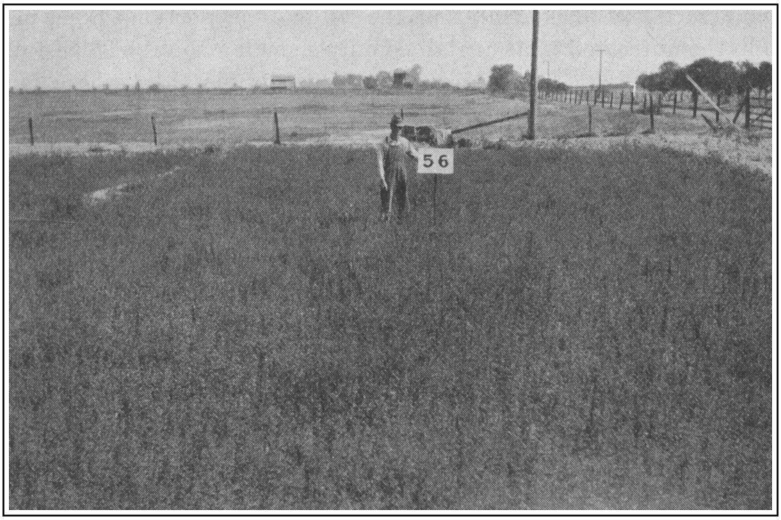

Fig. 5.—Alfalfa on the plot treated with elemental sulfur. The alfalfa was sown February 21, 1929, and photographed May 15, 1929.

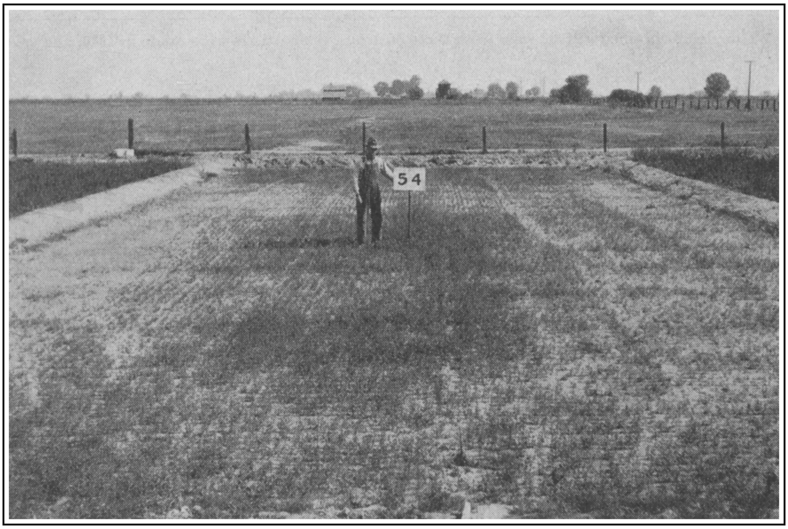

Fig. 6.—Alfalfa on the untreated plot. The alfalfa was sown February 21, 1929, and photographed May 15, 1929. Most of the plants died soon after the date the photograph was taken.

beginning of the experiment the soil in certain portions of each plot contained much less black alkali than the soil in other portions. Some of the soil in the untreated plots contained only a small amount of black alkali and other soluble salts, and was more permeable than where larger amounts of black alkali occurred. In passing through such soil, the irrigation water naturally leached out the soluble salts to a greater extent than in the remainder of the plot. On places of this kind in the check plots the alfalfa and oats made good growth after the concentration of soluble salts had been sufficiently reduced.

TABLE 10

CROP YIELDS IN POUNDS PER ACRE AS AFFECTED BY DIFFERENT KINDS OF SULFUR

Year	Inoculated sulfur	Elemental sulfur	Coarse sulfur	Colloidal sulfur	Untreated
		Alfalfa hay			
1929	10,937	10,000	10,058	10,097	4,082
1930	19,334	20,252	20,995	21,443	10,605
1931	17,225	16,867	20,495	21,412	14,772
1932*	7,362	7,598	8,887	8,946	5,918
		Oat hay			
933	5,195	5,235	5,478	5,488	4,179

* The yields obtained in 1932 were from three cuttings. Six cuttings were made in 1930, and seven in 1931.

SUMMARY

For several years good results have been obtained with the use of sulfur as a treatment of black-alkali soils. Both uninoculated and inoculated sulfurs have been used. All of the sulfurs used gave good results both in the laboratory and in the field, but the rates of oxidation were different. The rate of oxidation of sulfur inoculated with *Thiobacillus thioöxidans* was greater than that of the uninoculated sulfurs for the first 8 weeks of the experiment. Uninoculated sulfurs with particles similar in size to those of the inoculated sulfur underwent fully as rapid oxidation after the lapse of 8 to 10 weeks as the inoculated sulfur.

The rate of oxidation of the coarse sulfur was slower than that of any of the finer-grained sulfurs because of the difference in particle size. In the course of time, however, the coarse sulfur gave as good results as the other sulfurs. This was shown by the fact that 18 months after the coarse sulfur had been applied, the CO_3 content of the soil was reduced in each foot layer to a depth of 4 feet.

These results show that whatever form of sulfur is used it should be applied on the basis of actual sulfur content.

The laboratory and field experiments both indicate that various kinds of sulfur will be effective in the treatment of black-alkali soils which contain lime or other readily decomposable calcium minerals; however, the sulfur should be finely pulverized in order that the material may be evenly distributed. With the soils used in these experiments, at least, artificial inoculation of sulfur is unnecessary.

In order to secure the best results with sulfur, the soil should be leveled before application is made. When applied, the sulfur should be mixed with the soil by shallow plowing or disking, after which irrigation and cultivation should be as frequent as is necessary to keep the soil moist and well aerated.

Good drainage conditions are necessary in order that the soluble salts may be removed from the soil by leaching. In some cases it may be possible to leach the soluble salts from the root zone by the regular irrigations, while in other places it is necessary to subject the soil to heavy flooding in order to remove the salts.

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[4] Since the preparation of this manuscript, the following bulletin, dealing with the same subject, has been published. The results given in the two papers are in general agreement: MacGeorge, W. T., and R. A. Greene. Oxidation of sulfur in Arizona soils and its effect on soil properties. Arizona Exp. Sta. Tech. Bul. **56**:297–325. 1935.