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Sulfur as a Fertilizer for Alfalfa in Southern Oregon

By

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SULFUR AS A FERTILIZER FOR ALFALFA IN SOUTHERN OREGON*

It has been known for many years that sulfur is one of the elements absolutely necessary for plant growth. Chemists have found, by carefully conducted experiments, that no plant can be grown to maturity without this element and that it is present in the ash of all plants. The amount found in the ash of most plants, however, is comparatively small and in many cases extremely small. This amount, in fact, is usually so little when compared with even the limited amount present in the soil, and the sulfur brought down in rains, that it was formerly considered unnecessary to supply additional amounts in the form of fertilizers.

During recent years chemists have found that the ash contains only a part of the sulfur originally in the plant, and that a large portion is lost when the plant is burned. As early as 1902 Fraps (1), of the North Carolina Experiment Station, found that oats, cowpeas, corn, and peanuts contained far more sulfur than could be recovered in the ash of these plants. More recently Hart and Peterson (2) of Wisconsin, Shedd (3) of Kentucky, Ames and Boltz (4) of Ohio, and others have made many sulfur determinations and in all cases have found considerably more sulfur in the plant than in its ash. These analyses show that the legumes, such as alfalfa, clover, and beans, and the members of the cabbage family, cabbage, kale, and turnips, are particularly rich in sulfur.

For many years gypsum has been used as a fertilizer for clover, and in many soils it produced marked increases in yield, at least for a number of years. It often has been noted, however, that after using gypsum for many years further applications of this material produced no increases in yield. Since the effect of the gypsum appeared to be temporary, and as it contained no nitrogen, phosphorus, or potassium, it was regarded by many as simply a plant or soil stimulant, and not a plant food or fertilizer. For this reason it was often condemned, and in many regions its use was discontinued. That the earlier conclusions regarding its effect upon the plants and soil were wrong has been proved by recent experimental work.

During recent years fertilizer experiments with sulfur have been conducted in various parts of the United States. In some instances large increases in yield have been obtained, while in others no effect on the crop was observed. It should be expected that sulfur will not produce increases in yield on all soils as this would be true of any fertilizer. That sulfur is often the limiting factor in crop production in Southern Oregon is shown by the results obtained during the last seven years from the experiments conducted by the Southern Oregon Branch Experiment Station.

PRELIMINARY EXPERIMENTAL WORK

The earlier fertilizer work with alfalfa in Southern Oregon was conducted on various farms in cooperation with farmers. Owing to the location of these fields, and to the many duties incident to the starting

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*The work herein reported was inaugurated and the field experiments supervised by the senior author. The chemical phases of the work were under the direction of Mr. H. V. Tartar. Mr. A. C. McCormick of the Southern Oregon Branch Station rendered very valuable assistance in conducting the field experiments. Messrs. R. H. Robinson, H. G. Miller, and R. F. Beard assisted in making the chemical analyses.

The reference figures refer to bibliography given at the end of this bulletin.

of the work at the new Experiment Station it unfortunately was impossible to supervise the harvesting of the crops of those cooperative experiments. In several cases, therefore, no weights of yields were obtained; and in such cases the yields were simply estimated and comparative notes made. These earlier experiments were thus of a temporary nature and not very satisfactory.

The results of these simple experiments, however, were so striking and so consistent that they indicated the importance of sulfur as a fertilizer, emphasized the need of further experimental work, and gave rise to the later extensive experiments.

First Experiment

In the spring of 1912 a fertilizer experiment was started on R. W. Elden's ranch near Tolo, Oregon. The soil there has been designated by the Bureau of Soils as Medford Fine Sandy Loam. It is a deep soil, principally of granitic origin, and has the following composition:*

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
	%	%	%	%	%	%	%
Surface	1.62	.107	2.33	1.25	.052	.032	3.48
Subsoil	1.43	.026	1.83	1.03	.062	.016	2.56

The analysis shows that this soil contains an abundance of potassium, calcium, and magnesium. It is poor in phosphorus, and the subsoil is very low in nitrogen and sulfur.

At the beginning of the experiment the field had been in alfalfa for several years, contained a good stand, the roots were well supplied with nodules, and it was producing moderate yields. The field was not irrigated either before or during the experiment.

TABLE I. FERTILIZER USED AND YIELDS, MEDFORD FINE SANDY LOAM
Plots one-tenth acre in size. Fertilizer applied April 11, 1912

Plot	Application		Yield first cutting
		lbs.	lbs.
1	Dried blood	50	370
2	Superphosphate	50	490
3	Muriate of potash	25	330
4	Dried blood	50	470
	Superphosphate	50	
5	Dried blood	50	390
	Muriate of potash	25	
6	Superphosphate	100	418
	Muriate of potash	25	
7	Dried blood	25	452
	Superphosphate	50	
	Muriate of potash	25	
8	Gypsum	40	414
9	Checks		352

There were seven check plots, and these alternated with the fertilized plots. The weights of hay from the fertilized plots do not represent the effect of the fertilizers on the alfalfa as effectively as did the appearance of the plots. While all the plots which received superphosphate and gypsum yielded more than any of the others the difference in the appearance of the plots was far more remarkable. The superphosphate and the gypsum plots produced a much denser stand of alfalfa, which was conspicuously darker green in color, and contained a smaller percentage of weeds. The other fertilized plots did not differ in appearance from the check plots, the alfalfa possessing a pale green color, and

*All the soil analyses given in this bulletin have been taken from the bulletin, The Soils of Jackson County, by Tartar and Reimer (Ore. Exp. Sta. Bul. No. 164).

containing a very high percentage of needle grass (Bromus). The dried blood had no effect on the alfalfa but improved the growth of the needle grass, and this is responsible for the increased yield of this plot over the check plots and the potash plot. It is interesting to note that the plot which received potash produced less than the check plots.

The lesson learned from this experiment was that superphosphate and gypsum increased the yields, and had a favorable effect on the color of the plant. The field was ploughed and planted to wheat in the fall of 1912, hence the experiment was discontinued at that time.

Second Experiment

The increases in yield obtained from superphosphate during 1912 were attributed, **at that time,** to the phosphorus. Therefore tests were made in 1913 to determine whether the cheaper "ground rock phosphate" would give similar results. These tests were made near Talent, Oregon, one on J. H. Fuller's ranch, on Tolo Loam Soil, and one on Graves and McPhail's ranch on Agate Gravelly Loam Soil. The land in both cases had been in alfalfa for many years, hence contained a good supply of humus. The experiment included three plots on each ranch, each plot one-tenth acre in size. One plot received 30 pounds of superphosphate,

Fig. 1. Comparative yields of alfalfa from plots of equal size. Beginning on the left 1. Hay from unfertilized plot. 2. From plot fertilized with gypsum. 3. From plot fertilized with monocalcic phosphate. 4. From plot fertilized with superphosphate.

one 30 pounds of rock phosphate, and one was an untreated check plot.

The rock phosphate had no effect whatever on the yield or on the color of the plants. The superphosphate on both soil types produced an increase in yield of fully 100 percent over the check and rock phosphate plots. The stand of alfalfa on the superphosphate plots was much thicker and freer from weeds, and the plants possessed a much darker green color than on the other plots.

These plots received no further applications, but in 1914 the effect of the superphosphate was just as apparent as during the first year of the experiment. It was thought that possibly the rock phosphate would be more available and therefore more effective the second year after applying it, but the plots which received this material showed no improvement during 1914.

On an adjacent ranch, consisting of Tolo Loam soil, the owner in 1913 fertilized a portion of his field with gypsum and it produced an enormous increase in yield over the unfertilized portion.

The fact that the rock phosphate, which contained 13 percent phosphorus, had no effect whatever on the alfalfa, and that gypsum which contained no phosphorus produced similar effects to superphosphate, indicated that the increase in the yield and the rich green color produced by the superphosphate probably were not due to the phosphorus which it supplied. That gypsum and superphosphates should produce similar results was quite surprising. Both gypsum and superphosphate contain calcium and sulfur. That the calcium was not responsible for the increased yields was certain, as these soils contain an abundance of this element, and applications of lime had never increased the yield on these soils. The results indicated that possibly the increased yields produced by the superphosphate and the gypsum were due to the sulfur which they contain.

This possibility was strengthened by observations often made on the effect of lime-sulfur sprays on the leguminous cover crops in this valley. Many instances have been noted where alfalfa, red clover, vetch, and Canada field peas growing in orchards sprayed with lime sulfur made a far better growth and possessed a darker color under the trees and wherever the spray had drifted than between the rows.

EXPERIMENT WITH SULFUR

In the spring of 1914 an experiment was started to determine whether or not the sulfur in the gypsum and the superphosphate was responsible for the increased yield. (5) This experiment was also conducted on the Tolo Loam on J. H. Fuller's ranch. The alfalfa at that time was fourteen years old. Originally this field had produced excellent crops, but for three or four years previous to the beginning of the experiment the yields were unsatisfactory.

TABLE II. SHOWING FERTILIZERS APPLIED ON TOLO LOAM

Plots 2x13 rods. Applied March 2, 1914.

Plot	Application	lbs.
1	Superphosphate	50
2	Check	
3	Flowers of sulphur	50
4	Check	
5	Rock phosphate	50
6	Check	
7	Iron sulphate	50

The superphosphate, flowers of sulfur, and iron sulfate gave identical results. Each of these plots produced fully twice as much as the check plots; the stand was thicker, much freer from weeds, and the plants were larger and possessed a much darker green color. The rock phosphate had no effect whatever either on the yield or on the color, and no difference of any kind could be noted between this plot and the check plots. These plots produced a fair yield, contained a large amount of needle grass, and the alfalfa had a yellowish green color, indicating a starved condition.

None of the plots received further applications but the effect of the fertilizers applied in 1914 was very evident even during 1915.

The results of this experiment showed very plainly that it was the sulfur and not the phosphorus in the superphosphate that produced the increased yields and the richer color of the alfalfa. It is assumed, of course, that the sulfur in the flowers of sulfur changed to a sulfate before it was utilized by the plants.

VALUE AND EFFECT OF SULFUR FERTILIZERS

In the springs of 1915 and 1916 some new and permanent experiments were started to determine the following points:

1. The value of sulfur fertilizers on various types of soil.
2. The value of the various sulfates as fertilizers for alfalfa.
3. Do the sulfate fertilizers benefit the alfalfa plant directly as a plant food, or indirectly by the liberation of other plant foods already in the soil, such as potassium, phosphorus, calcium, or by increasing the available nitrogen supply?

These experiments were conducted on various soil types and in various localities in the Rogue River Valley.

Experiment on Antelope Clay Adobe Soil

The experiment on the Antelope Clay Adobe soil was conducted on Mrs. K. Bernst's ranch, about six miles northeast of Medford, Oregon. Since very extensive experiments were conducted on this soil, and valuable results obtained, a complete description of this soil will be given.

The soil is a very heavy, black adobe soil of a very sticky nature. It is deep and well drained. The following table gives the physical composition:

Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
%	%	%	%	%	%	%
1.5	6.1	5.5	10.3	5.8	31.6	39.1

As is indicated by the very high percentage of clay and silt this soil has a high water-holding capacity and retains moisture remarkably well. However, owing to the long dry season, it becomes dry and hard and checks badly during the latter part of the summer. This field has never been irrigated. An analysis of this soil showed the following chemical composition, expressed in percentages:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Limestone	Organic Matter
Surface	1.32	.117	2.32	1.15	.064	.020	0.11	7.35
Subsoil	0.62	.074	2.68	.72	.066	.017	1.29	6.25

It is evident that this soil is well supplied with potassium, calcium, magnesium, organic matter, and limestone. It is low in phosphorus and very low in sulfur. It shows no indications of acidity or alkalinity.

The alfalfa was planted in this field in the spring of 1913, and the first season was ideal for young alfalfa, as the rainfall during the spring months was normal and during June and July was far above normal. Thus a fine uniform stand was obtained.

Unfortunately it is impossible to determine whether the alfalfa seed planted in this field was inoculated, as the man who planted it died before the fertilizer experiment was started. Most of the soils of this valley are naturally so well supplied with the alfalfa nodule bacteria that inoculation of the seed is not necessary. All of the alfalfa roots examined in this field have some nodules, but they are not numerous.

The alfalfa made a fair growth the first season, but an unsatisfactory growth during 1914. During the two seasons the plants did not possess the deep green color characteristic under favorable conditions. During 1914 especially the plants possessed a pale yellowish color which indicated at once that something was lacking. When the fertilizer experiment was started in the spring of 1915 there was still a thick and uniform stand over the entire field.

The following table shows the plan and the results of the first experiment started in this field.

TABLE III. FERTILIZER APPLIED AND YIELDS, ANTELOPE CLAY ADOBE SOIL

Plots 2x8 rods. Fertilizer applied March 9, 1915, and the same application repeated March 30, 1917.

Plot	Application	lbs.	Fertilizing constituents	lbs.	Yield in pounds 1915	1916	1917	1918	Total
1	Check				299	96	76	38	509
2	Gypsum	59.5	Sulfur	10.0	1088	984	608	214	2894
3	Monocalcic phosphate	41.0	Phosphorus	9.6	318	142	94	52	606
4	Superphosphate	82.3	Phosphorus	7.4	1092	964	600	216	2872
			Sulfur	10.0					
5	Check				216	67	66	70	419
6	Sulfur	10	Sulfur	10	528	1054	740	230	2552
7	Sulfur	30	Sulfur	30	1002	1076	756	206	3040
8	Iron sulfate	84	Sulfur	10	1122	1156	896	272	3446

The low yields during 1917 are due to the dry season. The very low yields during 1918 are due to the cold spring and the exceptionally dry season.

In this experiment an equivalent amount of sulfur was applied to plots 2, 4, 6, and 8, or at the rate of 100 pounds an acre in each case. Plot 7 received three times as much sulfur as the other plots. Plot 3 received no sulfur but 2.2 pounds more phosphorus than plot 4.

In this experiment the plots which received the various sulfur fertilizers produced enormous increases in yield, amounting to more than 1000 percent in some of the plots during some seasons. While there is considerable variation in the yields of the various plots which received the same amount of sulfur, in general the results agree. These weights do not express the total difference in yields of actual alfalfa produced by the fertilized and unfertilized plots. The hay from the fertilized plots contained practically no weeds, while that from the check plots and from the monocalcic phosphate plot always contained a high percentage of weeds in the first cutting. For example, in 1915, samples were taken from the various plots in the first cutting and the weeds separated by hand from the alfalfa. By actual weight the hay from the check plots and the monocalcic phosphate plot contained 61 percent of weeds, while the plots fertilized with sulfur were almost entirely free from weeds.

It will be noted that the plot which received 10 pounds of flowers of sulfur produced only about one half as much alfalfa the first season as the plots which received the sulfur in a more available form. This is due to the fact that the sulfur in the flowers of sulfur must change to a sulfate before the plant can use it. This requires considerable time, and a large percentage of the sulfur did not change to a sulfate the first season, and hence was not available to the plant. It will be noted that the plot which received thirty pounds of flowers of sulfur produced practically twice as much the first year as the plot which received only ten pounds; and that this plot also produced nearly as much alfalfa as the plots which received sulfur in the more readily available forms of gypsum and superphosphate. Judging from these results it appears as though less than one-third of the sulfur in the flowers of sulfur became available the first season, and that this amount on this soil was not sufficient for maximum production where the flowers of sulfur was applied at the rate of 100 pounds an acre. It will be noted that after the first season the plot which received only ten pounds of flowers of sulfur in 1915 produced a greater yield than either the gypsum plot or the superphosphate plot, and only slightly less than the plot which received 30 pounds of flowers of sulfur.

It is interesting to note that the iron-sulfate plot has produced the highest yields during each of the four seasons. This is probably due to the fact that the iron sulfate is more soluble than any of the other materials applied. This would certainly affect the results the first season, and possibly also the following season. We cannot attribute any value to the iron in the iron sulfate as this soil contains enormous quantities of this element.

The gypsum has produced just as good results as the superphosphate on this soil when applied in amounts supplying equal quantities of sulfur. This would indicate that up to the present time this soil has not been in need of phosphorus for alfalfa where sufficient quantities of sulfur have been applied. How long this will continue to be the case can be determined only by continuing the experiment. It is certain, judging from the analysis of this soil, that the phosphorus content is not high and that it is slowly but constantly being removed by the alfalfa, and that eventually applications of phosphorus as well as sulphur will have to be made to this soil.

It is important to note that where monocalcic phosphate was added to the soil without any sulfur an increase in yield over the check plots

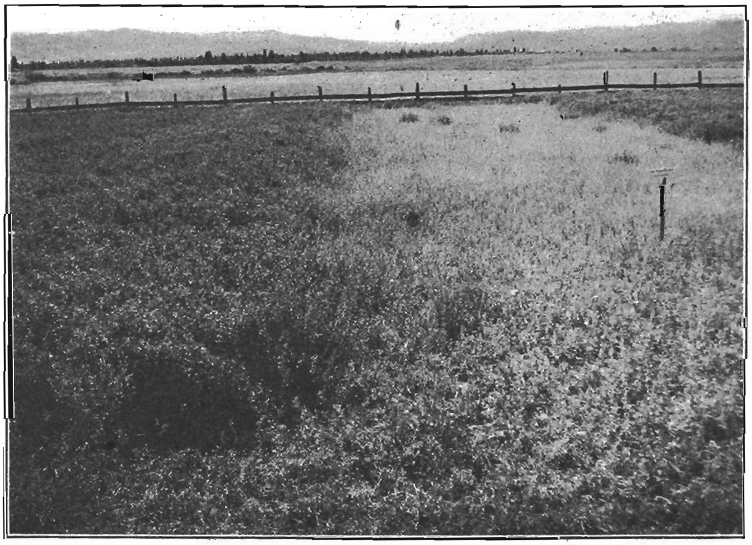

Fig. 2. Plot on left fertilized with flowers of sulfur at the rate of 100 pounds per acre, producing a very heavy yield and dark green color. Plot on right not fertilized, showing very poor yield and light, yellowish color. Antelope Clay Adobe soil.

was obtained. This increase, however, is small when compared with the increase produced by either the gypsum or the flowers of sulfur. The increase produced by the monocalcic phosphate does not appear to be in harmony with the comparative results obtained from gypsum and superphosphate, where the phosphorus apparently had no effect. The increase in yield of the plot receiving monocalcic phosphate was chiefly in the first crop. The check plots and the monocalcic phosphate plot produced such a thin growth of alfalfa that wild oats and weeds constituted more than half of the weight of the hay in the first cutting. The increased yield of the monocalcic phosphate plot over the check plots was chiefly due to the increased growth of weeds on this plot. However, there was an increase during some seasons in the second and third crops when there were no weeds on any of the plots. One explanation may be offered for this. It is possible that where there is such a deficiency of sulfates as in this soil and where there is only a moderate amount of phosphorus present, an application of a very available form of phosphorus without any sulfate may be slightly beneficial. The increased yield due to the phosphorus, however, has never been sufficient to pay for the fertilizer.

The monocalcic phosphate had no effect on the color of the alfalfa, as the plants on this plot had the same starved, yellowish appearance as those on the check plots.

In another experiment on this same field started in the spring of 1916 the monocalcic phosphate plot actually produced less than the nearest check plot. Hence, up to the present time the phosphorus added to these plots has proved of little or no value. While the total phosphorus content of this soil is not high, a large percentage of it is probably in an available condition owing to the large amount of lime present.

Not only was the yield greatly increased where sulfates were applied but the effect on the color of the plants was equally marked. The alfalfa on these plots possessed a rich, dark-green color, fully equal to the best alfalfa grown on the most famous alfalfa fields in the valley. The alfalfa on the check and monocalcic phosphate plots had a sickly, pale yellowish color which indicated at once that something was lacking. This difference in color is clearly shown in the illustrations.

The excellent results obtained from flowers of sulfur in these experiments is probably due in great measure to the large amount of lime, magnesium, and potassium in these soils. With such large amount of basic materials present the flowers of sulfur may be readily converted into available sulfates. It is highly probable that when flowers of sulfur is added to this soil the sulfur is oxidized and then combined with the large store of calcium, forming gypsum. Part of it probably combines with potassium, magnesium, and iron and forms sulfates with these basic elements.

Effect of Various Elements With and Without Sulfur

The results obtained in 1915 proved conclusively that the beneficial results obtained from superphosphate on alfalfa in this valley were not due to the phosphorus which this fertilizer supplied; and further that the beneficial results obtained from gypsum and flowers of sulfur were not due to a liberation of phosphorus in the soil. It still remained to be determined whether these beneficial results were due to a liberation of potassium or other elements in the soil. To determine this a second experiment was started on Antelope Clay Adobe soil, and on another part of the Bernst field in which the previous experiment was conducted. The plan of the experiment is shown in the following table.

TABLE IV. FERTILIZER APPLIED AND YIELDS, ANTELOPE CLAY ADOBE SOIL

Plots 2x8 rods. **Fertilizer applied Jan. 25, 1916.**

Plot	Application		Fertilizing constituents		Yield in pounds 1916	1917	1918	Total
		lbs.		lbs.				
1	Check				49	104	44	197
2	Sulfur	60.0	Sulfur	60.00	370	532	176	1078
3	Sulfur	10.0	Sulfur	10.00	284	708	208	1200
4	Sulfur	30.0	Sulfur	30.00	482	672	212	1366
5	Gypsum	59.5	Sulfur	10.00	789	652	200	1641
6	Monocalcic phosphate	31.6	Phosphorus	7.47	118	100	68	286
7	Superphosphate	82.3	Sulfur	10.00	772	652	224	1648
			Phosphorus	7.47				
8	Muriate of potash	53.3	Potassium	44.20	80	136	96	312
9	Sulfate of potash	54.9	Sulfur	10.00	5.96	692	240	1528
			Potassium	44.20				
10	Check				138	144	48	330
11	Nitrate of soda	55.8	Nitrogen	8.57	154	120	44	318
12	Sulfate of ammonia	42.3	Sulfur	10.00	772	516	180	1468
			Nitrogen	8.57				
13	Iron sulfate	86.9	Sulfur	10.00	754	628	200	1582
14	Magnesium sulfate	78.2	Sulfur	10.00	834	648	172	1654
15	Sodium sulfate	103.3	Sulfur	10.00	648	608	160	1416
16	Check				94	140	44	278

The soils of plots 1 and 2 proved to be somewhat shallower than on the other plots and this is responsible for the comparatively low yields on these plots. It would therefore be better to leave these two plots out of consideration entirely in studying the results.

The results obtained from the experiment are in harmony with those obtained in the experiment started on this soil in 1915. All of the plots which received sulfur fertilizers produced enormous increases in yield. On most of the plots these increases amounted to several hundred percent.

In this experiment, just as in the others, the more available sulfates gave much better results the first year than the flowers of sulfur. For example, the gypsum plot produced nearly three times as much the first season as the plot which received an equal amount of sulfur in the form of flowers of sulfur.

The plot which received 30 pounds of sulfur produced, as in the previous experiments, a much larger yield the first year than the plot which received only 10 pounds. This increase amounted to very nearly 70 percent. The second season the plot which received only 10 pounds produced 5 percent more than the plot which had received the 30 pounds. This is in harmony with the results obtained in the other experiments where it was found that the one application of 10 pounds to each plot or 100 pounds an acre, gave as good results the second and third years as an application of 30 pounds to each plot or nearly 300 pounds an acre. All these results indicate that moderate, and probably more frequent, applications of flowers of sulfur are as satisfactory and more economical than very large applications made at long intervals.

The plots which received the lighter applications of flowers of sulfur produced slightly more the second and third years than the plot to which gypsum had been applied.

The largest total yield was produced by the plot to which magnesium sulfate (Epsom salts) had been applied. The superiority of this plot was greatest during the first season. The magnesium sulfate is very soluble, and if the cost were not prohibitive would prove an excellent fertilizer for alfalfa, as this plant uses large quantities of magnesium as well as sulfur.

Special attention is called to the large increase produced by the alkali, sodium sulfate. This alkali when present in the soil in large amounts is injurious to plant life. In this experiment, however, the amount applied proved highly beneficial. It has been suggested by some that the beneficial effects produced by the flowers of sulfur in our experiments may be due to its effect in changing an injurious sodium compound in the soil to the less injurious sulfate form. The beneficial results obtained from applications of sodium sulfate itself indicate that this is not the case. Undoubtedly continued applications of sodium sulfate would in time prove detrimental and we are not recommending its use.

The results obtained on plots 6 to 12 inclusive are undoubtedly the most valuable of the entire experiment. These results show conclusively that the increased yields produced by the sulfates are not due to the liberation of potash or phosphorus in the soil, or to some influence on nitrification.

Plots 6 and 7 received an equal amount of phosphorus in a very available form. Plot 6, which received only phosphorus, actually produced less than the nearest check plot. It is therefore certain that this soil is not in need of phosphorus, and the beneficial results obtained from sulfur fertilizers cannot be attributed to any effect such fertilizers may have on the liberation of phosphorus in this soil. The superphosphate, applied to plot 7, produced an average annual increase of 399 percent over the nearest check plot. Since the phosphorus which the superphosphate supplies is not responsible for the increases which the material produced, such increases evidently are due to the sulfur which this fertilizer contains.

Plots 8 and 9 received an equal amount of potash in a very available form. During the three years of the experiment, plot 8, which received the muriate of potash at the rate of 533 pounds an acre, produced less than the nearest check plot. It is therefore apparent that this soil is not in need of potash at the present time, and the increased yields of alfalfa produced by the sulfate fertilizers cannot be attributed to any effect that such fertilizers may have in liberating potash in the soil. The sulfate of potash applied to plot 9 contained in addition to the potassium, 10 pounds of sulfur. This plot produced during the three years an average increase of 363 percent in yield over the adjacent check plot. The only conclusion which can be drawn from this experiment is that the sulfur, and not the potash, in the sulfate of potash is responsible for this increased yield.

Plots 11 and 12 received an equal amount of nitrogen. During the three years of the experiment the total yield produced by the nitrate of soda was slightly less than that produced by the adjacent check plot. In other words, an addition of 558 pounds of nitrate of soda an acre produced no increase in yield and had no effect on the color of the alfalfa. It is certain from this result that the poor yield of alfalfa naturally produced on this field cannot be attributed to an insufficient supply of nitrates in the soil. It is also certain, therefore, that the beneficial results obtained with sulfur fertilizers on this soil cannot be attributed to any influence they may have on nitrification.

The plot to which sulfate of ammonia was applied produced during the three years of the experiment an average increase of 344 percent in yield over the nearest check plot. The amount of nitrogen supplied by the sulfate of ammonia was the same as that supplied by the nitrate-of-soda plot; and since the nitrogen in the nitrate of soda had no effect on the alfalfa, it is apparent that the increased yields produced by the sulfate of ammonia cannot be attributed to the nitrogen which it supplied.

This increased yield unquestionably was produced by the sulfur in the sulfate of ammonia. That the nitrogen in the sulfate of ammonia also was of no additional benefit is certain since this plot did not produce any more than the iron sulfate and the magnesium sulfate plots which received the same amount of sulfur but no nitrogen.

The alfalfa on the plots which received the superphosphate, sulfate of potash, and the sulfate of ammonia possessed the rich, dark-green color which was so characteristic of all the plots that received sulfur or any of the sulfates. On the other hand the plots which received the monocalcic phosphate, the muriate of potash, and the nitrate of soda, produced alfalfa which was pale, sickly, yellowish, and which could not be distinguished from that produced by the check plots.

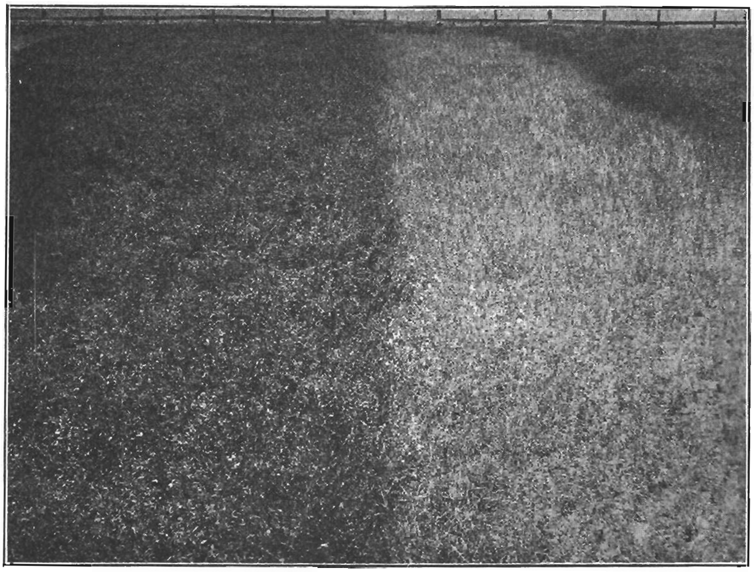

Fig. 3. Plot on left fertilized with superphosphate supplying sulfur at the rate of 100 pounds to the acre. Plot on the right received monocalcic phosphate supplying phosphorus at the same rate as on the superphosphate plot, but no sulfur. Note the dark color and heavy yield of the superphosphate plot, and the poor yield and very light color on the monocalcic plot. Antelope Clay Adobe soil.

A Comparison of Lime and Sulfur

The Antelope Clay Adobe Soil on which these experiments are being conducted is well supplied with lime, hence at the time the earlier experiments were started it was not deemed necessary to try applications of lime. After the work had been carried on for two years, however, it was thought best to try applications of lime to determine conclusively whether this material would prove beneficial to alfalfa on this soil. Therefore another experiment was started in another portion of this field where no fertilizers of any kind had ever been applied. The following table shows the plan of the experiment and the results obtained.

TABLE V. PLAN OF EXPERIMENT TO DETERMINE VALUE OF LIME

Antelope Clay Adobe soil. Plots 2x8 rods. Material applied Nov. 10, 1916

Plot	Application		Fertilizing constituents		Yield in pounds 1917	1918	Total
		lbs.		lbs.			
1	Check		Nothing		152	44	196
2	Pyrites	47.68	Sulfur	*19.22	240	140	380
3	Pyrites	47.68	Sulfur	*19.22	276	144	420
4	Sulfur	10.00	Sulfur	10.00	628	212	840
5	Gypsum	59.50	Sulfur	10.00	764	256	1020
6	Quick lime	200.00	Lime	200.00	168	56	224
7	Ground limestone	200.00	Lime	200.00	172	48	220
8	Check		Nothing		148	52	200

*While the pyrites contained a total of 19.22 lbs. sulfur only 52% of the material (containing 10 lbs. of sulfur) passed through a 200-mesh screen.

The yield on the plots which received the applications of lime was only slightly greater than that produced on the check plots. No difference in appearance whatever could be noted in the field between the lime-treated and the check plots in height, density of stand, or color of plants. The increase in yield was too small to pay for the cost of the lime.

The sulfur and the gypsum again produced enormous increases in yield amounting to 324 percent on the sulfur plot, and to 415 percent on the gypsum plot.

It is evident from these results that the beneficial results obtained from sulfur on this soil are not due to any influence that it might have on the liberation or availability of lime in the soil.

We have observed that very large applications of sulfur have an influence on the physical condition of the soil, making it loose and mellow, especially near the surface of the ground. It was thought that possibly this influence especially on the very heavy soils, might account for the marked increases in yield produced by sulfur. The results from this experiment indicate that this is not the case, since large applications of quick lime, which have a similar effect in mellowing heavy soils, have not produced any such increases in yield as has the sulfur.

Where the sulfur is applied to the soil in the fall as it was in this experiment giving it all winter to oxidize into the sulfate form, it gives much better results the first season than where it is applied in the early spring. However, even the fall application of sulfur in this experiment did not give as good results the first year as did the gypsum.

The iron pyrites used in this experiment was obtained from a large deposit of this material in the mountains near this valley. The sample used in this experiment contained 40.33 percent sulfur. Since the sulfur in the pyrites exists as iron sulfide we concluded that it would probably become available very slowly. For this reason it was ground as fine as possible with the available machinery. All of it passed through a 50-mesh screen, and 52 percent of it, containing 10 pounds of sulfur, passed through a 200-mesh screen. After the material was applied plot 2 was thoroughly harrowed with a spring-tooth harrow, while on plot 3 the material was left on the surface. It will be noted that nothing was gained by the harrowing, as plot 2 produced slightly less than plot 3. That nothing would be gained by harrowing was to be expected, as this heavy soil is moist all winter and spring, and as the surface freezes and thaws often throughout the winter the fertilizer very soon becomes covered with soil.

The two pyrites plots produced an average increase of 102 percent in yield. While this is a considerable increase over the check plots, it is still small when compared with the plots which received sulfur and gypsum. The pyrites was much more effective the second year of the experiment than the first. It is evident from these results that considerable time is required for the sulfide in the pyrites to change to the sulfate.

SULFUR AND ROCK PHOSPHATE

In the spring of 1917 a permanent experiment was started to determine the comparative value of sulfur, sulfur and rock phosphate, gypsum, gypsum and rock phosphate, and superphosphate, when used continuously for many years. This experiment also is being conducted on Antelope Clay Adobe soil on the Bernst ranch. The alfalfa was four years old at the beginning of the experiment, and as it had never received any fertilizer it was making a very poor growth. The plan of the experiment and the results to date are shown in the table below.

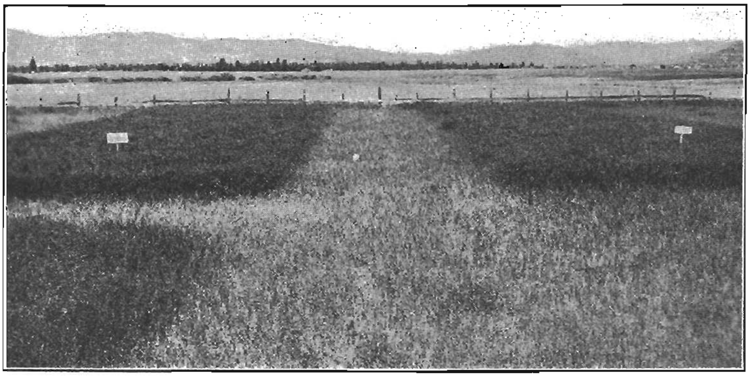

Fig. 4. Light-colored area in foreground unfertilized. Dark plot on extreme right fertilized with gypsum. Light-colored plot in center fertilized with monocalcic phosphate. Dark-colored plot on left fertilized with superphosphate. The gypsum and the superphosphate each supplied sulfur at the rate of 100 pounds to the acre. The monocalcic plot in the center received phosphorus at the same rate as the superphosphate plot, but contained no sulfur. Antelope Clay Adobe soil.

TABLE VI. EXPERIMENT TO DETERMINE COMPARATIVE VALUE OF SULFUR AND ROCK PHOSPHATE AND OTHER FERTILIZERS

Plots one-twentieth acre in size. Fertilizer applied Jan. 18, 1917.

Plot	Application		Yields in pounds 1917	1918	Total
		lbs.			
1	Check		52	22	74
2	Superphosphate	20.57	262	78	340
3	Gypsum	14.88	312	90	402
	Rock phosphate	14.05			
4	Gypsum	14.88	266	95	361
5	Check		58	15	73
6	Superphosphate	20.57	288	106	394
7	Sulfur	5.00	272	117	389
	Rock phosphate	14.05			
	Rock phosphate	14.05	272	117	389
8	Sulfur	5.00	278	133	411
9	Sulfur	10.00	322	130	452
	Rock phosphate	14.05			
10	Sulfur	10.00	284	122	406
11	Check		34	16	50

There is a slight swale between plots 5 and 6 which intersects the field. The soil on plots 6 to 11 inclusive is slightly better than that on plots 1 to 5 inclusive. Therefore plots 1 to 5 should be studied as one group and plots 6 to 11 as a separate group. All the fertilized plots produced enormous increases in yield over the check plots. The most interesting result, and perhaps the most important one, is that by far the largest yields were produced by plots 3 and 9 the first year. Both of these plots received rock phosphate as the source of phosphorus. Just why plot 3 should produce more than plot 2 is difficult to explain as both received the same amount of sulfur and phosphorus, and the phosphorus in the superphosphate is in a more available condition than that in the rock phosphate.

Plots 7 and 8 produced nearly as much the first year as plot 6 which received the superphosphate. The second year they actually produced more, and plot 8 considerably more. The rock phosphate added to the sulfur on plot 7 appeared to have no effect since this plot produced no more than plot 8 which received only sulfur. On plot 9 the rock phosphate appeared to be very beneficial, since this plot produced considerably more, especially the first year, than plot 10 which received an equal amount of sulfur. At the present time it is impossible to explain these inconsistencies.

Plot 9 produced the largest yield of all the plots the first year. This is probably due to the fact that more sulfur became available on this plot than on any of the other plots. While this plot did not receive any more sulfur than plot 10 it is probable that more of it became available the first year owing to the presence of the rock phosphate. The work of Brown and Gwinn (6) of the Iowa Station shows that flowers of sulfur is more readily changed to sulfates in the soil in the presence of rock phosphate than in its absence.

The second year the plot which had received the 5 pounds of sulfur produced the largest yield, even larger than the plot which received the 10 pounds of sulfur. This bears out the results of the other experiments; namely, that an application of 100 pounds of sulfur an acre each year is ample, and more desirable than larger applications.

The chief object of this experiment is to determine the comparative value of sulfur, superphosphate, and sulfur and rock phosphate, when used on alfalfa for many years. The results obtained the first two years are of secondary importance only, as they gave no clue to the ultimate results. The experiment will have to be carried on for a number of years, and probably for many years, before this question can be finally answered. The preliminary results indicate that sulfur and rock phosphate will prove just as effective as superphosphate, and far more economical.

In the future the amount of sulfur applied to plots 7 and 8 will be reduced to two and one-half pounds. This will supply the same amount of sulfur to these plots as that applied to the superphosphate plot.

SULFUR FERTILIZERS ON VARIOUS TYPES OF SOIL

During the summer of 1914 and the springs of 1915 and 1916 experiments were started to determine the value of sulfur fertilizers on various soil types in this county. The object of these experiments was to determine how generally sulfur fertilizers are beneficial on the widely different soil types. The results of these experiments are presented herewith, but as they agree in the main with those which have already been presented, it is not deemed necessary to discuss them at length.

Experiment on Medford Gravelly Clay Loam

This experiment was conducted on M. L. Hartley's ranch about one mile north of Talent, Oregon. The soil in this field is a dark, gravelly clay loam of moderate depth, and is underlaid with a tenacious yellow clay. It is well drained, and not irrigated. During the latter part of the summer it becomes dry and hard and checks considerably.

The chemical composition of this soil is as follows:

	Potassium	Calcium	Magnesium	Nitrogen	Phosphorus	Sulfur	Organic Matter
	%	%	%	%	%	%	%
Surface	1.66	2.43	1.05	.177	.069	.038	7.15
Subsoil	1.31	2.52	1.44	.061	.085	.025	4.62

The analysis shows this soil is well supplied with potassium, calcium, and magnesium, contains a fair amount of nitrogen in the surface soil, and is rather low in phosphorus. The subsoil is very low in sulfur.

Fig. 5. Plot on left fertilized with muriate of potash and plot on right with sulfate of potash. The same amount of potash was supplied to the two plots. The muriate of potash contained no sulfur, while the sulfate of potash supplied sulfur at the rate of 100 pounds to the acre. Note the poor yield and light color on the muriate-of-potash plot, and the heavy yield and dark color on the sulfate-of-potash plot.

The alfalfa was six years old at the beginning of the experiment. The plan of the experiment and results are indicated in the table below.

TABLE VII. FERTILIZER EXPERIMENT, MEDFORD GRAVELLY CLAY LOAM
Plots 2x8 rods. Fertilizer applied June 11, 1914.
Only one application made during three years.

Plot	Application		Yields in pounds 1915	1916	1917	Total
		lbs.				
1	Sulfur	30	395	309	454	1158
2	Check		121	220	299	640
3	Steamed bone meal	30	143	210	295	648
4	Check		134	285	343	762
5	Superphosphate	30	441	405	456	1302
6	Check		134	286	355	775
7	Iron sulfate	30	418	432	439	1289
8	Check		127	224	199	550
9	Steamed bone meal	30	159	222	208	589
10	Check		136	249	218	603
11	Sulfur	30	408	400	398	1206
12	Check		123	267	276	666
13	Iron sulfate	30	379	402	438	1219

Since the fertilizer was applied after the first crop had been cut in 1914, and since very little rain fell during the remainder of that summer, the fertilizer had no effect on the yield that season. While the soil in this field appeared to be uniform the stand of alfalfa was not sufficiently uniform to make it ideal for experimental work. To reduce error due to the variation in stand a large number of check plots were used. There is considerable variation in the yields of the various check plots, especally during 1917, which must be taken into consideration in interpreting the results. While considerable allowance must be made for this difference in the plots at the beginning of the experiment, the influence of the fertilizers was so great that there can be no doubt regarding their effect.

All of the fertilizers containing sulfur—flowers of sulfur, superphosphate, and iron sulfate—produced large increases in yield. The average yield for all the plots receiving flowers of sulfur was 394 pounds a plot each year, that of the superphosphate plot was 434 pounds a plot each year, that of the iron sulfate plots was 418 pounds a plot each year, while the average yield of all the check plots was 222 pounds a plot each year. The average of the two plots which received steamed bone meal was 206 pounds a plot each year, which is less than the average for all the check plots, and less than the average of the check plots adjacent to these steamed-bone-meal plots. It is thus evident that the phosphorus in the steamed bone meal was of no value to the alfalfa.

Owing to variations in the stand of alfalfa it is difficult to make a satisfactory comparison between the yields produced by the flowers of sulfur, superphosphate, and iron sulfate. Probably the most satisfactory way is to compare the yields produced by these plots with the adjacent check plots. Such a comparison shows that the flowers of sulfur produced an increase of 86%, superphosphate an increase of 70%, and the iron sulfate an increase of 89% over the adjacent check plots.

The increase of alfalfa on the fertilized plots is actually larger than these figures indicate, since the alfalfa hay produced on these plots contained a much smaller percentage of weeds than the check plots. It was impossible, owing to limited time, to separate the weeds from the alfalfa, hence these are included in the weights.

The superphosphate and the iron sulfate used in this experiment contained approximately 12% of sulfur, or 3.6 pounds to each plot. The flowers of sulfur plot received 30 pounds of actual sulfur. It is important to note that while the flowers-of-sulfur plot received more than eight times as much sulfur as the other two plots it actually produced a smaller increase over the check plots than the iron sulfate, and an increase of only 16% more when compared with the superphosphate plot.

It is remarkable that this small amount of sulfur (36 pounds to the acre) on the superphosphate and iron-sulfate plots should prove effective for at least three seasons. The reason for this will become apparent after studying the chemical composition of alfalfa as given later in this bulletin.

Experiment on Phoenix Clay Adobe Soil

This experiment was conducted on F. Barneburg's ranch, about two miles southeast of Medford, Oregon. The Phoenix Clay Adobe soil is the heaviest adobe soil in this valley, containing 63% of clay, and 21% of silt. It is black in color, averages about four feet deep, and is of very pronounced adobe structure. It is very retentive of moisture, but during the last half of the summer becomes dry and very hard and checks badly.

The chemical analysis of this soil shows the following percentage composition:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic matter	Limestone
Surface	1.18	.117	1.83	1.25	.048	.021	7.16	0.13
Subsoil	1.08	.074	2.42	0.88	.072	.020	5.00	2.23

The analysis shows that this soil is rich in potassium, calcium, and magnesium, and contains a fair amount of nitrogen in the surface soil, and of phosphorus in the subsoil. It is low in nitrogen in the subsoil, and in phosphorus in the surface soil. The sulfur content is low. It contains a fair amount of organic matter, and the subsoil is rich in limestone (calcium carbonate).

The alfalfa was five years old at the beginning of the fertilizer experiment. During the first three years after planting, this field produced excellent crops, but in 1914 the yield was very much smaller than during previous years. The field has never been irrigated.

The following table shows the plan of the experiment:

TABLE VIII. FERTILIZER APPLIED AND YIELDS PRODUCED.

Phoenix Clay Adobe Soil. Plots 2x8 rods. Fertilizer applied March 9, 1915.

Plot	Application	lbs.	Fertilizing constituents	lbs.	Yield in pounds 1915	1916	1917	Total
1	Check				227	450	736	1413
2	Gypsum	59.5	Sulfur	10.00	369	826	936	2131
3	Double superphosphate	40	Sulfur	0.97	361	418	608	1387
			Phosphorus	7.40				
4	Superphosphate	82	Sulfur	10.00	348	728	860	1936
			Phosphorus	7.40				
5	Check				159	260	544	963
6	Sulfur	10	Sulfur	10.00	216	478	676	1370
7	Sulfur	30	Sulfur	30.00	253	422	668	1363
8	Check				224	192	480	896

Check plot 1 borders on a stream and the soil of this plot is better than that of the other plots. This accounts for the larger yield of plot 1. It would probably be better to ignore this check plot entirely. The fertilizers containing sulfur again produced large increases in yield. The gypsum plot produced a larger yield than the superphosphate plot, and these two plots produced considerably more than the two plots which received flowers of sulfur. The small amount of sulfur in the double superphosphate, amounting to only 9.7 pounds an acre, produced a large increase in yield, especially the first and second seasons. This shows that only a very small amount of sulfur is necessary to produce material increases in yield. The effect of the double superphosphate was barely perceptible the third season of the experiment.

Fertilizer Experiment No. 2, on Phoenix Clay Adobe Soil

In the spring of 1916 a second fertilizer experiment on alfalfa was started on Phoenix Clay Adobe soil, and in the same field in which Experiment No. 1 was conducted.

TABLE IX. FERTILIZER AND RESULTS, SECOND EXPERIMENT.
Phoenix Clay Adobe soil. Plots 2x8. Fertilizer applied Feb. 3, 1916.

Plot	Application		Fertilizing constituents		Yield in pounds 1916	1917	Total
West Section:		lbs.		lbs.			
1	Sulfur	5.0	Sulfur	5.0	570	832	1402
2	Sulfur	10.0	Sulfur	10.0	558	804	1362
3	Sulfur	30.0	Sulfur	30.0	664	824	1488
4	Superphosphate	82.3	Sulfur	10.0	756	792	1548
			Phosphorus	7.4			
5	Monocalcic phosphate	31.6	Phosphorus	7.4	348	592	940
6	Sulfate of ammonia	42.3	Sulfur	10.0	504	720	1224
			Nitrogen	8.5			
7	Nitrate of soda	55.8	Nitrogen	8.5	182	516	698
8	Iron sulfate	86.9	Sulfur	10.0	528	632	1160
9	Check		Nothing		196	460	656
10	Check		Nothing.		180	384	564
East Section:							
1	Sulfur	60.0	Sulfur	60.0	768	696	1464
2	Sulfur	100.0	Sulfur	100.0	782	872	1654
3	Gypsum	100.0	Sulfur	16.8	676	864	1540
4	Gypsum	59.5	Sulfur	10.0	686	812	1498
5	Gypsum	30.0	Sulfur	5.0	582	828	1410
6	Check				288	580	868
7	Gypsum	20.0	Sulfur	3.3	506	684	1190
8	Gypsum	10.0	Sulfur	1.6	464	584	1048
9	Gypsum	5.0	Sulfur	0.84	376	464	840
10	Check		Nothing		146	384	530

In this experiment the various plots of the west section are directly opposite the plots of corresponding numbers of the east section.

Since the soil of this field is composed entirely of alluvial material it is not perfectly uniform, especially in depth. The soil of the south side of the field, including plots 1 to 5 in each section. is deeper than that on the north half, including plots 6 to 10. In studying the results of the experiment this fact must be taken into consideration.

The chief object of this experiment was to throw some light on the comparative value of large and small applications of both flowers of sulfur and gypsum; and to determine whether the increased yields produced by the various sulfur fertilizers could also be obtained by the use of either phosphorus or nitrogen.

All of the fertilizers containing sulfur produced large increases in yield. The largest yield was produced by the plot which received the largest application of flowers of sulfur. This result should not be considered conclusive on this point, since there is no regularity in the results obtained from the other applications of sulfur. For example, the plot which received 60 pounds of sulfur produced less than the one which received 30 pounds, and the plot which received 5 pounds produced more than the one which received 10 pounds. These inconsistencies may be due to variations in soil. These results and those obtained on other fields indicate that very large applications of sulfur are not necessary, and on some soils are undesirable.

The results obtained with gypsum show that the largest applications produce the largest yields, and the yields decrease with the smaller applications, although this decrease is not regular. While an application of 5 pounds to each plot, or 50 pounds an acre, produced an increase of 58%, much larger increases were obtained by the larger applications. The results indicate that the most profitable increases are obtained with application of 200 to 300 pounds an acre.

The largest total increase was obtained on the superphosphate plot. The second season, however, all except one of the flowers-of-sulfur plots and three of the gypsum plots produced more than the superphosphate plot.

The superphosphate plot produced 64% more than the monocalcic-phosphate plot which received an equal amount of phosphorus in a very available form. It is very evident from this that the large increase in yield produced by the superphosphate is not due to the phosphorus which it contains. It is also evident that the large increases produced in this field by the flowers of sulfur and gypsum are not due to any appreciable extent to a liberation of phosphorus in the soil.

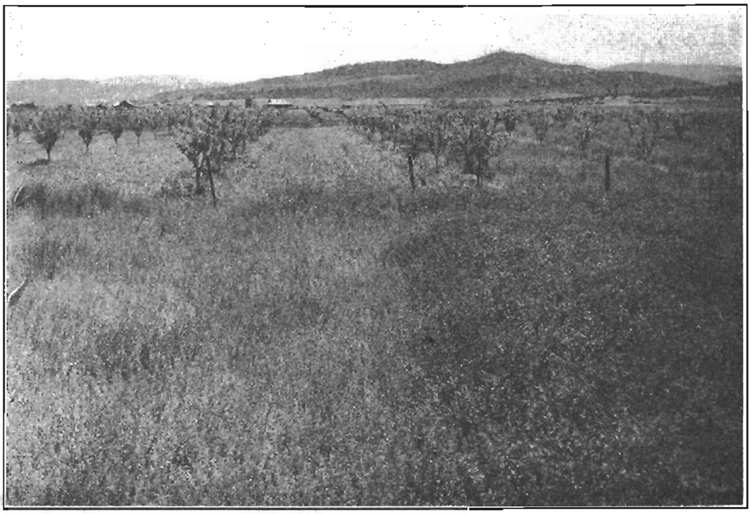

Fig. 6. Plot on left fertilized with nitrate of soda and plot on right with sulfate of ammonia. The two plots received exactly the same amount of nitrogen. The sulfate of ammonia also supplied sulfur at the rate of 100 pounds to the acre. Note the remarkable influence of the sulfur in the sulfate of ammonia. Antelope Adobe soil.

While the monocalcic phosphate produced more than the check plots this was not due to any effect that this material had on the alfalfa. The alfalfa on this plot had the same yellowish color possessed by that on the check plots. The increased yield on the monocalcic-phosphate plot was due to an increased growth of weeds which the phosphorus stimulated.

The sulfate of ammonia produced 42% more than the nitrate of soda plot, although both supplied an equal amount of nitrogen. It is apparent that the increased yield produced by the sulfate of ammonia is due to the sulfur which this material contains and not to the nitrogen. The nitrate of soda stimulated the growth of weeds on this plot, hence the greater weight of hay compared with the check plots. The nitrate of soda had no influence whatever on the color of the alfalfa such as is exerted by the sulfate of ammonia and the other sulfate fertilizers.

In this field the iron sulfate did not produce as large increases in yield as some of the sulfur and gypsum plots, which probably is due to the shallower soil on this plot.

Fertilizer Experiment on Salem Clay Loam

This experiment was conducted on Mike Hanley's ranch about two miles north of Medford. The soil is commonly known as Bear Creek Bottom, and is a deep, fertile clay loam. It contains 21% of clay and 40% of silt. Although it is very distinct from the adobe soil, it is quite sticky when wet and becomes very hard when dry.

The following table shows the percentage composition of this soil:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.50	.140	2.49	1.00	.050	.027	.615
Subsoil	1.28	.055	2.28	.90	.070	.024	3.32

The potassium, calcium, and magnesium content is high. The nitrogen content is fair in the surface soil and low in the subsoil. The phosphorus and sulfur content is low.

TABLE X. PLAN OF EXPERIMENT AND RESULTS, SALEM CLAY LOAM

Plots 2x8 rods. Fertilizer applied March 8, 1915, and application repeated March 27, 1917.

Plot	Application		Fertilizing constituents		Yield in pounds 1915	1916	1917	Total
		lbs.		lbs.				
1	Check				96	114	184	394
2	Gypsum	59.5	Sulfur	10.0	492	752	948	2192
3	Monocalcic phosphate	41.0	Phosphorus	9.6	178	120	228	526
4	Superphosphate	82.3	Sulfur	10.0	553	768	888	2209
			Phosphorus	8.5				
5	Check				286	388	344	1018
6	Sulfur	10.0	Sulfur	10.0	435	930	952	2317
7	Sulfur	30.0	Sulfur	30.0	618	1126	1100	2844
8	Iron sulfate	84.0	Sulfur	10.0	899	1060	1016	2975
9	Rock phosphate	56.0	Phosphorus	8.5	368	306	576	1250
10	Check				273	296	368	937

The soil on which this experiment was conducted is an alluvial deposit, and is quite variable. For this reason considerable allowance must be made in studying the results.

The soil on check plot 1 is shallower, and that on plots 7, 8, and 9 is deeper than that of the other plots. The alfalfa was two years old at the beginning of this experiment. It was not irrigated during the experiment.

It will be noted that the plots which received the sulfur fertilizers, gypsum, superphosphate, flowers of sulfur, and iron sulfate produced enormous increases in yield. While the largest yields were produced on plots 7 and 8, this is due in part to the better soil on these plots. There is very little difference in yield between the gypsum and superphosphate plots. The monocalcic-phosphate plot actually produced less than check plot 5. These results indicate that applications of phosphorus are not needed by the alfalfa on this soil at the present time. The larger yield produced by plot 9 is not due to the phosphorus but to the better soil of this plot.

The difference in the color of the alfalfa produced by the plots fertilized with the various sulfur fertilizers and the others was remarkable.

The alfalfa on these plots possessed a dark, rich green color while on the other plots it had a pale yellowish color. Furthermore, the plots treated with sulfur fertilizers were remarkably free from weeds owing to the rank growth of alfalfa, while the other plots produced such a poor growth of alfalfa that weeds in some cuttings were more abundant than alfalfa.

Experiment on Coleman Gravelly Clay Loam

This experiment was conducted on A. Schnebley's ranch one-half mile north of Phoenix, Oregon. The soil in this field is a very gravelly clay loam about eighteen inches deep, underlaid with a gravelly clay hard-pan. Owing to the impervious nature of the subsoil it becomes water logged in winter and dry and hard in summer.

The following table shows the percentage composition of this soil:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.03	.056	3.48	1.33	.065	.037	2.87
Subsoil	1.11	.018	3.38	1.92	.073	.014	3.79

An abundance of potassium, calcium, and magnesium is found in this soil, but it is low in nitrogen and phosphorus and the subsoil is low in sulfur.

TABLE XI. FERTILIZERS AND YIELDS, COLEMAN GRAVELLY CLAY LOAM

Fertilizer applied February 24, 1915. Plots 2x8 rods.

Plot	Application		Yields in pounds 1915	1916	Total
		lbs.			
1	Check		97	140	237
2	Gypsum	59.5	254	254	508
3	Monocalcic phosphate	41.0	138	50	188
4	Superphosphate	82.3	240	222	462
5	Check		150	138	288
6	Sulfur	10.0	194	242	436
7	Sulfur	30.0	213	266	479
8	Iron sulfate	84.0	229	246	475
9	Rock phosphate	56.0	100	46	146
10	Check		85	32	117

The plots which received the various sulfur fertilizers produced large increases in yield. The first year the plots which received the flowers of sulfur produced less than the plots to which the more soluble sulfate fertilizers were applied. The second year the plot which received 30 pounds of flowers of sulfur produced the largest yield. The phosphorus in the superphosphate apparently was of no benefit since the gypsum plot yielded slightly more. Owing to the sloping ground and seepage in winter check plot 5 received some benefit from the fertilizers on the two adjacent fertilized plots, and this is responsible for the larger yield. The phosphorus applied to the monocalcic-phosphate plot and the rock-phosphate plot stimulated the growth of weeds on these two plots but had no effect on the alfalfa.

During the summer of 1917 this field was irrigated, and owing to the rolling character of the land, and consequently the irregular distribution of water, this fertilizer experiment was discontinued.

Fertilizer Experiment on Barron Coarse Sand

This experiment was conducted in an old alfalfa field on F. Schneider's ranch two miles east of Ashland. The soil is a coarse granite of considerable depth, and the drainage is perfect. During the last half of the summer this soil becomes extremely dry and the subsoil very hard.

Table showing percentage composition of Barron Coarse Sand:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.86	.052	2.20	.51	.077	.028	1.49
Subsoil	2.63	.015	1.54	.73	.089	.015	2.06

This soil contains a large amount of potassium, calcium, and magnesium, and a fair amount of phosphorus. It is very poor in nitrogen, sulfur, and organic matter. The alfalfa was five years old at the beginning of the experiment. It has never been irrigated.

TABLE XII. FERTILIZER APPLIED AND RESULTS ON BARRON COARSE SAND

Plots 2x5 rods. Fertilizer applied March 12, 1915

Plot	Application		Yields in pounds 1915	1916	Total
		lbs.			
1	Gypsum	23.4	334	269	603
2	Check		158	149	307
3	Double superphosphate	16.5	265	228	493
4	Superphosphate	33.0	321	342	663
5	Check		194	162	356

The gypsum, double superphosphate, and superphosphate produced very large increases in yield in this field. It is important to note that the small amount of sulfur in the double superphosphate, amounting to 5.7 pounds an acre, produced an increase of 186 pounds over the nearest check plot. It is also clear that this amount of sulfur is not sufficient to produce maximum yields on this soil, as shown by the larger increases produced by the larger amount of sulfur supplied to the gypsum and superphosphate plots.

Experiment on Tolo Loam

This experiment was conducted on H. W. Frame's ranch about one and a half miles west of Talent. The soil is typical red, foothill, clay loam soil classified as Tolo Loam. The surface soil varies from 15 to 24 inches deep, and is underlaid with a tenacious yellow clay.

The percentage composition of the soil is as follows:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.83	.148	1.50	0.85	.065	.029	5.63
Subsoil	1.41	.039	1.63	1.21	.061	.013	3.78

This soil contains an ample supply of potassium, calcium, and magnesium; a fair amount of nitrogen in the surface soil, and a small amount in the subsoil. The phosphorus is rather low and the sulfur very low, especially in the subsoil.

The alfalfa was one year old at the beginning of the experiment, and was not irrigated before or during the experiment.

TABLE XIII. TREATMENT AND ALFALFA YIELDS, TOLO LOAM

Plots 2x8 rods. Fertilizer applied March 9, 1915.

Plot	Application		Yields in pounds 1915	1916
		lbs.		
1	Check		155	308
2	Gypsum	59	363	400
3	Double superphosphate	40	306	438
4	Superphosphate	82	356	377
5	Check		161	289
6	Sulfur	10	215	298
7	Sulfur	30	288	377

The first year the gypsum and superphosphate plots produced more than twice as much as the nearest check plots, and the double superphosphate nearly twice as much as the check. The two plots which received the flowers of sulfur produced large increases but less than the more soluble gypsum and superphosphate. The second year all of the plots produced more than the first. The increases over the check plots are not so large, however, as the first year. It is quite remarkable that the double superphosphate plot should produce more than any of the others the second season.

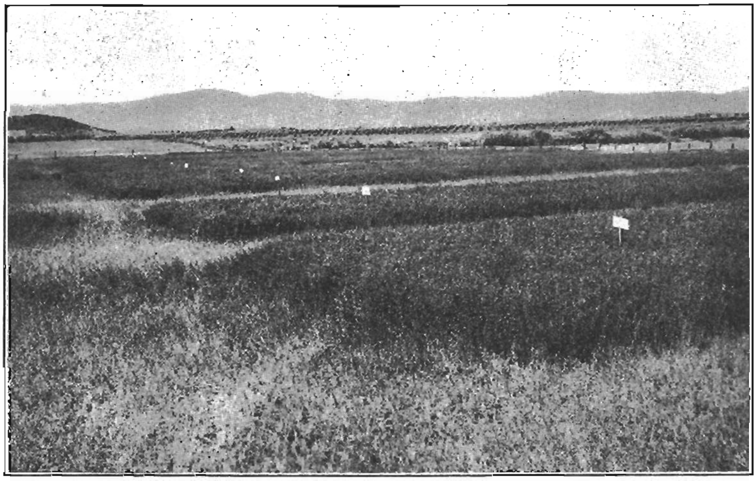

Fig. 7. Plot in foreground not fertilized. First dark-green plot fertilized with gypsum. First narrow yellow plot fertilized with monocalcic phosphate. Second dark-green plot fertilized with superphosphate. Second light strip not fertilized. Dark plot in background fertilized with flowers of sulfur at the rate of 100 pounds to the acre. Note the heavy yield and dark color of all the plots which were fertilized with materials containing sulfur. Antelope Clay Adobe soil.

Experiment on Medford Fine Sandy Loam

The experiment on Medford Fine Sandy Loam was conducted on E. B. Hanley's ranch two miles north of Jacksonville. See page 6 for description and composition of this soil.

The stand of alfalfa in this field was very good and uniform. The alfalfa was producing fair crops, although the color was a rather light green. This field had never been irrigated, and was not irrigated during the experiment.

TABLE XIV. TREATMENT AND RESULTS, MEDFORD FINE SANDY LOAM.

Plots 2x8 rods. Fertilizer applied Feb. 26, 1915.

Plot	Application		Yields in pounds 1915	1916	Total
		lbs.			
1	Superphosphate	30	300	424	724
2	Check		209	272	481
3	Gypsum	30	349	426	775
4	Sulfur	30	288	404	692

The superphosphate produced an increase of 50%, the gypsum 61%, and the flowers of sulfur an increase of 43 percent. The gypsum produced 11% more than the superphosphate, which is probably due to the larger amount of sulfur in the gypsum applied. The flowers-of-sulfur plot produced less than the gypsum plot, although it received much more sulfur. It is probable that only a small percentage of the sulfur had become available on the sulfur plot, and that there was actually less sulfate sulfur on this plot than on the gypsum and superphosphate plots.

The check plot contained a much larger percentage of weeds than the fertilized plots, and the alfalfa on this plot possessed a pale yellowish color.

Experiment on Salem Fine Sandy Loam (Coarser Phase)

This experiment was conducted on the Modoc ranch in the Table Rock district. In the soil survey made by the Bureau of Soils, this field is included in the Salem Fine Sandy Loam. The soil in this field, however, contains considerably more coarse sand and less clay than that type. For this reason it is designated in this bulletin as the coarser phase of Salem Fine Sandy Loam. The chemical analysis of the soil in this particular field shows the following percentage composition:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	.88	.081	3.45	1.21	.076	.015	2.85
Subsoil	.83	.025	3.40	1.68	.079	.030	2.05

The soil contains an abundance of potassium, calcium, and magnesium, a moderate amount of phosphorus, and a fair amount of nitrogen in the surface soil. The subsoil is very low in nitrogen, and the surface soil extremely poor in sulfur. This soil is a deep, mellow, sandy loam, of alluvial origin. The stand of alfalfa was good, although it was making a poor growth at the beginning of the experiment, and possessed a yellowish color. It was not irrigated during the experiment. The fertilizer was applied Feb. 9, 1915, and the alfalfa planted during April, 1915. Owing to the dry season the alfalfa was not cut the first season.

TABLE XV. FERTILIZER APPLIED AND RESULTS, SALEM FINE SANDY LOAM

Plots 2x8 rods. Fertilizer applied Feb. 9, 1915.

Plot	Application		Yields in pounds 1916
		lbs.	
1	Gypsum	20	360
2	Superphosphate	20	264
3	Steamed bone meal	20	152
4	Flowers of sulfur	20	306
5	Check		152

The value of the various sulfur fertilizers on this field is apparent. It is important to note that the gypsum produced a much larger increase than the superphosphate. This is probably due to the fact that the gypsum applied contained one-third more sulfate than the superphosphate. In this field the flowers of sulfur actually produced more the first year than the superphosphate. It is probable that the large amount of lime in this soil permitted the sulfur to change to the sulfate form rapidly.

The change in the growth and the appearance of the alfalfa on the sulfur-fertilized plots was quite remarkable.

The yield on the steamed-bone-meal plot was exactly the same as that on the check plot, and the alfalfa on this plot possessed the same yellowish color. It is evident, therefore, that the phosphorus in this material and in the superphosphate had no effect on the alfalfa.

The manager of this ranch was so impressed with the results of the experiment that the following year the entire field was fertilized and the experiment discontinued.

SULFATE FERTILIZERS ON RED CLOVER

During the season of 1915 a fertilizer experiment was conducted to determine the value of sulfate fertilizers on red clover. This experiment was conducted on G. Hilton's ranch about two miles north of Medford. The soil in this field is classed as Agate Gravelly Sandy Loam, and is locally known as Desert Soil. It is a gravelly, sandy. clay loam soil. varying from 15 to 20 inches deep, and underlaid with an impervious hard-pan. This soil is exceedingly poor in nitrogen and contains .024% of sulfur in the surface soil and .021% in the subsoil. The field was thoroughly irrigated during the experiment.

TABLE XVI. PLAN OF EXPERIMENT AND YIELDS, RED CLOVER.

Agate Gravelly Sandy Loam. Plots 2x8 rods. Fertilizer applied March 11, 1915.

Plot	Application	lbs.	Fertilizing constituents	lbs.	Yield in pounds 1915
1	Gypsum	59	Sulfur	10.0	725
2	Superphosphate	82	Sulfur	10.0	729
			Phosphorus	8.5	
3	Check				468
4	Sulfur	10	Sulfur	10.0	948
5	Sulfur	30	Sulfur	30.0	704

The clover produced two heavy cuttings, and the effect of the various fertilizers containing sulfur is very apparent. The yields produced by the gypsum, superphosphate, and 30 pounds of sulfur and superphosphate are practically the same. While the application of 30 pounds of sulfur produced slightly less than the gypsum, this may be due to a slight difference in soil. It is impossible to explain why the plot receiving only 10 pounds of sulfur should produce a much greater yield than the plot receiving gypsum which contained exactly the same amount of sulfur and in a much more available form.

This field was plowed up in the spring of 1916 and the land devoted to another crop.

Red Clover Fertilizer Experiment on Agate Gravelly Loam

During 1915 another simple experiment with sulfur fertilizers was conducted on Agate Gravelly Loam. The soil used was typical Desert Land, one mile south of Rogue River. This is a red, clay loam soil, about 15 inches deep, and underlaid with an impervious hard-pan.

The following table gives the percentage composition of this soil:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.20	.030	2.20	.77	.057	.024	4.00
Subsoil	.98	.055	2.03	.49	.057	.026	4.03

This soil contains an abundance of potassium, calcium, and magnesium. It is low in nitrogen, phosphorus, and sulfur.

TABLE XVII. FERTILIZER APPLIED AND YIELDS, AGATE GRAVELLY LOAM

Plots one-fifteenth acre in size. Fertilizer applied March 11, 1915.

Plot	Application		Yields in pounds
		lbs.	
1	Gypsum	40	81
2	Check		38
3	Superphosphate	53	138
4	Check		19
5	Flowers of sulfur	7	110

This experiment was conducted on graded land, consequently the soil varied considerably. Check plot 4 was on shallower ground than the other plots, and should be disregarded. Owing to the variation in the soil no comparative study can be made of the various fertilizers. It is apparent, however, that all of the fertilizers containing sulfur proved very beneficial.

SOILS WHICH DID NOT RESPOND TO SULFUR FERTILIZERS

Medford Loam

One experiment was conducted on W. H. Gore's ranch two miles west of Medford, Oregon. The soil, classified as Medford Loam, is a deep, fertile, brown, silt loam. It is considered one of the best alfalfa soils in the Rogue River Valley.

The percentage composition of Medford Loam is as follows:

	Potassium	Nitrogen	Calcium	Magnesium	Phosphorus	Sulfur	Organic Matter
Surface	1.18	.140	2.88	1.35	.065	.036	4.80
Subsoil	1.38	.067	2.82	1.54	.063	.025	3.72

The soil contains a large amount of potassium, calcium, and magnesium, and the surface soil is well supplied with nitrogen. The phosphorus content is low. The sulfur content of the surface soil is good, and that in the subsoil fair when compared with the other soils in the valley.

The stand of alfalfa in this field was originally fine and large crops were produced. At the beginning of the experiment, however, the alfalfa was twenty years old and the stand had become rather thin. The usual amounts of the various sulfate fertilizers were used in this experiment in the spring of 1916. These fertilizers included flowers of sulfur in various amounts, gypsum, sulfate of ammonia, sulfate of potash, with check plots.

As far as could be observed from a careful examination, the various fertilizers exerted no influence whatever on the height, thickness of stand, or color of the alfalfa. All of the plots, both fertilized and check plots, produced a uniformly heavy yield. Owing to lack of time it was impossible to secure the weight of the hay on the various plots. Judging from the large yields produced by the check plots it is apparent that this soil already contained sufficient available sulfur at that time to produce maximum crops, and was not in need of sulfur fertilizers.

While this soil does not contain a great deal more sulfur than some of the other soils which did respond to the use of sulfur fertilizers, it is probable that a larger percentage of the sulfur in the soil is in the available sulfate form. The Medford Loam is a mellow soil of great depth, and contains considerable gravel. It is therefore probable that the aeration is excellent, and that sulfofication takes place more readily than in many of the other types studied. Owing to the great depth the alfalfa roots have a greater feeding area than in many of the heavy and shallower soils.

Anderson Clay Loam

This experiment was conducted on G. Morse's ranch about one mile west of Talent, Oregon. The soil is a deep, black, fertile clay loam of alluvial origin, bordering on Anderson Creek. In the survey made by the Bureau of Soils it is classified as Medford Gravelly Clay Loam. This soil, however, is sufficiently distinct from the typical Medford Gravelly Clay Loam to be classed as a distinct type.

Unfortunately we have no complete chemical analysis of the soil in this field. An analysis of the soil solution from one check plot and one plot fertilized with 300 pounds of sulfur gave the following results:

	Mgms. $BaSO_4$ from 100 grams soil
1. Check plot	9.9
2. Plot fertilized with 300 lbs. sulfur	12.4

This analysis shows 25% more sulfur in the sulfate form on the sulfur-fertilized plot than on the check plot.

In the spring of 1916 various plots in this field were fertilized with gypsum and sulfur varying from 50 to 1000 pounds to the acre, and iron sulfate at the rate of 869 pounds an acre, several check plots being retained. The fertilizer had no influence whatever on the yield or color of the alfalfa. All the check plots as well as the fertilized plots produced bountiful crops. It is evident that this field naturally contained sufficient sulfur in an available form to produce maximum crops.

The fact should be emphasized that the depth and physical condition of the soil must be taken into account in considering the relation of the sulfur content of the soil to alfalfa yields. Two fields may show upon analysis the same percentage of sulfur, and one of these may respond to the use of sulfur and the other may not simply because of a difference in the depth and physical condition of the soil. The deep mellow soil provides new feeding areas for the roots for several years after the shallower soil has been exhausted.

SULFUR AND SOIL ACIDITY

Owing to the large amount of basic material present in these soils there is probably little danger of producing acidity with moderate applications of sulfur, at least not for a number of years. It is now evident that only small applications of flowers of sulfur are necessary, and just how many of such applications would eventually produce an acid soil cannot be foretold at the present time. That very large applications of flowers of sulfur will soon produce acidity is evident from some of our results. Plots on Antelope Clay Adobe which received an application of 100 pounds of flowers of sulfur an acre in the spring of 1915 and another similar application in the spring of 1917 show no signs of acidity. A plot which received only one application of 300 pounds of sulfur in the spring of 1915 shows no acidity. Another plot which received 300 pounds of sulfur in 1915 which was repeated in 1917 showed slight acidity in the spring of 1918. Another plot which received 600 pounds of sulfur in 1916 showed considerable acidity in the spring of 1918. The alfalfa has not been injured in the least on any of these plots, and these have been among the best producing plots in the entire experiment. Such heavy applications are not necessary and are not recommended.

If any of our soils should become acid this condition could be easily and cheaply remedied by applying ground limestone which can be obtained from the large lime deposits in this county.

The plots which received applications of gypsum, superphosphate, and iron sulfate show no sign of acidity. Wherever the soil is deficient in lime it would be better to apply gypsum or both sulfur and lime.

EFFECT OF SULFUR FERTILIZERS ON ALFALFA ROOT SYSTEM

A number of investigators have found that certain sulfate fertilizers have a stimulating effect on the root system of clover. Hart and Tottingham (7) of Wisconsin, found that the root system of clover fertilized with gypsum was fully twice as large as on the unfertilized plants.

We have found that the same principle applies to alfalfa grown in this valley. The root system of alfalfa fertilized with any of the various sulfur fertilizers is from two to three times as large as that of the unfertilized plants. The effect on the branching of the root system is especially striking. On the heavy adobe soils the unfertilized plants usually have a long, slender root system consisting principally of one tap-root and very few lateral roots. The roots of the plants on the fertilized plots of these soils are well branched, with numerous fibrous roots. This is clearly shown in the photograph reproduced in this bulletin.

It is obvious that this larger root system is very valuable to the plant in taking up greater amounts of plant food and water and therefore in producing more abundant crops.

EFFECT OF SULFUR FERTILIZERS ON THE ALFALFA NODULES

Pitz (8) of the Wisconsin Station has demonstrated that gypsum has a very stimulative effect on the nitrogen-gathering or nodule-forming bacteria of red clover roots. He found that the bacteria were from two to three times as numerous in culture media to which calcium sulfate had been added as in the checks; also that there were three times as many nodules on the roots of young red clover plants fertilized with gypsum as on the untreated plants.

Duley (9) of the Missouri Station has shown that sulfur and gypsum enormously increase the number of nodules on red clover roots in certain Missouri soils.

In our work with alfalfa no special experiments have been conducted to determine whether this principle holds good on our local soils. Roots have been examined from the fertilized and unfertilized plots, however, and on some soils the nodules on the roots of alfalfa plants from the fertilized plots have been far more numerous than on those from the unfertilized plots. This is particularly true where the alfalfa is several years old and especially so on the extremely heavy soils. The greatest difference was found on the fertilized and unfertilized plants on the Antelope Clay Adobe soil where the fertilizers produced the remarkable increases in yield reported in Table III.

Since these bacteria largely supply the alfalfa plant with its nitrogen the great importance of this stimulative effect can hardly be over-estimated. It is of special value on our soils, in which the number of nodules on the roots of old alfalfa plants is usually comparatively small.

EFFECT OF FERTILIZER ON THE COMPOSITION OF ALFALFA

Applications of sulfur fertilizers not only produced a marked increase in yield but also affected the composition of the alfalfa hay, as shown in the following table.

TABLE XVIII. COMPOSITION OF FERTILIZED AND UNFERTILIZED ALFALA HAY

Soil Types	Application	Total Sulfur	Sulfate Sulfur	Organic Sulfur	Nitrogen	Protein (Nitrogen X6.25)
		%	%	%	%	%
Antelope	Check Plot	.118	.0000	.118	2.01	12.60
Clay	Sulfur 300	.167	.0356	.131	2.16	13.53
Adobe	lbs. an acre					
Yolo	Check Plot	.127	.0000	.127	2.21	13.81
Loam	Sulfur 300	.227	.0603	.167	2.51	15.70
	lbs. an acre					
Barren	Check Plot	.118	.0000	.118	2.09	13.08
Coarse	Gypsum 590	.200	.059	.141	2.38	14.87
Sand	lbs. an acre					

The fertilizer was applied to these plots in the spring of 1915 and the samples of hay collected from the first cutting in June, 1915.

The samples of cured hay from the plots which received the various sulfur fertilizers contained from .049% to .1% more sulfur, from .93% to 1.89% more protein, and from .15% to .1% more sulfur, from the samples from the check plots. It is important to note that on these three entirely distinct types of soil the amount of sulfur in the hay even from the heavily fertilized plots which produced large yields did not exceed 4.54 pounds to each ton of hay. It is evident from this that the minimum amount of sulfur required by alfalfa for maximum growth is considerably less than the total amount of sulfur often found in alfalfa hay in the middle western states. Peterson (10) found that alfalfa hay grown in Wisconsin contained a total of 7.24 pounds of sulfur to each ton of hay; also that one-half of this was present as unoxidized sulfur and one-half as sulfate sulfur. It is probable that the sulfate sulfur present in the plant is not absolutely necessary for maximum growth as long as there is sufficient sulfur present to supply the other requirements of the plant. If this supposition is correct the 3.62 pounds of unoxidized sulfur is sufficient for the production of one ton of alfalfa hay. Our results shown in the table above certainly indicate that this is the case. The amount of sulfur found in the alfalfa hay from our heavily fertilized plots varied from 3.34 to 4.54 pounds to each ton of hay. This hay was gathered from plots which produced a vigorous growth, excellent crops; and the plants possessed the rich, dark-green color characteristic of the best alfalfa. It was cured in the field with bright, sunny weather and no rain, hence none of the sulfur was lost by leaching. It is evident therefore that on some soils under local conditions alfalfa requires for maximum yields only 3.34 pounds of sulfur to each ton of hay.

The figures also show that from 71% to 79% of the sulfur in the fertilized alfalfa is in organic form, while the remainder is in the sulfate form. All of the sulfur in the unfertilized alfalfa is in the organic form.

It is certain that under these field and climatic conditions the amount of sulfur found in the hay from the unfertilized plots is not sufficient for maximum growth. This amount varies from 2.36 to 2.54 pounds for each ton of hay. The alfalfa on these plots, as has already been noted, made an unsatisfactory growth and had a yellowish color and generally starved appearance. Just what the minimum requirement of sulfur is for maximum production has not been determined. But it is certain that 2.54 pounds a ton is below the minimum, and that 3.34 pounds a ton is sufficient. For example, the check plot which contained only 2.54 pounds of sulfur to each ton of hay produced only 2160 pounds an acre in 1915, while the fertilized plot which contained 3.34 pounds of sulfur a ton produced at the rate of 10,020 pounds of hay an acre. That the plant will take up considerably more sulfur when there is an abundance available in the soil than where there is a limited amount is certain.

The increase in the protein content of the hay from the sulfur-fertilized plots varied from .93 percent to 1.89 percent. This is of very great importance, since the protein content gives alfalfa hay its chief value. The feeding value of the hay from the fertilized plots, without reference to the increased yield, is, in fact, sufficiently greater to pay for the fertilizer used.

HOW MUCH AND HOW OFTEN TO APPLY SULFUR FERTILIZER

Our experiments have not been in progress for a sufficient length of time to determine definitely the most profitable amount of sulfur to apply and how often to repeat the application. This will probably vary somewhat with different soils. From the results already obtained it is apparent that very large applications are not necessary, and in the case

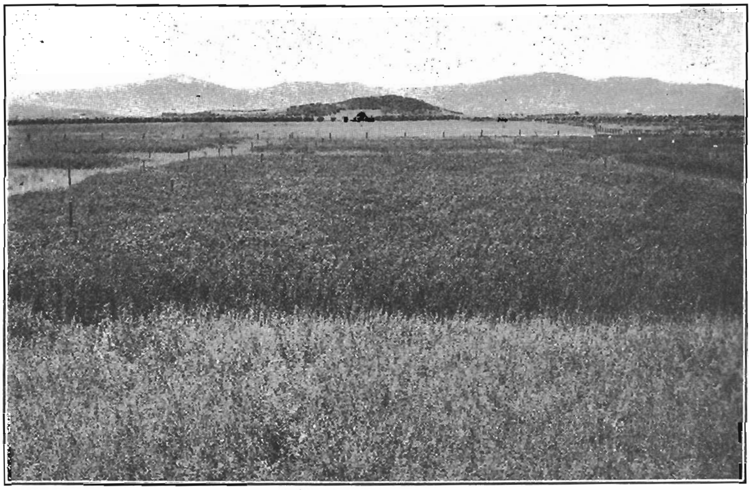

Fig. 8. Plot in foreground not fertilized. Plot in background fertilized with flowers of sulfur at the rate of 200 pounds to the acre. Antelope Clay Adobe soil.

of flowers of sulfur not desirable. These results indicate that on some soils an application of 100 pounds of flowers of sulfur, or 595 pounds of gypsum, is sufficient for at least three years, and will have considerable beneficial effect the fourth season. For example, the plots on Antelope Clay Adobe which in the spring of 1915 were fertilized with 100 pounds of flowers of sulfur, 595 pounds of gypsum, and 823 pounds of superphosphate to the acre, without any additional applications produced just as much during 1917 as adjacent plots which received the same amount in 1915 with the application repeated in the spring of 1917. During the very unfavorable season of 1918 a difference between these plots began to appear. During that season the plots which had received the second application in the spring of 1917 produced from 86% to 91% more than those which had received only the one application in 1915. Owing to the exceptionally cold spring the first cutting was an extremely light one, and owing to drought no second cutting was obtained. The plots which received the one application in 1915 will be left untreated in the future to determine how long this will show an influence.

At first it appears quite remarkable that the one application of 100 pounds of sulfur an acre should prove sufficient for three seasons. But when we consider the composition of alfalfa hay in this valley, and the fact that the largest amount of sulfur removed by one ton of hay in our experiments was only 4.54 pounds, this result is readily explained. If every particle of the sulfur applied to the soil could be readily utilized by the plant, an application of 100 pounds of sulfur would be sufficient for slightly more than 22 tons of alfalfa when grown on the soils used in these experiments. This, of course, is impossible since part of the sulfur applied to the soil is lost in the drainage water and part of it enters into compounds which are not available to the plant.

Judging from the results obtained up to the present time it is probably safe to say that for local conditions an application of 40 pounds of sulfur an acre each year would prove ample. This would be the equivalent of 266 pounds of gypsum (15% sulfur), or 333 pounds of superphosphate (12% sulfur). If one-half of this were utilized by the alfalfa plants it would be sufficient for at least five and one-half tons of hay. It is quite probable that a smaller application of the more available gypsum or superphosphate will prove sufficient. The writers are inclined to believe that an application of 200 pounds of gypsum (15%), or 250 pounds of superphosphate (12%) to the acre each year will prove ample.

A PERMANENT SYSTEM OF ALFALFA FERTILIZATION

It has been demonstrated by these experiments that when either flowers of sulfur or gypsum is applied to alfalfa fields of this valley increased yields will be obtained on most of the soils, at least for a number of years. These materials supply the element sulfur which at the present time appears to be the only element present in too small quantities in most of our local soils to produce maximum crops of alfalfa. Just how long this element when used by itself will be sufficient to produce maximum crops of alfalfa cannot be stated. It is certain that eventually at least one other element, phosphorus, must be added to these soils, and judging from the soil analyses this will have to be done in the near future on some of our soils.

While in most of our experiments so far no increases have been obtained, and in none of them have the increases been very large when phosphorus was added in addition to the sulfates, this will probably not continue to be the case very long. The soil analyses show that some of our soils are already low in phosphorus and none of them contain a very large amount of this element. Analysis made at the Wisconsin Experiment Station (2) show that a five-ton crop of alfalfa removes 29 pounds of phosphorus. The amount removed varies somewhat with the available supply in the soil. When we consider the fact that the total phosphorus content of many of our soils is comparatively low, that only a small portion of the total supply is in an available condition, and that this is constantly being removed by crops, it is obvious that in time this element must also be added to these soils.

Gypsum has been used as a fertilizer on clover in eastern states for many years, and in most instances its use has been discontinued. For a number of years it would produce large increases in yield, and if its use was continued for many years without the addition of other fertilizers its effect would become less and less apparent and in some instances the treated portion of the field would eventually produce less than the untreated part. A probable explanation of this may now be advanced. The gypsum added nothing to the field except the sulfate and a small amount of calcium, while the increased yields removed the phosphorus, potassium, and other elements much faster from the soil than the smaller yields of the untreated fields. A point was eventually reached when some of these elements became too limited for maximum production. If at this stage such elements had been added to the soil in addition to the gypsum it is probable that the beneficial effect of the gypsum would have continued.

The writers believe that ultimately, and in some instances in the near future, the beneficial effects of gypsum and sulfur will become less and less apparent on local alfalfa fields unless phosphorus is also added. Experiments are in progress to determine how long gypsum, when used by itself, will produce maximum yields.

While up to the present time gypsum has given just as good results as superphosphate on most of our alfalfa fields we believe that this will not continue to be the case. The superphosphate adds not only the sulfate that is now needed, but also the phosphorus which will later become deficient in these soils. It appears that superphosphate is a far better permanent fertilizer for alfalfa than gypsum. The superphosphate contains the sulfate and the phosphorus in a very available form, and approximately in the proportion in which the alfalfa plant uses these elements, according to analysis of the alfalfa plant made by the Ohio Experiment Station.

The only objection which can be raised against superphosphate as a fertilizer is its cost. While the cost is not excessive, and while its use is proving highly profitable here, the amount of sulfur and phosphorus which it supplies can be obtained at less cost from certain other materials. These materials are powdered sulfur and rock phosphate. The amount of sulfur and phosphorus contained in one ton of superphosphate can usually be purchased in the form of powdered sulfur and rock phosphate for one-half the price of the superphosphate. The chief advantage of superphosphate is that the sulfur and phosphorus which it contains are far more readily available to plants than that in the flowers of sulfur and the rock phosphate. In fact, before the plants can utilize the sulfur in the flowers of sulfur and the phosphorus in the rock phosphate these materials must undergo certain chemical changes. That such changes do take place in the soil when these materials are added to it has been well demonstrated in laboratory experiments conducted by Lipman, McLean, and Lint (11) of the New Jersey Experiment Station, and by Brown and Gwinn (6) of the Iowa Experiment Station. The work done so far has not demonstrated that all of the sulfur and the phosphorus in these materials becomes available when added to the soil. It is certain that considerable time will be required for all of it to become available. The work done by Brown and Gwinn in Iowa indicates that these elements do become available with sufficient rapidity to supply the needs of the plants. The experiments conducted by these workers show that when sulfur and rock phosphate are added to the soil, part of the sulfur changes to sulfuric acid, which combines with part of the calcium in the rock phosphate, thereby forming calcium sulfate or gypsum; and the rock phosphate being thus robbed of part of its calcium, its phosphorus becomes available to plants. In other words, when these two materials are added to the soil the same chemical changes take place which occur in the fertilizer factory when superphosphate is manufactured by mixing sulfuric acid and rock phosphate. The soil in this case takes the place of the fertilizer factory, although the process of manufacture is very much slower, but cheaper, than that of the factory.

As indicated in Table VI of this bulletin good results have been obtained by applying a combination of 100 pounds of sulfur and 281 pounds of rock phospate to the acre. This one application has proved very effective for two seasons, and judging from our other experiments will prove effective for the third season. We believe that an application of 40 to 50 pounds of sulfur and 200 pounds of rock phosphate an acre each year is ample, and will prove a satisfactory, and the most economical, permanent fertilizer for alfalfa on local soils.

RAINFALL DURING YEARS OF EXPERIMENTAL WORK

It is well known that the rainfall of a region influences to a certain extent the sulfur supply of the soil. The rain contains a small percentage of sulfur, and consequently where the rainfall is very heavy a larger amount is supplied to the soil than in a region where it is light.

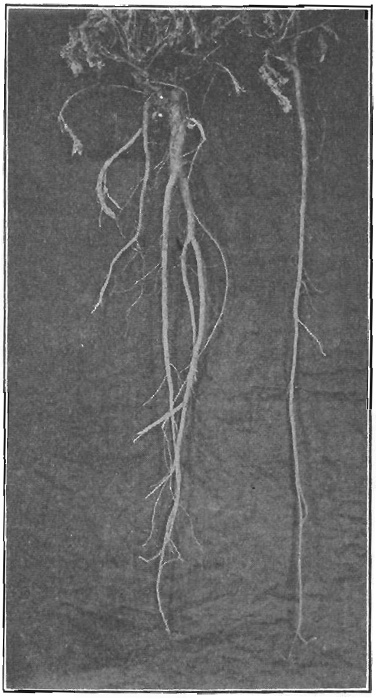

Fig. 9. Large plant with well-branched root system from plot fertilized with gypsum, which supplied sulfur at the rate of 100 pounds to the acre. Small plant, with long, slender, unbranched root system from check plot which received no fertilizer. Note the marked influence of sulfur fertilizers on the development of the root system. Antelope Clay Adobe soil.

Where the rainfall is very heavy, however, more sulfur in the form of sulfates is carried away from the soil in the drainage water than in a region where the rainfall is light. Chemical analyses made of the rainfall at Rothamstead, England, show that approximately 7 pounds of sulfur an acre is brought to the soil every year in that region. The percentage of sulfur in the rain is also probably greater in manufacturing districts where much coal is burned than in regions where little or none is consumed.

In this connection we give below the rainfall of Medford, Oregon, during the past seven years, expressed in inches. These figures were supplied by the U. S. Weather Bureau at Medford.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1912	3.59	2.63	1.66	4.40	2.45	2.19	.20	.07	1.11	1.09	3.38	2.06	24,83
1913	3.62	.10	.43	2.45	1.72	3.09	2.74	.08	.46	.62	2.82	1.91	20.04
1914	5.34	.67	.42	1.43	1.35	.66	.19	.00	.87	2.12	1.02	.56	14.63
1915	1.34	2.46	.89	1.64	1.35	.12	.30	.02	.03	.40	2.96	2.24	13.75
1916	1.99	1.51	1.76	1.66	.69	.74	1.15	.66	.37	.28	1.99	1.71	14.51
1917	1.94	3.37	1.88	1.25	1.01	.06	.00	.09	.30	.00	4.26	2.75	16.91
1918	2.17	2.64	1.69	.39	.54	.01	.03	.25	1.66	1.57	2.29	1,44	14.68

There has been considerable variation in the total annual rainfall and the monthly rainfall during these seven years. The rainfall during the spring and early summer months of 1912 and 1913 was comparatively heavy, while that of the same period during the other years was light. The influence of the fertilizers was just as apparent during the wet as during the dry seasons.

The total rainfall is light compared with the eastern and middle western states.

SUMMARY

1. Recent investigations have shown that the legumes, such as clover and alfalfa, require considerably more sulfur for maximum production than the earlier analyses indicated.

2. In general fertilizer experiments conducted by the Southern Oregon Branch Experiment Station during 1912 and 1913, superphosphate and gypsum produced a marked increase in the yield of alfalfa, and a much darker color, while rock phosphate had no effect whatever.

3. It was often observed that alfalfa, red clover, Canada field peas, and vetch, made a much better growth and possessed a darker color under trees sprayed with lime sulfur than elsewhere.

4. In an experiment during 1914 flowers of sulfur, iron sulfate, and superphosphate each produced an increase of fully 100% in yield of alfalfa, and greatly improved the color of the plants. Rock phosphate in the same field had no influence.

5. Experiments conducted from 1915 to 1918 inclusive on various types of soil showed that the alfalfa and clover crop can be increased from 50% to 1000% on many soils by the use of various fertilizers containing sulfur. These soils include very diverse types ranging from the coarse granite soils to the heaviest adobes.

6. The following fertilizers, containing sulfur, have produced similar beneficial results: flowers of sulfur, superphosphate, gypsum, iron sulfate, sulfate of ammonia, sulfate of potash, sulfate of magnesium, and sodium sulfate.

7. On these soils applications of nitrate of soda, monocalcic phosphate, muriate of potash, and lime have had little or no effect on alfalfa. It is apparent from this that the beneficial results obtained from the various sulfur fertilizers cannot be attributed to any extent to any effect such fertilizers may have in liberating phosphorus, potassium, or lime in the soil, or on nitrification.

8. The soils on which these experiments have been conducted are well supplied with potassium, calcium, magnesium, and iron. Most of these soils contain only limited amounts of sulfur. None of them are acid, and none contain noticeable amounts of alkali.

9. The flowers of sulfur must first change to the sulfate form before the alfalfa plant can use it. This requires considerable time, and for this reason better results are obtained the first season where the sulfur is applied to the soil in the fall or early winter than where applied in the spring.

10. The first season the gypsum and other sulfate fertilizers usually give better results than flowers of sulfur if applied in quantities supplying equal amounts of sulfur. The second season there is little or no difference in the yield.

11. The various sulfur fertilizers have a very stimulative effect on the root system, increasing its size and the number of nodules. This is of great value in taking up larger quantities of plant food, moisture, and atmospheric nitrogen.

12. Analyses made of the alfalfa plant grown under local conditions from fertilized and unfertilized plots show that the fertilized plants contain more sulfur, more protein, and more nitrogen, than the unfertilized plants.

13. Alfalfa hay grown under local conditions does not contain as much sulfur as that in the middle western states. The amount in alfalfa hay from fertilized, vigorous plants varied from 3.34 to 4.54 pounds of sulfur to the ton. The amount in the hay from the unfertilized plots varied from 2.36 to 2.54 pounds of sulfur to the ton.

14. In the hay from the fertilized plots from 71% to 79% of the sulfur is in organic form, the remainder in sulfate form. In the hay from the unfertilized plots all the sulfur is in organic form.

15. Up to the present time in our experiments gypsum (calcium sulfate) has given as good results on most of our soils as superphosphate (calcium sulfate plus phosphorus). Since the phosphorus content of many of these soils is rather low it is probable that the superphosphate will eventually give better results than gypsum.

16. On most of the soils in Southern Oregon an annual application on alfalfa of 200 pounds of gypsum, or 250 pounds of superphosphate, or 40 to 50 pounds of sulfur and 200 pounds of rock phosphate, will prove highly profitable. The latter combination will supply both sulfur and phosphorus most economically.

17. Sulfur should not be used by itself on soils deficient in lime, as it will cause soil acidity. On such soils it should be used only in conjunction with liberal quantities of lime or rock phosphate.

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