Gypsum and Elemental Sulfur as Fertilizers on Annual Grassland[1]

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ABSTRACT

Gypsum and elemental S, each fine enough to pass through a 100-mesh screen, were applied at equivalent rates in each of 4 years to soils deficient in S. Forage yields, percent clover, total S uptake, and concentration of S in the plants were recorded over a 5-year period. The two sources of S were equally effective in increasing yield, S uptake and concentration in the forage, and percentage of clover in the stand the first season after application. However, more S from gypsum than from elemental S was taken up during the winter of the first year, while the reverse was true for the following spring. In the second season after treatment, forage production from elemental S approximated that of the first year; however, yields from gypsum were significantly less than in the first year. In subsequent years forage production declined until there was no significant effect from gypsum in the fourth season nor from elemental S in the fifth season. A significant increase in S uptake and percent S in the forage from gypsum was measured the second year; however, with elemental S a significant increase in S uptake persisted through the third year. Percentage clover declined rapidly with each additional year following application with the decline more rapid where gypsum was applied. Efficiency of the S applied varied from 13 to 34%.

THE IMPORTANCE of sulfur as a fertilizer on California grasslands has been widely recognized. Not only have large increases in production been reported (3, 9) where sulfur was applied, but the areas where the responses occurred are widespread (3, 6).

Sulfur is present in many different fertilizers, generally in the sulfate form. Elemental S also is used as a source of S in fertilizer. Before this form can be utilized by plants, however, it must be oxidized by soil bacteria to sulfate sulfur. The rate at which elemental S is oxidized in the soil is dependent on soil conditions and upon the particle size of the S applied (4). The rapid availability and low residual value of sulfate sulfur applied as gypsum or as superphosphate has been reported by a number of workers (2, 4, 5, 7, 10).

A comparison between surface-applied gypsum and elemental S was made by Conrad (3) with unreplicated treatments at a number of locations in California. Elemental S stimulated yield increases about equal to those obtained with gypsum S, except in areas or seasons of limited rainfall. Under these conditions, gypsum plots outyielded the elemental S plots the first season after application. Residual values of the S carriers were not reported. Bentley and Green (1) reported no differences in the response of annual grassland species when sulfur was applied as gypsum, elemental S, or single superphosphate on California foothill rangeland. Fox et al. (4) reported field experiments in which alfalfa responded more to elemental S the second year after application than the first, while response to gypsum was greater during the first year where the two S carriers were surface applied. In a greenhouse experiment they found that sulfur flour, when mixed with the soil, was as available to corn over a 32-day period as was S from gypsum. However, the availability of larger particles of elemental S was not so rapid as that of the sulfur flour.

Jones (9) applied sulfur at increasing rates up to 80 pounds per acre as gypsum, and reported that near maximum annual forage yields were obtained the first year after application at the 40-pound rate. The subclover component of the forage increased up to the 80-pound rate. In the second season after application forage production from the 40-pound rate was about 72% of the maximum, and from the 80-pound rate it was about 85% of the maximum. The 80-pound rate in the second year was about equivalent to 20 pounds of sulfur as gypsum in the first year.

Information was lacking on how long the effects of gypsum and elemental S persist under field conditions. Therefore, the present study was established to compare the current and residual effects of equivalent amounts of S, applied as gypsum and elemental S, on forage production, S uptake, and botanical composition of annual grassland pasture at two locations in the humid north coastal region in California.

PROCEDURE

Zero, 10, 20, or 40 pounds S per acre were applied as gypsum or elemental S to the surface of an S-deficient Pinole gravelly loam near Hopland, California, in October of each of 4 years. The schedule of treatments and harvests is given in Table 1. Both S carriers were very fine powders, passing through a 100-mesh screen. Sufficient plots were staked out at the beginning of the experiment so that applications were made to plots not previously fertilized. Residual effects were measured until they ceased to be statistically significant. Each treatment was replicated four times. Forage production and botanical composition were measured before the forage began to dry and shatter, usually the latter part of April. During the summer, all forage was removed from the plots.

A similar experiment was established on a more productive but still S-deficient site near Boonville, California, on a soil classified as Willits loam. Management of the plots was similar at both sites except that forage production and botanical composition were estimated both in late February and May in 1964 and 1965; the site was grazed closely by sheep after each sampling.

Subclover (*Trifolium subterraneum* L.) and hardinggrass (*Phalaris tuberosa*) had been seeded at both sites some years previous to the experiments. Adequate stands of subclover were growing on both sites during the experiment. At both locations yields were determined by clipping three 1-ft^2 quadrats per plot, oven-drying the harvested material at 70C, and then weighing it. Botanical composition was determined by visual estimates and by hand-separating clipped grab samples. Total S in the harvested forage was determined by the method described by Johnson and Nishita (8).

RESULTS AND DISCUSSION

Hopland site. Annual rainfall at this site averages about 40 inches per year, falling almost entirely from October through May. The heaviest precipitation occurs in the coolest months of December, January, and February.

Average forage production and S uptake the first year after application of gypsum and elemental S at various rates are shown in Fig. 1. The curves in this figure represent means of 4 years' data. The analysis of variance of both forage production and S-uptake data indicated no significant difference between the two S carriers and no signifi-

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Table 1. Schedule of gypsum and elemental S treatments.

Growing seasons after S application	Year of fertilizer applications*			
	1960	1961	1962	1963
	Year of harvest†			
1	1961	1962	1963	1964
2	1962	1963	1964	1965
3	1963	1964	1965	
4	1964	1965		
5	1965			

* Fertilizer was applied to previously unfertilized plots in October of each year.
† Yields were determined in April each year except 1964 when samples were taken in late May.

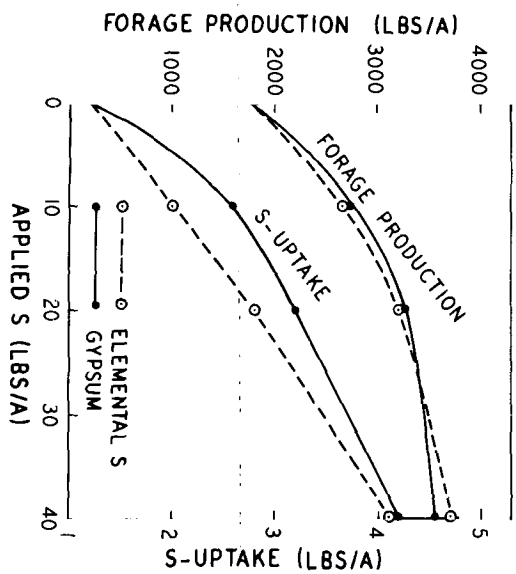

Fig. 1. Forage production and S uptake on Pinole gravelly loam as affected by increasing rates of applied gypsum or elemental S first year after application.

cant carrier-year interaction or carrier-rate interaction. The greatest increases in forage production came with the first increments of S applied. Near maximum amounts of forage were produced with the application of 40 pounds of S per acre. Sulfur uptake increased approximately linearly with each added increment of S up to the 40-pound rate. The concentration of S in the forage varied from .067% where no S was applied to .118 and .110% where 40 pounds of S per acre were applied as gypsum and elemental S, respectively. These results are in agreement with a previous study using rates of S up to 80 pounds per acre and reporting yields and S uptake by grass and clover species (9).

Increased clover, grass and forbs, and total forage production in the four growing seasons immediately following application of 40 pounds of S per acre as gypsum or as elemental S are shown in Fig. 2. The average increase in forage production the first season from the gypsum-treated plots and the plots treated with elemental S were 1750 and 1960 pounds per acre, respectively. Since total forage production from the check treatment averaged 1800 pounds per acre, the application of 40 pounds S per acre from either source increased production about 100% the first season. Clover comprised 12% of the forage in the check treatment, and 59 and 62% of the forage in the gypsum and elemental S treatments, respectively. Both carriers increased the yield of clover slightly more than total production was increased, while the yield of grasses decreased slightly. Nitrogen was limiting as well as S. When S was applied the clovers increased in growth but the grass did not because N was still limiting for the latter. After the first season gypsum and elemental S were not equally effective in increasing forage

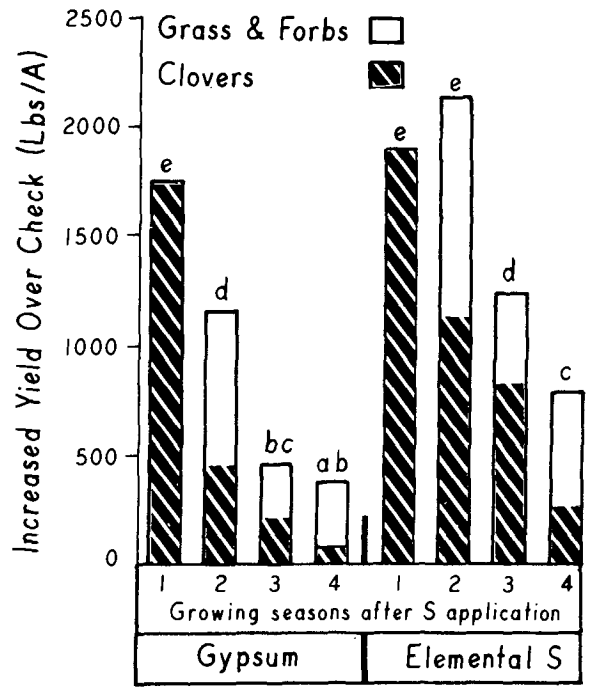

Fig. 2. Increase in forage production, as related to time, following applications of 40 pounds S per acre as gypsum or elemental S. Values indicated by the same letter are not significantly different at the 5% level. The letter "a" indicates the value is not different from the check.

production (Fig. 2). Yields declined rapidly during the second and third season where gypsum had been applied. The clover component of the forage declined more than the grass and forbs component. Forage yield the second season was as high as the first season where elemental S had been applied but declined significantly the third and fourth seasons. As in the gypsum plots, clover declined more than the grass and forbs. The residual effects of the 10- and 20-pound S rates are not given because the increase in production after the first season was approximately linear with each increment of S applied.

In the fifth year after application (data not shown) neither S carrier produced yields significantly different from the check.

For the first four growing seasons immediately following application of 40 pounds of S per acre, gypsum-treated plots produced 3750 pounds per acre more than the check plots, while plots fertilized with elemental S yielded 6140 pounds more. The largest differences in production from gypsum and elemental S plots occurred in the second and third years after application when carry-over effects of elemental S were most evident.

Table 2 indicates the increase in uptake of S from forage harvested at the end of each of five growing seasons following an initial application of 40 pounds of S per acre as gypsum or elemental S. In the first season after application, gypsum increased S uptake 3.0 pounds per acre and elemental S increased uptake 2.9 pounds per acre. There was no significant difference between the amounts of S supplied by the two carriers, indicating that under the conditions of this experiment oxidation of fine S was sufficiently rapid to supply to growing plants as much S as gypsum the first season after application. At the end of the second growing season, S uptake on the gypsum plots was only 1.4 pounds per acre more than on the check, while on the elemental S plots it was 3.0 pounds per acre more.

Table 2. Increases in sulfur uptake when 40 pounds per acre S were applied to Pinole gravelly loam and to Willits loam as gypsum or elemental S.

Seasons after S applied	Increase in S uptake (lb/A) over check*			
	Pinole gravelly loam		Willits loam	
	Gypsum	Elemental S	Gypsum	Elemental S
1	3.0 f	2.9 f	7.5 d	5.9 c
2	1.4 e	3.0 f	2.0 b	5.5 c
3	0.5 bc	1.0 de	0.7 a	2.1 b
4	0.3 ab	0.8 ed	---	0.8 a
5	---	0.3 ab		
Total	5.2	8.0	10.2	14.3

* On one soil type increases in S uptake followed by the same letter are not significantly different at the 5% level. The letter "a" indicates the value is not significantly different from the check treatment. Sulfur uptake in the check treatment had a mean value of 1.5 lb/A on Pinole gravelly loam and 4.1 lb/A on Willits loam.

Table 3. Winter and spring forage production and uptake of S the first (1964)and second (1965) years after the October (1963) application of S as gypsum and elemental S on Willits loam.

Season after application	S carrier and lb S/A	S yield, lb/A			Forage yield, lb/A		
		Feb	May	Total	Feb	May	Total
First	0	1.8 a*	2.3 a	4.1 a	2330 a*	2920 b	5250 a
	Gypsum-40	7.2 b	6.4 b	13.6 b	3240 c	4460 d	7700 b
	Elemental-40	6.2 b	8.1 d	14.3 c	3400 c	4640 d	8040 b
Second	0	1.7 a	2.4 a	4.1 a	1120 a	3650 c	4770 a
	Gypsum-40	3.5 b	3.6 b	7.1 b	1650 b	4430 d	6080 b
	Elemental-40	4.5 c	7.3 d	11.8 c	1680 b	6560 e	8240 c

* Means within a box followed by the same letter are not significantly different at the 5% level.

Apparently more gypsum S than elemental S was leached in the first season. This resulted in greater S uptake from elemental S the second season and in subsequent seasons as well. Over the 4-year period, a cumulative total of 5.2 pounds per acre more S was removed from the single application of 40 pounds per acre S as gypsum than was taken from the check treatment. The elemental S treatment yielded 7.7 pounds per acre more S than the check over the same period. Thus 13 and 19% of the S added as gypsum and elemental S, respectively, were recovered in the 4 years following application.

The concentrations of S in the forage the second year after application of elemental S and gypsum were .106 and .089%, respectively. In the third year the respective values were .071 and .074% and were not significantly different than the check treatment.

Boonville site. Average annual rainfall is about 60 inches, and occurs mainly from October through May. During this period the soil is poorly drained. Total forage production from the check treatment on this site averaged about 4500 pounds per acre per year over the 5-year period. The increases in production of annual forage following S applications were greater than those on the Pinole soil but the relationship between production from gypsum and elemental S was similar on both soils. Therefore the data are not shown. However, the recovery of S from the two carriers on the Willits soil (Table 2) was somewhat different from that on Pinole soil. In the first season after application, 7.5 pounds of S per acre were recovered from gypsum compared with 5.9 from elemental S, indicating the more readily available S in gypsum. In the second year, 5.5 pounds of S per acre from elemental S were recovered, but only 2.0 pounds per acre from the gypsum. During the third growing season, 2.1 pounds per acre were recovered from elemental S and 0.7 pound from gypsum. In the fourth growing season, results from the elemental S treatment were not significantly different from those of the check. Cumulative S recovered during the 4 years following application was 10.2 pounds per acre from gypsum and 14.3 pounds per acre from elemental S. Twenty-six percent of the S added as gypsum and 34% of that added as elemental S was recovered during the period. The recovery of applied S reached nonsignificant levels 1 year sooner on the Willits soil site than on the Pinole. This is probably due to the heavier amounts of rainfall on the Willits soil. In spite of this higher rainfall a greater percentage of applied S was recovered from the Willits soil. This was probably due to the higher level of crop production on the Willits soil.

A comparison of the effects of the two S carriers between the winter period and spring period was of interest because of differences in temperature and rainfall for the two periods. The winter weather is characterized by stormy periods, when the temperature is near 50F night and day, and alternate clear periods, when minimum temperatures are near 30F and maximum temperatures are near 60F. During the spring months there are fewer storms; minimum temperatures during clear periods average near 40F and maximum temperatures average near 70F.

Production of forage in the winter and spring seasons of 1964 and 1965, following application of S in October 1963, are given in Table 3. No significant differences between amounts of forage produced by the individual carriers were noted the first season or at the winter harvest the second year. More forage was produced in the spring of the second year where elemental S had been applied. These facts indicate that both carriers supplied sufficient S until the spring of the second year.

The uptake of S during the winter and spring months of 1964 and 1965 is shown in Table 3. At the February sampling date the first season after application there was no significant difference between the uptake of S from gypsum and elemental S. During the first spring more S was taken up from elemental S than from gypsum, indicating that considerable leaching of gypsum S may have occurred during the winter period. In the second season more S from elemental S than from gypsum was taken up during both the winter and spring periods.

The concentration of S in unfertilized forage in May at the Boonville site was about the same as at the Hopland site. However, where 40 pounds S was applied S percentages were higher at Boonville than at Hopland. The gypsum applied in October 1963 increased the S percentage in the forage to .222 in February and .143 in May 1964 and to .212 in February and .081 in May 1965. The values where elemental S was applied were .182 in February and .174 in May 1964 and .267 in February and .111 in May 1965.

CONCLUSIONS

Forty pounds of S per acre applied as elemental S supplied sufficient S for annual grassland forage needs for 2 years. The same amount of S as gypsum was sufficient for only 1 year. Where elemental S was applied, more forage was produced the second, third, and fourth seasons after application than where gypsum was used. Uptake of S by the crop showed similar differences between elemental S and gypsum.

Most of the benefits derived from fertilizing with S were derived from increased productivity of subclover and indirectly from nitrogen supplied to associated grasses.

The efficiency of the applied gypsum and elemental S varied from 13 to 34%.

These data indicate maximum forage production requires an annual application of gypsum or biennial application of elemental sulfur.

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