Effect of Applied Sulfur on Yield and Sulfur Uptake of Various California Dryland Pasture Species[1]

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SYNOPSIS. Forage production was increased by sulfur applied up to 40 pounds per acre. The subclover component increased up to 80 pounds of S per acre. Annual grass yields at the high rates of S were decreased by clover competition. Higher rates of S application had a greater carry-over effect than the 20-pound rate. Subclover and hardingrass had the greatest increase in uptake of S with increasing rates of applied S, while annual grasses had the least.

LARGE increases in production on California annual grassland pastures, due to S fertilization have been reported by a number of workers. Usually, fall applications of S produced increases in legume growth the first year after application. Yields of nonlegumes increased in the second and third years as available soil N was increased by increased N fixation (1, 2, 3, 8). In some instances a high percentage of the S applied was lost the first year (4, 9). Walker and Williams (11) applied N with and without S and noted that nonlegumes responded to S the first year where N was supplied. McKell and Wilson (10) concluded that S uptake by rose clover *(Trifolium hirsutum* All.) and subclover *(T. subterranean* L.) was increased by S fertilization, but that the uptake might be limited by low temperature even with ample available S.

Much of the work on S fertilization previously reported was done on the dryer parts of California's annual grassland area where subclover is not adapted. Subclover is well adapted to the higher rainfall areas of the north coastal valleys of California. Rose clover also grows on some of the dryer sites in this region. Previous greenhouse studies (7, 10) have indicated that S fertilization is important for both of these species. However, information on the response of rose and subclover to S fertilization under competitive field conditions has been lacking.

The present paper reports the effects of increasing rates of S applied to California's dryland pasture. Of special interest was the effects on (a) forage yields the first and second year after application, (b) contribution of each major species or group to yield, (c) yields at the end of winter and at the end of spring growth, and (d) uptake of S by the various species.

PROCEDURE

The experimental site was a Laughlin gravelly loam at the University of California's Hopland Field Station in the north coastal mountain ranges of California. It had been seeded to sub, rose, and crimson *(T. incarnatum L.)* clovers and to soft chess *(Bromus mollis)* and hardinggrass *(Phalaris tuberosa)* in September 1956. After seeding, the plot was fertilized with varying rates of N and P. By the spring of 1958 there was a good stand of each of the seeded species except crimson clover. However, visual symptoms of S deficiency were noted. In October 1958, half of each of the plots, arranged in a 4 by 4 Latin square, were fertilized with gypsum at the rates of 0, 20, 40, or 80 pounds S per acre. Half of each plot was left for treatment on October 1959. Subplots in each of the S treatments were given 0, 17, 35, or 70 pounds per acre P, applied as treble superphosphate containing about 3% S. Each subplot was fertilized with 160 pounds N per acre as urea to reduce the variability from N applied in previous years.

In October 1959, the previously unfertilized halves of the plots were fertilized with the same treatments as applied in 1958, except that KH_2PO_4 was used to supply the P instead of treble superphosphate in order that S would not be applied in the P carrier, and no N was applied.

The plots which received gypsum in 1958 were refertilized in October 1960 at the same rates. The plots fertilized in 1959 were not fertilized in 1960.

Winter forage production was measured each year of the study by weighing the clippings from 3 one-square-foot quadrats per plot in February or early March; spring forage production was determined from clippings taken in May. All yield samples were oven dried at 70° C. before weighing. After the first clipping each year the plots were heavily grazed by sheep for a short period until the forage was cropped sufficiently close to reduce grass competition to maintain the clover stand.

The yields in Table 1 represent averages for the 2 years, 1960 and 1961. By including only these 2 years, a statistical comparison of yield the first season after application with yield in the carry-over season could be made, over the same 2 seasons. There was a highly significant difference in yield between years, but no significant difference in the interaction between year and rate of sulfur application. Therefore, the data were summarized, omitting the effect of years.

On February 2 and May 5, 1961, grab samples of clipped forage from each plot were placed in a deep freeze to preserve them until they could be separated into species or groups, oven dried, and the contribution of each species to yield measured. Total S (5) in each species was determined.

RESULTS AND DISCUSSION

Sulfur effect on yield. Winter forage yields were increased significantly by the application of 20 pounds S per acre both in the first year of application and in the carry-over year (Table 1). Greater amounts of sulfur than this did not increase yields significantly. Also, there was no significant difference between the first and second year after application at this early date of clipping. Apparently a small amount of S satisfied the need for this element early in the season.

At the May harvest the largest increment of increase during the first season after application was obtained at the 20-pound rate, but 80 pounds S produced significantly more forage than did 20 pounds. On the carryover plots 20 pounds S did not increase yields significantly and yield from 80 pounds was roughly equivalent to that at the 20-pound rate in the first year of application. Thus, while there was significant carry-over into the second year, it occurred only at the 40- and 80-pound rates of application, and even there it was significantly lower than where S was applied during the current season.

Total cumulative yield was increased with each rate of S applied. Highest yields occurred the first year after ap-

Table 1. Forage production at two dates the first and second year after application of increasing rates of S applied as gypsum.

Season after application	Pounds S per acre	Yield,* lb./A., when clipped in		
		February	May	Total
First	0	1,170 a†	2,900 d	4,070 a
	20	1,571 b	5,106 fg	6,677 c
	40	1,686 b	6,193 gh	7,879 d
	80	1,747 b	6,321 h	8,068 d
Second	20	1,800 b	3,810 de	5,610 b
	40	1,681 b	4,124 ef	5,805 b
	80	1,633 b	5,128 fg	6,761 c

* Mean of two years 1960 and 1961. † Means within a column followed by the same letter or letters are not significantly different at the 5% level.

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plication of 80 pounds of S, but yields on the 40-pound plots were not significantly less. Carryover of the 80-pound S rate into the second year increased yields about equal to plots fertilized with 20 pounds of S per acre applied during the current year. Twenty and 40 pounds of S significantly increased yields in the carry-over year.

Contributions of species to yield. Contributions of subclover, rose clover, and the grasses to total yield in February 1961, are given in Table 2. Subclover made the largest and most consistent increases in production as the rate of S increased; rose clover also increased with increasing rates of S, but the results were not so consistent as with subclover. Where S was applied in October 1960, the increase of rose clover was not significant. There were no significant changes in contribution of the grasses at this clipping.

In May 1961, subclover, rose clover, the native clovers, soft chess, and hardinggrass were separated to determine the contribution of each to total production (Table 3). Subclover increased in yield approximately as much from the second 40 pounds of S applied in October 1960 as from the first 40 pounds of S. Much of the subclover yield from the 80-pound S treatment compared to 40 pounds of S was made at the expense of yields from other less desirable species. Near maximum total production of all species combined was reached where 40 pounds of S were applied in October 1960. The 80-pound rate produced the highest yield by a slight, but not significant, margin. The variability of the rose clover, native clover, and hardinggrass data was such that changes were not significant. The production of soft chess was decreased significantly with certain applications of S.

Subclover appears to require more sulfur for maximum growth than the other species. Where S is deficient the application of the 80-pound S rate to a subclover pasture would be desirable in terms of increased clover production. The highest rate of S, coupled with the grazing management on these plots, gave subclover a competitive advantage over soft chess. Previous work by Jones and Evans (6) indicated that the percentage of subclover was greater in a grazed treatment compared to an ungrazed treatment where both were fertilized with single superphosphate.

Decreases in grass yields and increases in subclover yields occurred even in the carry-over year, which is at variance with reports in the literature (1, 2, 3) that S carryover into the second year resulted in a large increase in grasses. The heavy grazing of these subclover plots, in contrast to no grazing of the plots in previous reports, as well as differences in species, soils and climate involved, may account in part for the differences in results.

Uptake and percent S. Total uptake of S the first and second seasons after application increased with increasing rates of S applied, but the increase was greater the year of application than in the carry-over year (Table 4).

Where no S was applied, the annual grasses took up the most S and the native clovers the least. The uptake of S in subclover, rose clover, and hardinggrass was not statistically different from the extremes. Where 20 pounds of S per acre were applied in 1960, rose clover took up the most S, and native clovers took up the least. Where 40 and 80 pounds of S were applied, subclover took up the most and native clovers the least.

The uptake of S by subclover was increased nearly 15-fold, compared with the check, by the application of 80 pounds of S per acre. The same treatment increased hardinggrass 10-fold, and rose clover 3-fold. Sulfur uptake by native clover and annual grasses was not increased significantly.

On the carry-over plots, subclover and hardinggrass accumulated the greatest amounts of S at the heaviest rates of S applied.

The percentages of S in the plants increased with increasing rates of S applied. In the unfertilized plots the values ranged from 0.06% in rose clover to 0.10% in hardinggrass, but these values were not statistically different. The percentages of S approximately doubled the first season after the application of the 80-pound S rate in each species except hardinggrass, which increased about 5-fold. In the carry-over year the percent S also increased, and these increases were significant at the 80-pound rate in subclover, native clovers, and hardinggrass but not in rose clover and the annual grasses.

Nitrogen percentages. The percentage of N in each species increased with increasing rates of S applied except in hardinggrass, where there was no change. Detailed consideration of N concentration in the plants is not within the scope of this paper. It is planned that this information will be presented in a future paper.

Table 2. Winter production of clovers and grasses as affected by increasing rates of S applied as gypsum. Harvested February 2, 1961.

Sulfur applied		Yields, pounds per acre			
Date	lb./A.	Subclover	Rose clover	Grass	Total
Oct. 1960	0	140 a*	70 a	640 a	850 a
	20	397 ab	135 a	850 a	1,382 ab
	40	673 bc	91 a	838 a	1,602 b
	80	932 c	145 a	737 a	1,814 b
Oct. 1959	20	435 b	302 b	761 a	1,498 b
	40	756 c	143 a	854 a	1,762 b
	80	572 bc	182 ab	691 a	1,445 b

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

Table 3. Spring production of grasses and clovers as affected by increasing rates of S applied as gypsum. Harvested May 5, 1961.

Sulfur applied		Yield, pounds per acre					
Date	lb./A.	Subclover	Rose clover	Native clover	Annual grasses	Harding grass	Total
Oct. 1960	0	510 a*	1,220 a	150 a	1,500 a	210 a	3,590 a
	20	1,328 ab	2,391 a	368 a	1,315 ab	612 a	6,011 c
	40	2,221 b	2,482 a	267 a	1,450 a	815 a	7,235 d
	80	3,873 c	1,453 a	377 a	1,019 bc	559 a	7,281 d
Oct. 1959	20	1,725 ab	1,402 a	260 a	744 c	560 a	4,689 b
	40	1,901 ab	1,319 a	342 a	1,163 a	546 a	5,270 b
	80	2,755 bc	1,219 a	310 a	858 c	925 a	6,066 c

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

Table 4. The uptake of S by five competing pasture species as affected by increasing rates of S applied as gypsum.

Sulfur applied		S uptake, pounds per acre					
Date	lb./A.	Subclover	Rose clover	Native clover	Annual grasses	Harding-grass	Total
Oct. 1960	0	0.40 ab*	0.72 a-c	0.13 a	1.20 b-g	0.20 ab	2.65 a
	20	1.27 b-h	2.03 d-i	0.35 ab	1.30 b-h	1.08 a-f	6.03 d
	40	3.04 ij	2.28 f-d	0.41 ab	2.12 d-i	2.01 d-i	9.86 f
	80	5.85 k	2.16 e-i	0.49 ab	1.77 c-i	2.36 g-i	12.63 g
Oct. 1959	20	1.41 b-h	0.94 a-e	0.25 ab	0.62 a	0.92 a-e	4.14 b
	40	1.96 d-i	0.90 a-d	0.40 ab	1.07 a-f	1.01 a-e	5.34 c
	80	3.69 j	1.10 a-g	0.47 ab	1.06 a-f	2.51 b-j	8.83 e

* Means within a column followed by the same letter are not significantly different at the 5% level. A dash represents intervening letters.

SUMMARY

A pasture of subclover, rose clover, and harding and annual grasses produced near maximum response the first year where 40 pounds of S per acre was applied as gypsum; however, the proportion of clover to grass continued to increase as the S rate increased to 80 pounds per acre. The carry-over effect into the second year from 80 pounds of S was roughly equivalent to 20 pounds of S the first year

after application. During the cool winter season 20 pounds of S per acre produced maximum yields. The higher levels of S were not utilized for increased production until the warmer spring months.

Subclover and hardinggrass had the greatest increase in total S uptake as the rate of S applied increased. The uptake in subclover resulted primarily from a large increase in total yield with a relatively small increase in percent S compared with hardinggrass, which increased relatively little in yield with increasing rates of S.

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