THESIS

on

STUDIES OF ECONOMIC RATES, FORMS, AND COMBINATIONS OF USE OF SULFUR AS A FERTILIZER

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STUDIES OF ECONOMIC RATES, FORMS, AND COMBINATIONS OF USE OF SULFUR AS A FERTILIZER

Joseph D. Haynes

INTRODUCTION

Experiments concerning the value of sulfur in agricultural practice have well established the worth of this element for correcting soil alkalinity, bringing bases into solution, controlling certain plant pests and diseases, and, in some sections, supplying a limiting plant food element.

This paper reports experiments dealing with economic means of supplying sulfur where helpful. Extensive reviews of the literature are available (13) and reference will be made only to those researches that are especially pertinent to this investigation.

New forms of commercial sulfur, including a "black gas" sulfur, have recently appeared on the market, the relative value of which has not been established. Before recommendations can be made regarding the use of these products for fertilizer purposes, it is necessary that experiments establish their fertilizer value.

This study was undertaken to throw some light on economic forms, rates, and combinations of sulfur for fertilizer purposes. With the appearance of different forms of sulfur it was necessary to ascertain the value of these forms and rates to apply per acre, along with promising combinations with gypsum, manure, and lime for increased efficiency or more economic use.

These studies were made on the neutral arid soils and also with soils containing large amounts of black alkali salts.

The rate of sulfur oxidation is a pertinent question to manufacturers of sulfur and to the farmer who uses this material. The amount and time of application depend much on the rate of oxidation. Manufacturers must know the needs of the farmers so that a sulfur may be manufactured that will give the greatest return for the investment. Rate of sulfur oxidation is important in the field of plant nutrition, because too rapid sulfur oxidation may result in leaching of sulfates, while slow oxidation may fail to meet plant requirements.

HISTORICAL

Sulfur has been used in Oregon as a fertilizer for fifteen years. Powers (12) found sulfur to be as effective as calcium sulfate or potassium sulfate in the Deschutes Valley, and Reimer (15) found that elemental sulfur in acid phosphate, or lime-sulfur spray increased the yield of alfalfa and legume cover crops in Southern Oregon.

Much of the early experimental work was developed on the theory that sulfur might be a limiting plant food element in certain soils. Increases in yield secured, especially with legume crops, were considered as being due to supplying sulfates. Experimental work by Reimer and Tartar (16) found that sulfur is used by plants as an essential nutrient in increasing the protein. Cystine, one of the amino acids of protein, contains sulfur, which may be a connecting link in the protein series.

Sulfur oxidation depends largely upon two important factors: fineness of division or surface area, as shown by Stephenson (18); and type of soil, according to Halversen and Bollen (6). Materials finer than 40 mesh Stephenson (18) found oxidized at a rate that was adequate to meet plant requirements. Soils containing sand having little buffer action oxidized sulfur more rapidly than heavier soils containing large amounts of clay (6).

Various other activities result in sulfur oxidation. According to Waksman and Joffe (19), Thiobacillus thiooxidans, a sulfur-oxidizing organism, isolated by Lipman and associates, is very active in sulfur oxidation. MacIntire, Gray, and Shaw (11) found that some non-biological oxidation took place in pure quartz, but that sulfur was not oxidized sufficiently to be a means of supplying sulfates for plant growth. Abbott (1) reports that Penicillium luteum oxidized 20.3 mg. of sulfur in a period of 20 days. This organism is one of the common molds universally found in soil. Weather and moisture conditions will retard or accelerate oxidation. Optimum moisture condition and warm temperature are ideal for sulfur oxidation.

For some time gypsum has been advocated for reclamation of "black alkali" soil. Hilgard (7) was among the first to suggest it. Some failures were probably due in part to the reversibility of the reaction of gypsum with the alkali and the low solubility of the gypsum.

Na_2CO_3	+	$CaSO_4$	$\rightleftarrows$	Na_2SO_4	+	$CaCO_3$
Sodium carbonate		Calcium sulfate		Sodium sulfate		Calcium carbonate

Lipman (10) suggested sulfur for reclamation of alkali land, the advantage being the non-reversible reaction of the oxidized product as shown below.

Na_2CO_3	+	H_2SO_4	$\longrightarrow$	Na_2SO_4	+	H_2O	+	CO_2
Sodium carbonate		Sulfuric acid		Sodium sulfate		Water		Carbon dioxide

Investigations of sulfur as a fertilizer for alfalfa have been conducted in most of the alfalfa producing areas of Oregon and the Northwest. Reclamation experiments in Oregon for alkali land have been centered at Vale. A progress report on this work (14) indicates that the use of a rapid oxidizing sulfur in combination with a legume green manure may prove economical for the reclamation of black alkali land having deep drainage and plentiful irrigation.

Field trials indicate that the state of Oregon has 140,000 acres of good alfalfa land on which the yield may be increased at least one ton more per acre if sulfur were applied. This would mean an increase in hay value of over $1,000,000 a year with an annual cost of about one dollar per acre, which is less than a dollar per ton for the additional hay. The use of sulfur has contributed to productive value of land in irrigated projects in Oregon.

Extensive fertilizer trials have been conducted on Antelope Clay Adobe soil on the Reimer plats near Medford, Oregon. These trials were started in 1915 and continued for a period of twelve years. Over this period of years alfalfa treated with sulfur has given phenomenal results. For a period of ten years check plats averaged 118 pounds, and the sulfur treated plats averaged 455 pounds from the one-tenth acre plats. This is of particular interest due to the long period of time over which these results were obtained. These trials indicate that sulfur can be used for a period of time without detrimental effect on the soil, or a decrease in plant growth. In these plats application of a total of 1000 pounds per acre has been used without apparent injury to the land. Also, the increase from this heavy application was no greater than from a lighter one of 100 pounds per acre.

The tendency on the lighter soils is to use a frequent light application of 50 pounds an acre. On the heavy soils such as the Klamath Clay Loam a 100-pound application caused a yearly two-ton increase for a period of five years.

METHODS AND PROCEDURE

To secure information over such a wide range it is necessary to make laboratory and greenhouse studies under controlled conditions and then develop these leads with field studies to check the laboratory and greenhouse work.

The forms of sulfur available for this study were "gasco," "black gas sulfur," "sand sulfur," and "inoculated sulfur." Gasco is a sulfur by-product of the gas plant at Portland, Oregon. Black gas sulfur is a by-product of the gas plant at San Francisco, California. Sand sulfur is coarsely ground, containing particles about the size of sand. Inoculated sulfur contains the sulfur-oxidizing organism Thiobacillus thiooxidans. Since several of these forms of sulfur are new to the trade it was essential that preliminary tests should be made to make sure that these forms would oxidize and be worth careful investigations.

Having selected those forms of sulfur that showed promise from the preliminary experiments, further studies were planned to compare them, using various rates and combinations in promoting the growth of alfalfa in the greenhouse trials on a soil known to be low in sulfate. These data should serve as an indication of their possible value under field conditions.

For the study of these forms of sulfur in relation to the reclamation of alkali land, laboratory studies on rate of oxidation of different forms of sulfur and percolation trials with sulfur in different combinations were planned to be supplemented by field trials.

The following studies were undertaken:

The rapidity of oxidation of new forms of sulfur in neutral soil; oxidation of inoculated and non-inoculated sulfur on neutral and alkali soils; biological changes in soil; greenhouse studies with rates, forms, and combinations of sulfur on neutral soil supplying sulfates as a plant nutrient; flocculation effect of sulfur on soils; neutralization of carbonates and displacement of sodium on the ultra clay complex with calcium.

Air-dry soil was weighed out in 2-pound amounts, placed in quart mason jars, and mixed with sulfur in different rates and forms, water being added until an optimum moisture condition was reached. This was maintained during the experiment, treatments as shown in Tables 1 and 2. Sulfate determinations were made periodically from 1:5 water extract, and precipitation with a solution of barium chloride was followed by gravimetric determinations. Heavy applications of sulfur were used in order to obtain differences that would be significant.

A medium for determining the number of microorganisms in the soil was made according to Fred and Wakeman (5).

Malheur Clay Loam was employed in this study, 25-pound lots being used in each jar as shown in Table 8. The method used for determining the replaceable bases in alkali soil was that of Burgess and Breazeale (3), percolation tests being made over three periods of time, between which the soil was thoroughly dried. The first trial was for 252 hours, the second for 396 hours, and the third for 540 hours. Percolate from each jar was measured each 38 hours. At the end of each trial, the total amount of salts removed was determined by analysis of an aliquot part of the percolate. At the close of each trial, hydrogen-ion concentration determinations were made with a hydrogen electrode. At the beginning of each trial, the soil was thoroughly mixed to avoid channeling.

Nineteen jars of soil treated with sulfur, lime, and manure at different rates or in different combinations were used for this experiment. The first twelve jars were filled with Malheur Clay Loam (used by Young) (20), and the last seven jars were of the same type of soil, but having less alkali than the former.

Experiment No. 1

RATE OF OXIDATION OF DIFFERENT FORMS OF SULFUR

Besides studying rate of oxidation of the various sulfurs, another reason for these studies was to find if the small amount of tar present in the black gas sulfur would in any way check oxidation. As sulfur must pass to the sulfate form before it can be used by plants it is necessary to determine with what facility oxidation occurs.

Oxidation studies were undertaken with Deschutes Sandy Loam treated at the rate of 1,000 pounds per acre and tested periodically for this study (Table 1).

Table 1. Rate of Oxidation of Different Forms of Sulfur.

Deschutes Sandy Loam

Treatment 1,000 lbs. per acre	Period of Incubation 3 Weeks SO_4	6 Weeks SO_4	6 Weeks pH	9 Weeks SO_4	9 Weeks pH	% oxidized 9 Weeks
Check	.0339	.0499	7.2	.0550	7.2	0
Black gas sulfur (melted & ground)	.0740	.1207	6.8	.1544	6.4	66.6
Gasco by-product (43% S)	.0575	.0797	7.1	.0820	7.1	41.8
Black gas sulfur (Colloidal)	.0987	.1295	6.3	.1290	6.4	49.3
Bac-sul	.0986	.1143	6.5	.1169	6.4	41.2
Sand sulfur	.0330	.0611	7.1	.0964	6.8	27.6

Data presented (Table 1) indicate that black gas sulfur oxidizes at a comparatively rapid rate. The small amount of tar present in this material does not seem to interfere with oxidation. The gasco by-product oxidizes at a rate comparable with other commercial forms of sulfur. Sand sulfur oxidizes slowly due to the small surface area exposed.

According to Powers, (13) alfalfa seems to require most sulfate in the early period of growth. During the first six to nine weeks alfalfa takes up most of the sulfates needed; therefore, sulfur should be rapidly oxidized to the sulfate form and available for absorption into the plant in early stages of growth. From data secured it appears that black gas sulfur oxidizes promptly and should supply sulfate requirements for young alfalfa seedlings as well as later needs.

Experiment No. 2

RATE OF OXIDATION OF SULFUR ON ARID SOILS.

Studies were made with arid soils; namely, Umatilla Medium Sand, Deschutes Sandy Loam, and Malheur Clay Loam, for the purpose of determining the sulfofying power of soils that were neutral, or alkaline in reaction. Of the three soils investigated, the sulfofying power of the alkali soil from Vale, Oregon, was unknown. It was necessary to allow a period of time for sulfur to oxidize before leaching this alkali soil. Under field conditions the sulfur was applied about three months before leaching began. It was undetermined whether this was time enough for the sulfur to oxidize to sulfate. Field trials indicate that sulfur did largely oxidize, but laboratory studies were necessary to determine the rate of oxidation; therefore, an experiment was set up using different rates of sulfur, to determine the amount oxidized, and the changes occurring in hydrogen-ion concentration.

In Table 2 is presented the amount of sulfates formed after two, four, eight, and sixteen weeks, together with the changes in hydrogen-ion concentrations. Black gas sulfur oxidizes at nearly the same rate as the inoculated sulfur, except with the highly alkalinesoil, Malheur Clay Loam. The inoculated sulfur for the first eight weeks oxidizes more rapidly than the black gas sulfur, after which time the two yield sulfate at a similar rate.

All the soils show a decided change the first four weeks, the pH dropping rapidly and then continuing to remain about the s ame throughout the remainder of the experiment. The curve for Umatilla Medium Sand shows a steep drop, more so than the other soils. This is due to the low buffer property of this particular soil. The other two soils are finer textured and do not allow such rapid changes in hydrogen-ion concentration.

Thistrial indicates that sulfur oxidizes well under alkaline conditions, and that the high concentration of salts does not prevent sulfur oxidation. This is also in accord with findings of Kelley and Thomas (8) and Samuels (17), who found that sulfur oxidation is reasonably active in alkaline soils.

From this work it appears that after two months an application of sulfur would oxidize sufficiently so that leaching could take place, as the black gas sulfur at eight weeks was 77.6 per cent oxidized and at the end of sixteen weeks 90.2 per cent oxidized. The tendency appears to be for rapid oxidation the first eight weeks and then the process slows up, probably due to the sulfuric acid stopping the action of sulfur oxidizing organisms. This is particularly noticeable with the heavy applications.

This application of one ton has neutralized the carbonates present, but probably has had little effect on the exchange of calcium for sodium on the base absorbing complex. One ton of sulfur would not completely reclaim the soil, but should improve it to the extent that crops could be grown.

Leaching intermittently with periods of incubation should be ideal for sulfur oxidation on alkali soils, as the pH would rise with the formation of sodium hydroxide caused by leaching the soil. It appears that one ton of black gas sulfur will neutralize the Malheur Clay Loam employed.

Flocculation With Sulfur

Figures 5, 6, and 7 show flocculation effect on certain soils; namely Malheur Clay Loam, Umatilla Medium Sand, and Deschutes Sandy Loam. These flocculation photographs were taken at the end of a 16-week incubation period. Treatments are recorded in Table 2.

Soils treated with sulfur were flocculated as represented by the above figures. Checks in all cases remained dark; the treated tubes clearing up. Heavy application of sulfur caused flocculation more rapidly than light application, as is shown in figure 7, with gradual clearing of the tubes from left to right.

In the alkali soil flocculation begins as neutrality is approached. Definite flocculation started at pH 7.5. This flocculation, according to Comber, (4) is in part indirect due to bringing some other material into solution which flocculates the soil. The material that is brought into solution in the greatest quantity from application of sulfur, according to Powers, (13) and Larson (9), is calcium. It appears that flocculation from sulfur is due to bringing into solution calcium and possibly some other ions that would tend to flocculate, along with the neutralizing effect from the sulfur.

Table 2. Oxidation Studies on Three Arid Soils.

Jar		2 Weeks SO$_4$	2 Weeks pH	4 Weeks SO$_4$	4 Weeks pH	8 Weeks SO$_4$	8 Weeks pH	16 Weeks SO$_4$	16 Weeks pH	S. oxidized per cent
	Malheur Clay Loam									
1	Check	.0351	9.5	.0738	9.4	.0781	9.5	.0879	9.5	0
2	1 ton B.G.S.	.1176	8.2	.2982	8.1	.3109	8.1	.3482	7.8	86.0
3	2 tons "	.1307	7.7	.3966	7.7	---	7.5	.5384	6.5	74.2
4	4 tons "	.3680	6.5	.4112	6.4	---	6.3	.5927	5.1	41.9
5	8 tons "	.4310	6.3	---	6.2	.5675	5.9	.6827	3.8	24.6
6	1 ton Inoculated	.1922	8.2	.3135	8.1	.3206	7.8	.3520	7.5	87.6
7	2 tons "	.2889	8.2	.4103	7.9	.3940	7.5	.6107	5.4	86.5
8	4 tons "	.4606	7.7	---	6.8	.4914	6.5	.6970	4.3	50.0
9	8 tons "	.5075	6.8	.4903	6.2	.7879	5.6	.7114	3.9	25.4
	Umatilla Medium Sand									
10	Check	.0000	7.9	.0039	7.9	.0084	7.9	.0181	7.9	0
11	1 ton B.G.S.	.0220	6.2	.0738	4.8	.1883	4.4	.2304	3.8	70.1
12	2 tons "	.0777	5.2	.1594	4.1	.2890	3.9	.3717	3.8	58.3
13	4 tons "	.1048	5.0	.1761	4.1	.2693	3.8	.5339	3.0	43.7
14	8 tons "	---	4.8	---	4.1	.4036	3.7	.4188	2.9	16.6
15	1 ton Inoculated	.0128	5.8	.0831	4.8	.1699	4.8	.2210	4.3	70.7
16	2 tons "	.0139	5.8	.0993	4.4	.1891	4.4	.3591	3.4	56.4
17	4 tons "	.0634	5.3	.1527	4.1	.3708	3.7	.4165	3.2	33.2
18	8 tons "	.0651	5.3	.1584	4.1	.3605	3.7	.4983	2.8	19.9
	Deschutes Sandy Loam									
19	Check	.0445	7.2	.0557	7.2	.0561	7.2	.0672	7.1	0
20	1 ton B.G.S.	.1402	6.1	.2307	5.5	.2386	5.4	.2861	5.3	72.8
21	2 tons "	.1948	5.2	.3460	4.8	.3429	4.8	.4124	4.7	57.4
22	4 tons "	.2326	5.2	.3168	4.8	.4315	4.4	.4907	3.7	34.9
23	8 tons "	.2468	5.2	.3570	4.5	.5758	4.2	.5200	2.8	18.6
24	1 ton Inoculated	.1471	5.8	.2419	5.4	.2651	5.3	.2957	5.4	76.1
25	2 tons "	.2478	5.0	.3284	4.9	.4052	4.5	.4063	4.4	56.5
26	4 tons "	.2803	5.0	.3936	4.8	.5371	4.2	.4415	3.7	31.1
27	8 tons "	.2824	5.1	.4018	4.8	.5894	4.1	.6978	3.1	26.0

Table 3. Microorganisms Per Gram Air-Dry Soil.

Jars	Treatments	Molds	Bacteria	pH
	Malheur Clay Loam			
1	Check	29,500	1,620,000	9.5
2	1 ton B.G.S.*	29,500	2,520,000	7.8
3	2 tons "	51,400	2.320,000	6.5
4	4 tons "	95,000	2,050,000	5.1
5	8 tons "	34,000	1,450,000	3.8
6	1 ton Inoc.	43,500	2,060,000	7.5
7	2 tons "	44,900	1,830,000	5.4
8	4 tons "	59,000	1,790,000	4.3
9	8 tons "	26,000	1,920,000	3.9
	Umatilla Medium Sand			
10	Check	27,400	2,870,000	7.9
11	1 ton B.G.S.	34,600	1,340,000	3.8
12	2 tons B.G.S.	29,000	383,000	3.8
13	4 tons B.G.S.	62,000	81,500	3.0
14	8 tons "	94,000	11,000	2.9
15	1 ton Inoc.	41,300	1,640,000	4.3
16	2 tons "	33,300	394,000	3.4
17	4 tons "	94,000	23,300	3.2
18	8 tons "	91,000	11,600	2.8
	Deschutes Sandy Loam			
19	Check	61,200	1,570,000	7.1
20	1 ton B.G.S.	137,000	2,250,000	5.3
21	2 tons "	124,000	1,870,000	4.7
22	4 tons "	62,800	651,000	3.7
23	8 tons "	251,000	77,000	2.8
24	1 ton Inoc.	187,000	1,850,000	5.4
25	2 tons "	128,000	1,540,000	4.4
26	4 tons "	52,500	59,000	3.7
27	8 tons "	55,000	10,000	3.1

*B.G.S. Black gas sulfur.

EFFECT OF ALKALI ON MICROFLORA OF SOIL

Soils containing black alkali salts have fewer bacteria than neutral soils, as shown in Table 3. The reproduction of microorganisms is retarded due to unfavorable alkali medium. Application of sulfur to alkaline soil has increased the molds and bacteria due to neutralizing the alkali.

Experiment No. 3

GREENHOUSE TRIALS

Deschutes Experiments

Table 4 and figure 1 represent the results of sulfur on the Yakima Sandy Loam. Three cuttings of hay were secured from these pots and all sulfur treatments increased yield. Leaves from the sulfured plants were greener and larger than from the non-treated. The rate of application of 150 pounds per acre as used in this experiment is a little larger than actual field applications for the soil.

Table 4 with rates, forms, and combinations of sulfur on Deschutes Sandy Loam shows some increases. Little difference is noted from rates of application as the 50-pound application appears to give about the same result as obtained with 100 pounds. Four different forms used all gave about the same increase, so it appears that one form of sulfur is as effective as another under the conditions of the experiment. Sulfur usually results in increased yield on this soil, yet little of it is needed. However, this small amount seems to be essential. The returns from use of sulfur were similar whether used alone or with manure or green manure.

Table 4. Greenhouse Trials Showing the Effect of Sulfate Fertilizers on Deschutes Sandy Loam.

	Treatments	Wt. in grams First Cutting	Wt. in grams Second Cutting	Total
1	Check	10.2	10.3	20.5
*2	B.G.S. 50 lbs. per acre	12.6	12.4	25.0
3	B.G.S. 75 lbs. per acre	12.7	11.8	24.5
4	B.G.S.100 lbs. per acre	12.4	10.8	23.2
5	Gypsum 75 lbs.sulfur per acre	14.5	12.5	27.0
6	Bac-sul 75 lbs. per acre	13.0	12.1	25.1
7	Gasco (43.3 per cent S) 75 lbs. per acre	12.1	12.4	24.5
8	Sulfur 75 lbs. per acre	12.8	13.3	26.1
9	B.G.S. 75 lbs. S + 10 T. manure per acre	10.2	11.3	21.5
10	B.G.S. 75 lbs. S + 5 T. green manure per acre	12.8	11.3	24.1
11	Gasco (43.3 per cent S) 75 lbs. S + 5 T. green man. per acre	13.4	11.7	25.1
12	Check	12.6	9.3	21.9

*B.G.S. Black gas sulfur.

Table 5. Greenhouse Trials Showing the Effect of Sulfate Fertilizer on Yakima Sandy Loam.

	Treatments	Wt. in grams			
		First Cutting	Second Cutting	Third Cutting	Total
1	Check	8.7	6.7	6.5	21.7
4	*B.G.S. 150 lbs. per A.	10.3	8.2	10.8	29.3
5	Bac-sul 150 " " "	11.1	7.5	11.1	29.6

*B.G.S. Black gas sulfur.

Experiment No. 4

TANK EXPERIMENTS ON ALKALI SOILS.

The tanks filled with alkali soil from Vale experiment field formerly used by Johnston (14) had been stored in the basement since the previously reported leaching tests. These tanks were placed outdoors at Corvallis fully exposed to winter rainfall first of March, 1927. Barley was planted in these tanks the middle of May. The seeds germinated in all these tanks and shoots grew to a length of two or three inches, at which time they turned yellow at the tips and finally died. The exceptions to the above are the tanks shown in figure 4. Increases in straw and grain of the sulfur treated tank over the gysum treated tank and check tank are shown in table 6. Initial reaction of this soil was pH 10.4.

Table 6. Barley Grown on Alkali Soil in Tanks.

Treatments	Yield in grams: Grain	Straw	pH
Check	0.0	0.0	9.1
Gypsum 10 T per acre	18.5	6.5	8.5
Sulfur 1000 lbs. per acre	31.0	12.5	7.8

These data indicate that sulfur applied at a rate of 1,000 pounds per acre has produced a fair crop of barley on alkali land, when it has been leached with copious amounts of water. The straw from the sulfur treated tank was taller than that grown with gypsum treated and the heads of grain were larger, as shown in figure 4; also sulfur appears to hasten crop maturity.

Hydrogen-ion concentration tests of the three tanks indicate that a pH of 8.5 or above makes it difficult to get barley to mature. It may germinate at a greater alkalinity, yet fail to grow for any length of time. The reaction value should be of the order of pH 8.5 or below if barley is to mature. This is verified by the field trials.

The alkalinity of the gypsum tank increased from pH 7.8 to pH 8.5 between the close of Johnston's work with the tank and the end of present investigation. It appears that the sulfate has reverted to carbonate as reported in the historical section of this paper.

Figure 1 showing difference in growth on sulfur treated and non-sulfur treated alfalfa. Treatment No. 1 check, No. 4, 150 lbs. per acre B.G.S.,* No. 5 Bac-sul 150 lbs. per acre.

Figure 2 showing difference in growth resulting from treating alfalfa with sulfur. Soil used, Deschutes Sandy Loam. Treatments No. 12 check, No. 2 50 lbs. B.G.S. per acre, No. 4 B.G.S. 100 lbs. per acre.

*B.G.S. Black gas sulfur.

Figure 3 alfalfa treated with black gas sulfur, sulfur, and Gasco by-product. Soil used, Deschutes Sandy Loam. Treatments No. 12 check, No. 14, B.G.S. 75 lbs. per acre, No. 8, sulfur 75 lbs. per acre, No. 11, Gasco by-product 37 lbs. per acre.

Figure 4, Leached black alkali land reclaimed with sulfur and gypsum.

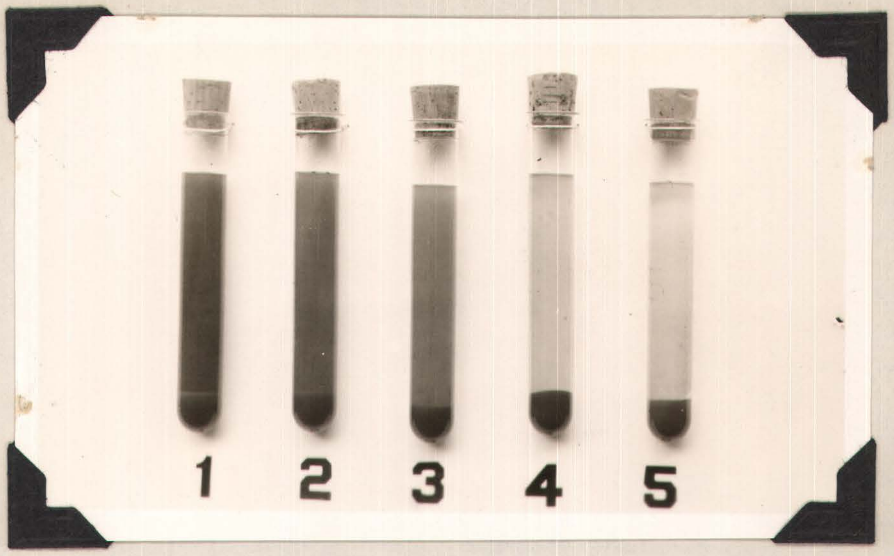

Figure 5, Flocculation of alkali soil with sulfur. Treatments No. 1 check, No. 2 one ton, No. 3 two tons, No. 4 four tons, No. 5 eight tons. After 16 weeks incubation.

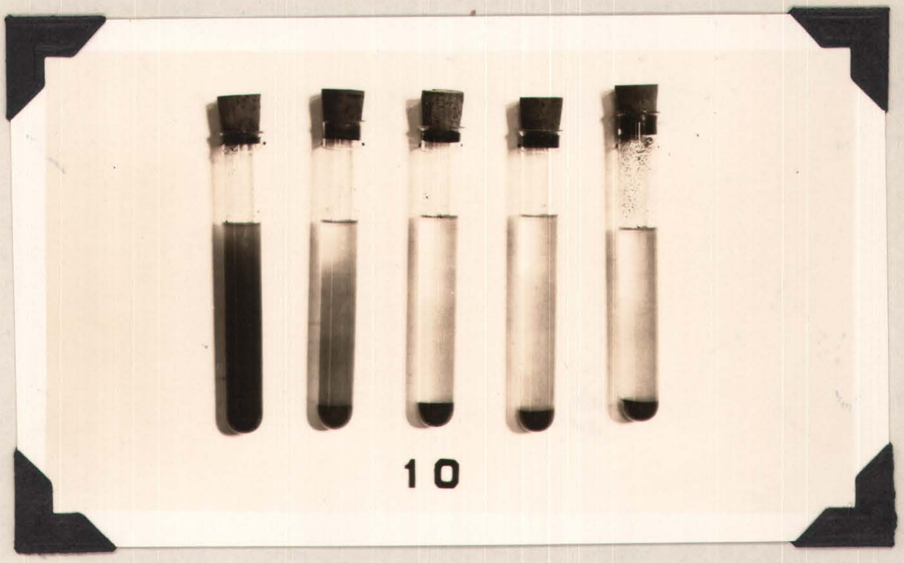

Figure 6, Flocculation of slightly alkaline soil with sulfur. Treatments No. 1 on left a check, No. 2 one ton, No. 3 two tons, No. 4 four tons, No. 5 eight tons. After 16 weeks incubation.

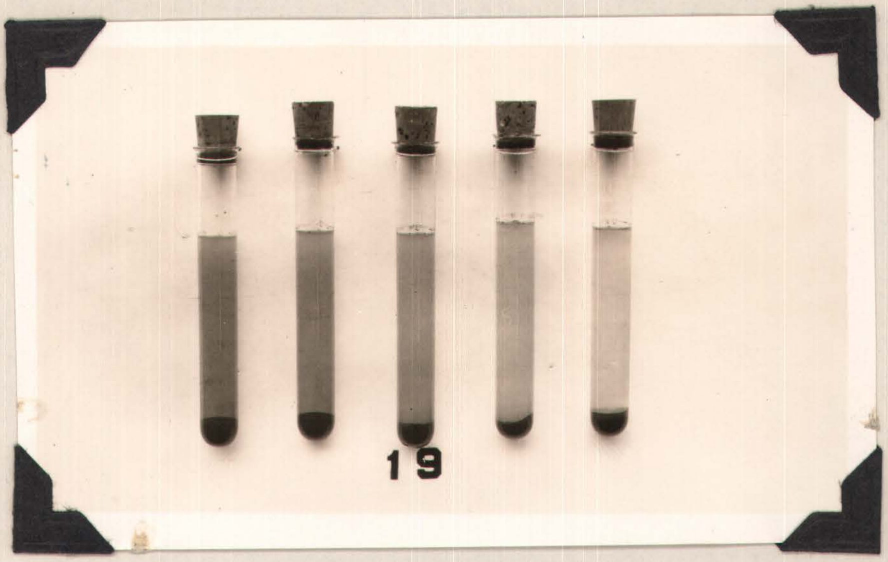

Figure 7, Flocculation of neutral soil with inoculated sulfur. Treatments No. 1, on left check, No. 2 one ton, No. 3 two tons, No. 4 four tons, No. 5 eight tons. After 16 weeks incubation.

Experiment No. 5

STUDIES WITH SULFUR FOR IMPROVING ALKALI SOILS

The reclamation of black alkali soil is a difficult task due to the "freezing up" after a short period of leaching. According to Breazeale and Burgess (2), this is due to the hydrolysis of the sodium clay complex, sodium carbonate and the hydrated sodium aluminum silicate. All of these compounds will hydrolyze to form sodium hydroxide, which brings about soil disperson. Probably the cation and anion are both concerned in the dispersion, but the cation is believed to be most responsible. As long as there are free sodium ions in solution, the soil will remain dispersed. This means that some chemical should be added to the soil that will neutralize the sodium hydroxide before leaching is continued.

A percolation experiment was set up for the purpose of determining the amount of salts that could be leached from the soil, and to study decrease in hydrogen-ion concentration and increase in permeability that might occur with exchange of sodium for calcium on the ultra clay complex.

Percolation Experiment

Nineteen jars with different forms, rates, and combinations of sulfur with other materials were used for this experiment. As indicated in table 8, the first twelve jars were of Malheur Clay Loam used by Young (20). The last seven jars were the same type of soil, but having less alkali than the former.

Percolation experiments were made in three trials. The first trial was for 252 hours, the second for 396 hours, and the third for 540 hours. Water was measured from each jar at regular intervals. At each period the total number of c.c. of percolate were measured from each jar, also at the end of each period the total number of c.c. leached were aggregated, with the total amount of salts removed. At the close of each trial hydrogen-ion determinations were made so that the decrease in pH could be recorded.

Final results show that leaching Jar 5 treated with sulfur at the rate of 2000 lbs. removed a large amount of salts and the alkalinity decreased from pH 10.2 to ph 8.8.

Jar 15 treated with 4000 lbs. of sulfur an acre allowed a rapid percolation compared to check Jar 19. Averaged rate of percolate per hour for the three trials from Jar 15 was 12.7 c.c., and check Jar 19 was 3.7 c.c. The pH decreased on Jar 15 from 9.5 to 8.3, while in check Jar 19 the pH fell only from 9.5 to 9.

From the data for check Jar 1 it appears that leaching with alternate drying removed appreciable quantities of salts, with some lowering of the pH value. Alternate drying and leaching appears to have some advantage in the reclamation of alkali land.

Manure, green manure, gypsum, and lime all decreased the hydrogen-ion concentration to some extent, but the most effective decrease resulted from sulfur.

Jars 14, 15, and 16 treated with applications of 3000, 4000, and 3000 pounds of sulfur an acre have been reclaimed to the extent that some crops could be grown.

Jar 3 containing lime and manure has a tendency to stay open well, but the total salts are not so rapidly removed when compared to the sulfur treated jars.

Jars No. 14 and 16 with 3000 lbs. of sulfur appear to remove the most salts and at the same time remain open fairly well. The heavier application of sulfur on Jar 15 gives a more rapid percolation, but the total salts removed in quantity is a little less than from Jars 14 and 16.

Table 7. Exchangeable Bases as Affected by Treatments and Leaching.

Malheur Clay Loam

Jar	Treatment, Series 1			pH
1	Check	(Replaceable Ca	0.1080	9.2
		(Replaceable Na	0.3588	
7	10 tons gypsum plus 2000lbs. B.G.S.*	(Replaceable Ca	0.1620	9.1
		(Replaceable Na	0.2737	
9	1200 pounds sulfur	(Replaceable Ca	0.1260	9.1
		(Replaceable Na	0.3160	
	Treatment, Series 2			
14	Sulfur B.G.S.* 3000 pounds	(Replaceable Ca	0.2790	8.5
		(Replaceable Na	0.1506	
15	Sulfur B.G.S.* 4000 pounds	(Replaceable Ca	0.2960	8.3
		(Replaceable Na	0.1006	
19	Check	(Replaceable Ca	0.1800	9.0
		(Replaceable Na	0.2530	

*B.G.S. Black gas sulfur.

EXCHANGEABLE GASES AS AFFECTED BY TREATMENT AND LEACHING

An exchange of sodium for calcium on the ultra clay complex is found to take place with approach to neutrality caused by different treatments. Table 7 shows the replacement of sodium ion by the calcium ion on the ultra clay complex caused by the use of sulfur and leaching. It appears that between pH 9.0 and 8.3 the calcium becomes reactive and rapidly displaces the sodium. This soil at a pH above 8.5 tends to have a high concentration of sodium on the complex.

The ratio of sodium to calcium on the complex changes with the salt concentration of the soil solution. Some sodium will be removed from the complex when the concentration of salts in the soil solution is reduced. It is not necessary to neutralize the soil solution before exchangeable sodium will be replaced by calcium. A change in calcium concentration in the soil may cause a base exchange on the clay complex.

Table 8. Rate of Percolation as Affected by Different Soil Treatments.

Series No. 1 Treatments.

Jar		pH	First 36-hr. period	Last 36-hr. period
1	Check	10.8	525	1040
2	20 T. manure	10.5	500	880
3	6 T. lime, 20 T. manure	10.3	1130	1740
4	6 T. lime	10.2	770	1430
5	2000 lbs. sulfur	10.2	660	1090
6	1200 lbs. sulfur	10.5	1350	1700
7	10 T. gypsum, 2000 B.G.S.	9.8	505	720
8	1200 lbs. gypsum	10.5	710	1050
9	1200 lbs. sulfur, 20 T. manure	10.5	580	1110
10	20 T. green manure	9.8	860	1270
11	4000 lbs. alum	10.2	570	940
12	Saturated solution gypsum	10.7	550	910

Series No. 2 Treatments.

13	2000 lbs. black gas sul.	9.5	785	840
14	3000 lbs. " " "	9.5	1655	1340
15	4000 lbs. " " "	9.5	2585	1930
16	3000 lbs. sulfur	9.5	1020	980
17	Bac-sul sulfur 3000 lbs.	9.5	870	830

Table 8 (Continued)

Jar		pH	First 36-hr.period	Last 36-hr.period
18	Gasco 3000 lbs.	9.5	860	770
19	Check	9.5	405	360

3	4	5	6	7	Total c.c. percolate	Total salts removed gms.	Final
1060	1110	1060	640	440	5875	24.6705	9.9
920	960	880	620	440	5200	54.4740	10.2
1700	1630	680	930	570	9380	21.4912	9.8
1410	1400	1350	700	430	7490	19.1369	9.8
920	900	860	580	350	5260	17.6683	9.9
1630	1680	1560	780	460	9160	22.9091	10.0
690	670	610	460	330	3985	21.6945	9.3
1050	1050	950	580	350	5750	20.9932	10.0
1150	1190	1080	630	480	6220	12.8878	10.0
1240	1200	1060	700	460	6790	26.6914	9.8
880	860	810	660	440	5160	10.7265	10.2
850	850	780	620	420	4980	14.5515	9.8
640	490	375	320	180	3630	19.2317	9.1
880	700	530	440	370	5915	36.8855	9.0
1350	1150	940	830	700	9485	14.3277	9.1
660	530	390	300	250	4130	24.3041	9.1
650	510	380	300	270	3810	24.7965	9.1
570	470	370	200	260	3600	17.0172	9.1
290	260	220	175	160	1870	4.0354	9.1

Amount Percolate by 36-hour Periods in c.c., Second Trial

Jar	Initial pH	1	2	3	4	5	6	7	8	9
1	9.9	330	220	250	220	250	290	200	240	200
2	10.2	350	250	240	220	220	240	160	190	170
3	9.8	450	390	380	300	380	410	270	320	290
4	9.8	480	350	340	280	370	400	270	320	280
5	10.0	580	400	390	300	370	400	250	290	260
6	10.0	590	450	460	370	450	500	330	400	340
7	9.3	510	360	350	280	340	360	240	280	250
8	10.0	340	240	220	180	220	240	160	190	170
9	10.0	640	430	420	330	400	430	280	330	290
10	9.8	390	320	300	250	300	320	220	250	240
11	10.2	440	290	280	240	290	300	210	250	220
12	9.8	570	400	400	330	400	430	290	350	300
13	9.4	220	180	170	150	170	170	120	150	120
14	9.0	480	300	250	200	230	240	160	180	170
15	9.1	420	260	220	170	210	210	150	150	140
16	9.1	320	200	140	130	140	160	120	120	120
17	9.1	320	200	160	130	150	160	110	130	130
18	9.1	260	180	160	140	150	140	100	120	100
19	9.1	270	170	150	100	140	150	100	120	100

10	11	Total c.c. percolate	Total salts removed	pH at final
220	180	3813	10.3332	9.5
170	140	2420	3.7916	9.6
300	230	3720	8.6676	9.5
300	220	3610	9.1044	9.5
270	220	3730	12.9251	9.2
360	290	4540	10.7779	9.4
260	210	3440	13.1408	9.3
160	140	2260	6.0322	9.5
300	240	4090	9.5051	9.4
230	190	3010	12.1303	9.2
220	190	2930	7.0320	9.5
220	190	3900	9.3444	9.5
120	110	1680	11.8507	8.8
160	140	2510	12.4295	8.8
100	100	2130	17.1166	8.7
100	100	1640	13.3135	8.9
110	100	1700	13.1546	8.8
80	70	1500	6.7553	8.9
100	70	1470	4.1113	9.0

Amount of Percolate by 36-hour Periods c.c., Third Trial.

Jar	Initial pH	1	2	3	4	5	6	7	8
1	9.5	370	380	320	310	300	280	250	240
2	9.6	220	330	260	230	220	220	170	160
3	9.5	570	350	290	270	250	240	200	210
4	9.5	250	280	250	210	200	200	210	200
5	9.2	500	410	310	300	280	280	240	250
6	9.4	370	340	300	280	270	270	240	230
7	9.3	490	350	280	260	250	230	200	190
8	9.5	200	240	200	180	160	150	140	120
9	9.4	220	250	200	170	150	140	140	120
10	9.2	230	350	290	260	230	210	180	160
11	9.5	250	310	260	260	250	220	200	210
12	9.5	280	300	260	260	250	200	180	190
13	8.8	0	180	170	160	150	150	130	120
14	8.8	620	290	250	240	220	190	190	200
15	8.7	530	430	270	250	220	210	190	190
16	8.9	320	270	210	240	230	200	170	160
17	8.8	250	280	180	220	200	190	150	140
18	8.9	0	0	70	130	140	130	120	110
19	9.0	0	0	0	80	90	120	110	100

9	10	11	12	13	14	15
250	220	200	200	200	190	190
170	140	130	120	120	120	120
210	170	180	170	170	160	160
200	170	170	160	160	170	160
250	220	230	200	200	200	210
240	230	220	190	190	200	200
210	160	150	150	150	160	160
130	120	110	100	110	100	100
130	110	120	100	100	110	110
210	150	160	140	150	160	160
200	180	170	160	160	170	160
190	160	160	150	160	150	160
140	120	120	110	110	100	110
200	180	170	140	150	160	160
200	230	220	200	210	200	210
180	140	150	140	140	150	140
150	130	140	130	130	130	140
130	100	100	100	100	100	100
90	100	100	90	90	100	100

Jar	Total c.c. percolate	Total salts removed	pH at Final
1	3900	11.2632	9.2
2	2730	7.0980	9.0
3	7148	15.4396	9.1
4	2990	10.4035	9.4
5	4080	30.0288	8.8
6	3770	13.0096	9.0
7	7160	17.2412	9.1
8	2160	5.7024	9.1
9	2170	7.7252	9.1
10	3180	15.1140	9.0
11	3160	10.0551	9.1
12	3050	9.2476	9.2
13	1870	6.6507	8.7
14	3360	13.4748	8.5
15	3760	21.5824	8.3
16	2840	22.6632	8.4
17	2560	19.2204	8.6
18	1440	8.7696	8.8
19	1180	4.4934	9.0

Table 1 (Cont'd.) Showing Total Loss and Reaction Change for a Period of 1188 Hours.

Jar	Total c.c. Water	Total salts: grams	pH at Start	pH at Close
1	13,588	46.2669	10.8	9.2
2	10,330	55.3636	10.5	9.0
3	20,248	45.5984	10.5	9.1
4	13,590	38.6448	10.2	9.4
5	13,070	60.6222	10.2	8.8
6	17,470	46.6966	10.5	9.0
7	14,585	52.0763	9.8	9.1
8	10,170	32.7278	10.5	9.1
9	12,480	30.1181	10.5	9.1
10	12,980	53.9357	9.8	9.0
11	11,250	27.8136	10.2	9.1
12	11,930	33.1435	10.7	9.2
13	7,180	37.7331	9.5	8.7
14	11,785	62.7898	9.5	8.5
15	15,375	53.0267	9.5	8.3
16	8,610	60.2808	9.5	8.4
17	8,070	57.1715	9.5	8.6
18	6,540	32.5421	9.5	8.8
19	4,520	12.6401	9.5	9.0

FIELD TRIALS WITH SULFUR AND OTHER FERTILIZERS ON CERTAIN CROPS

Alfalfa field trials for these sulfur investigations have been centered at Redmond and Vale, Oregon.

Experiments with normal soil were conducted at Redmond, Oregon, the purpose being to determine the economic amount and form of sulfur to be applied per acre to Deschutes valley soils. Sulfur was applied at the rates of 50, 75, and 100 pounds per acre on two different farms; also, several different forms of sulfur were applied at the rate of 75 pounds per acre, on new seeding of alfalfa. Next year definite results should be secured from these two trials.

Sulfur applications, however, produced some increases in weight of crop, and these increases were visible during the growing season. Superphosphate, which contains sulfur, also increased growth.

Potato fertilizer trials indicate supplying nitrogen in some form to be necessary, as vine growth was increased noticeably during the growing season thereby. When the potatoes were harvested the tubers fertilized with ammonium sulfate were larger than the ones unfertilized. Sulfates improve the color of potato foliage. Increased yields resulted from the complete fertilizers in all the trials.

ALKALI LAND RECLAMATION TRIALS

Alkali reclamation work at Vale has been in progress since 1921. Crops on the old plats of this field have been planted for several years, but the problem of reclaiming this land from an economic point of view has not been fully solved. It appears to have taken about 3000 pounds of sulfur an acre to reclaim this soil. It is at least doubtful if prevailing land values there will justify this expense.

A new series of plats were started in April, 1927, treated with newer forms and most promising combinations of sulfur to find some means of reclaiming this land with less expense than was involved on the older plats. Alkali "greasewood land" was cleared and fitted in one-tenth acre strip border plats. Treatments were applied at the rates and forms shown, table 9.

Fertilizers were harrowed in and the soil maintained as moist fallow until August, then copious irrigations were applied to leach out the excess salts until late September, when the whole range of plats was seeded to rye, with alfalfa and sweet clover. The stand secured is indicated in the table No. 9 as observed 4 weeks after seeding.

The initial hydrogen-ion concentration of alkali land as determined from composite soil samples was pH 10.4. As reclamation progresses, chemical determinations are being made periodically to note the progress of neutralization of excess salts.

Table 9. Forms of Sulfur Used in Reclamation of Alkali Land. Vale, Oregon.

Plats		Per Cent Stand
11	Iron sulfate 1672 lbs. 1 T. manure	25
12	Ammonium sulfate 300 lbs. 1 T. manure	2
13	Manure 1 T.	0
14	Gypsum 700 lbs. 1 T. manure	25
15	Sulfur 300 lbs. 1 T. manure	10
16	Check	10
17	Sulfur 300 lbs. 1 T. manure	25
18	Sulfur 300 lbs., gypsum 500 lbs., 1 T. manure	40
19	300 lbs. sulfur	10
20	300 lbs. black gas sulfur	8
21	300 " Bac-sul	5
22	700 " Gasco	0
23	Sand sulfur 300 lbs. 1 T. manure	1
24	Sublimed sulfur 300 lbs. 1 T. manure	1
25	Tailings 300 lbs. 1 T. manure	1
26	Check	0

Check No. 26 had manure piled and stored on one corner for several years.

CONCLUSIONS

1. The new forms of sulfur were studied and found to include rapid oxidizing materials that should supply sulfate-ion needed for the early period of plant growth.
2. Black gas sulfur compared with inoculated sulfur oxidizes at approximately the same rate except on alkali soil. During the first eight weeks the inoculated material yielded sulfates more rapidly than black gas sulfur, after which time the two were found to yield about the same quality of sulfates.
3. Plants grown in pots that had sulfur in applications of 50, 75, 100 lbs. per acre, in combination with manure, all showed increases over the untreated pots. Little differences appeared between the 50, 75, and 100 lb. applications. The 50 lb. application on Deschutes Sandy Loam gave just as good returns as 100 lb. application when used in greenhouse trials.
4. Sulfur produces a decided flocculating effect on alkali soils. Soils treated with 4000 lbs. of sulfur are flocculated rapidly, while non-treated soils remain deflocculated. Flocculation starts as

neutrality is approached.

5. For reclamation of alkali soil sulfur is superior to any other single chemical, due to its neutralizing and bringing calcium-ion into solution, resulting in displacing sodium on ultra clay complex with calcium.

6. The percolate from untreated alkali soil decreases as the time of leaching increases; deflocculation increases as leaching proceeds.

7. Laboratory studies combined with field trials indicate that the newer forms of sulfur tested have a promising future. Due to the colloidal form of the black gas product its use for control of disease and reclamation of alkali land offers some advantages over other available forms of sulfur of similar purity.

8. Under alkaline conditions sulfur appears to have increased the microflora of the soil, probably because of neutralizing alkali present, which produces a favorable flora for soil organisms.

9. Sulfur treatment of soils subjected to leaching causes calcium to become reactive and to displace the sodium on the ultra clay complex. For the soil employed a pH above 8.5 has a high concentration of sodium on the complex. Base exchange is a contin-

uous process and is affected by the concentration of salts in the soil solution.

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