# Effect of Sulfur Applied and Date of Harvest on Yield, Sulfate Sulfur Concentration, and Total Sulfur Uptake of Five Annual Grassland Species[1]

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SYNOPSIS. There were differences in yield, $SO_4$-S concentration, and total S uptake among competing species growing at different levels of available S. Yield response to S increased as the season advanced, but the concentration of total S and $SO_4$-S in the plants decreased. The $SO_4$-S concentration in each of the species where no S was applied was indicative of S deficiency. The $SO_4$-S concentration in subclover at flowering appeared to be the best single indicator of S status.

IN CALIFORNIA, S ranks a close third to N and P as a major plant nutrient which must be supplied to maintain crop production (8). While a great many areas of S deficiency are now known through field plot studies, it is important to know the S status of each field in order that it can be fertilized properly. One approach is first to determine the minimum $SO_4$-S concentration in plant tissue required for maximum growth of a given crop. When this is known, samples of a crop then may be taken from the field and analyzed. A comparison between the $SO_4$-S value obtained and that required for good growth would indicate the S status of the field.

The $SO_4$-S concentration as related to growth has been reported for a number of crops. Dijkshoorn (2) found that S deficiency in perennial ryegrass occurred when the $SO_4$-S concentration in the tissue was 320 ppm or less. Ulrich (9) reported that the critical concentration of $SO_4$-S in recently matured sugar beet leaf blades was about 250 ppm. In a greenhouse study Jones (6) found that the critical $SO_4$-S concentrations for immature subclover *(Trifolium subterranean L.)* with from 1 to 5 flowers per runner was about 170 ppm. He found no significant difference among the critical concentrations in the leaflets, petioles, and stems. Jones also found that the critical concentration of $SO_4$-S in flowering subclover growing in the field was about 170 ppm.

Further work was needed to determine the relation of $SO_4$-S concentration in several competing pasture species to total production. Under pasture conditions competition among species is very important and should be considered where fertilizers are under study. Therefore, the purpose of the present investigation was to determine the effect of increasing levels of available S on yield, concentration of $SO_4$-S, and total S uptake for 5 competing annual grassland species at 3 growth stages. The relation of total yield to $SO_4$-S concentration in each of the species was of particular interest.

The five species chosen for this study are common in the annual pastures of the north coastal area of California. Subclover is a high-producing legume well adapted to the area and important in increasing pasture production. Soft chess *(Bromus mollis)*, ripgut *(B. rigidus)*, and filaree *(Erodium botrys)* are important resident annuals found in almost every pasture in the area. Medusahead *(Elymus caput-medusa L.)*, a range weed notably unpalatable after heading, tends to utilize late moisture and crowd out more desirable species.

## PROCEDURE

Eighteen pounds of Holcomb clay loam known to be deficient in S were placed in each of sixty 2-gallon glazed pots. Each pot was fertilized with 50 pounds N, 87 pounds P, and 110 pounds K per acre. The N was applied as $Ca(NO_3)_2$ and the P and K as $KH_2PO_4$. Five S levels (0, 5, 10, 20, and 30 pounds per acre) were applied as $Na_2SO_4$. There were 12 pots for each S treatment, thus making it possible to harvest 4 pots from each treatment at each of 3 harvest dates (February 14, March 23, and April 19, 1961). The surface of each pot was divided into five areas. Each area was seeded to 1 of 5 species on November 14, 1960, and thinned to 3 plants. After each species was clipped, it was oven-dried, weighed, and ground in a Wiley mill. Total S and $SO_4$-S were determined by Johnson and Ulrich's (4) method.

## RESULTS

Yields at each of the clipping dates are given in Table 1. At the first harvest date all plants were in the vegetative stage of growth. The combined yields were increased by the addition of S, and maximum total production came at the 10-pound rate. Increasing the rate of S application from 10 to 20 and 30 pounds per acre significantly lowered the total yield. When the species were considered individually only ripgut increased in yield significantly with the addition of S at the first harvest. Also, ripgut yielded more than any other species at all levels of S. There was no significant difference among the other four species.

At the second clipping all species were vegetative except filaree, which was flowering. The largest increment increase in total production resulted from the addition of the first 5-pound increment of S. There was an additional increase in yield at the 10-pound rate, where production reached a maximum. Increasing the rate of S to 20 and 30 pounds per acre lowered the total yield. Considering the species individually, subclover, soft chess, and ripgut increased significantly in production with the addition of S. Soft chess and ripgut made a relatively large increase with the addition of the first 5-pounds S, while subclover made no large change between any 2 rates. The yields of medusahead and filaree were erratic, and differences were not significant.

By the third clipping filaree had begun to shatter some seeds; there was also some flowering continuing in this

Table 1—Yield of 5 competing annual grassland species as affected by rate of S applied and date of harvest.

| Date | S, lb./acre | Mg. S per pot for various species | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sub-clover | Soft chess | Ripgut | Medusa-head | Filaree | Total |
| Feb. 14 | 0 | 1.1 | 1.3 | 3.3 | 1.7 | 1.8 | 9.2 |
| | 5 | 1.9 | 2.3 | 7.2 | 1.9 | 4.4 | 17.7 |
| | 10 | 3.2 | 4.1 | 9.0 | 2.8 | 4.1 | 23.2 |
| | 20 | 3.3 | 5.2 | 9.8 | 2.9 | 1.8 | 23.0 |
| | 30 | 4.7 | 5.1 | 11.0 | 3.1 | 3.0 | 26.9 |
| LSD (.05) btw. S rates | | 1.1 | 1.8 | 3.5 | 0.7 | ns | 1.0 |
| Mar. 23 | 0 | 1.4 | 1.1 | 3.0 | 0.9 | 2.8 | 9.2 |
| | 5 | 2.5 | 3.0 | 8.1 | 2.3 | 2.8 | 18.7 |
| | 10 | 4.4 | 3.3 | 12.0 | 3.2 | 5.9 | 28.8 |
| | 20 | 8.2 | 3.5 | 11.9 | 2.4 | 7.4 | 33.4 |
| | 30 | 11.0 | 5.8 | 17.2 | 3.1 | 2.1 | 39.2 |
| LSD (.05) btw. S rates | | 3.5 | 1.9 | 5.3 | 1.6 | ns | 1.6 |
| Apr. 19 | 0 | 1.1 | 1.8 | 3.9 | 1.3 | 2.5 | 10.6 |
| | 5 | 3.1 | 3.2 | 8.7 | 2.9 | 2.7 | 20.6 |
| | 10 | 4.9 | 5.6 | 13.3 | 2.7 | 3.9 | 30.4 |
| | 20 | 11.0 | 4.6 | 21.4 | 4.4 | 4.0 | 45.4 |
| | 30 | 15.1 | 6.7 | 18.1 | 2.2 | 7.9 | 50.0 |
| LSD (.05) btw. S rates | | 4.4 | 1.6 | 5.3 | 1.7 | ns | 1.5 |
| LSD (.05) btw. dates | | 1.3 | 0.6 | 1.9 | 0.6 | ns | 0.4 |

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species. Subclover was flowering and setting some seed at this date, medusahead was in the boot, and soft chess and ripgut were flowering. Total yield increased with increasing rates of S applied. The largest increase came with the addition of the first 5-pounds of S per acre; the increases became progressively smaller with each additional increment of S. Considering the species individually, subclover, soft chess and ripgut increased significantly in production with the addition of S. Subclover yields increased most with the first 5-pounds of S, and reached a maximum at the 30-pound rate. Soft chess yields reached a maximum at 10 pounds of S per acre. Ripgut outyielded all other species at all levels of S, reaching a maximum yield at the 20-pound rate. Medusahead and filaree yields were not increased significantly by the addition of S.

The $SO_4$-S concentrations in the plants at each clipping date are given in Table 2. At the first harvest the concentration of $SO_4$-S in the plants grown in soil to which no S was applied was 100 ppm or less, and there was no significant difference among species; however, where S was applied, subclover generally had the greatest $SO_4$-S concentration, followed by soft chess, filaree, ripgut, and medusahead in that order. Several exceptions to this order may be noted.

At the second harvest the $SO_4$-S concentration in the plants receiving no S fertilizer was below the critical value in all instances. Soft chess had the highest concentration of $SO_4$-S of the 4 species at the 5- and 10-pound rates. At the 20- and 30-pound rates the concentration of $SO_4$-S in subclover was equal to that in soft chess, and greater than that in the other 3 species.

Table 2—Effect of increasing S on concentration of $SO_4$-S in 5 annual species at 3 maturity dates.

| Date | S, lb./acre | Ppm $SO_4$-S in various species | | | | |
|---|---|---|---|---|---|---|
| | | Subclover | Soft chess | Ripgut | Medusahead | Filaree |
| Feb. 14 | 0 | 100 a | 100 a | 70 a | 100 a | 90 a |
| | 5 | 820 d | 570 c | 420 bc | 280 b | 670 cd |
| | 10 | 1320 f | 1320 f | 870 de | 610 d | 1120 ef |
| | 20 | 2690 h | 1970 g | 1250 ef | 1020 ef | 1390 fg |
| | 30 | 2760 h | 2140 g | 1280 ef | 1030 | 1520 fg |
| Mar. 23 | 0 | 40 i | 80 a | 40 i | 80 a | 50 i |
| | 5 | 120 j | 270 b | 100 j | 180 j | 100 j |
| | 10 | 290 b | 560 cd | 340 b | 340 b | 340 b |
| | 20 | 1070 e | 970 e | 530 cd | 530 cd | 590 cd |
| | 30 | 1140 e | 1290 e | 710 d | 770 d | 620 cd |
| Apr. 19 | 0 | 40 i | 110 aj | 40 i | 80 a | 50 i |
| | 5 | 50 i | 240 b | 80 a | 140 j | 80 a |
| | 10 | 120 i | 410 c | 270 h | 200 b | 220 b |
| | 20 | 490 c | 700 d | 360 b | 390 b | 290 h |
| | 30 | 820 d | 800 d | 490 c | 380 b | 280 b |

Values followed by the same letter are not significantly different from each other at the .05 level.

Table 3—Total S uptake of 5 competing annual grassland species as affected by rate of S applied and date of harvest.

| Date | S, lb./acre | Yield, g. per pot, for various species | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sub-clover | Soft chess | Ripgut | Medusa-head | Filaree | Total |
| Feb. 14 | 0 | 1.0 | 0.8 | 2.5 | 1.2 | 1.5 | 7.0 |
| | 5 | 1.1 | 1.3 | 3.2 | 1.1 | 2.4 | 9.1 |
| | 10 | 1.3 | 1.5 | 3.9 | 1.5 | 1.6 | 9.8 |
| | 20 | 1.0 | 1.3 | 4.2 | 1.2 | 0.7 | 8.4 |
| | 30 | 1.2 | 1.4 | 4.3 | 1.3 | 1.1 | 9.3 |
| LSD (.05) btw. S rates | | ns | ns | 1.3 | ns | ns | 0.4 |
| Mar. 23 | 0 | 2.4 | 1.6 | 5.1 | 1.3 | 4.3 | 14.7 |
| | 5 | 2.9 | 2.4 | 9.9 | 2.0 | 3.4 | 20.6 |
| | 10 | 3.6 | 2.6 | 10.7 | 2.3 | 5.6 | 24.8 |
| | 20 | 4.1 | 2.2 | 10.1 | 1.7 | 5.1 | 23.2 |
| | 30 | 4.7 | 2.8 | 11.8 | 1.8 | 1.4 | 22.5 |
| LSD (.05) btw. S rates | | 1.8 | 0.7 | 3.4 | ns | ns | 1.0 |
| Apr. 19 | 0 | 2.3 | 2.8 | 8.4 | 2.1 | 6.4 | 22.0 |
| | 5 | 6.1 | 4.0 | 15.8 | 3.9 | 5.7 | 35.5 |
| | 10 | 7.1 | 5.2 | 18.8 | 3.6 | 6.0 | 40.7 |
| | 20 | 8.2 | 3.5 | 23.8 | 3.9 | 4.9 | 44.4 |
| | 30 | 9.5 | 4.7 | 19.2 | 2.0 | 9.6 | 45.0 |
| LSD (.05) btw. S rates | | 2.8 | 1.3 | 8.2 | ns | ns | 2.1 |
| LSD (.05) btw. dates | | 0.8 | 0.4 | 2.0 | 0.5 | 1.9 | 0.4 |

At the third harvest subclover and ripgut had the lowest $SO_4$-S concentrations and soft chess the highest, where no S fertilizer was applied. At the 5- and 10-pound rates subclover was lowest in $SO_4$-S among the 5 species, and soft chess highest. Soft chess also was highest in $SO_4$-S, with subclover next, where 20 pounds of S were applied. Subclover and soft chess were highest and about equal in $SO_4$-S concentration compared to the other 3 species at the 30-pound S rate.

Johnson and Ulrich (4) indicated that organic S may be obtained by subtracting $SO_4$-S from total S. Analysis of the data showed no significant increase in the concentration of organic S due to S application except in subclover at the second and third harvest dates. Therefore, in all species except subclover, the change in total S concentration with treatment was a reflection of change in $SO_4$-S concentration. In subclover, changes in total S also reflected, in large measure, changes in $SO_4$-S. Therefore, data showing organic and total S concentrations in the plant are not given. There was a decrease in organic S as the season advanced.

Total S uptake by the plants is given in Table 3 for the 3 harvest dates. In general, the uptake of S increased as the rate of S increased, except in filaree, which was quite erratic. Where no S was applied there was little or no uptake of S after the first harvest, but where other S rates were applied uptake continued through the third harvest date. However, the species differed in their capacity to take up S through the season. In February, the application of 30 pounds S per acre had increased S uptake by subclover 327% over the check. The same treatment increased S uptake by ripgut 233%. In April, the increase in S uptake was 1273 and 364%, comparing the 30-pound S rate with the check for the 2 respective species.

## DISCUSSION AND CONCLUSIONS

The relation between total production at the final harvest and $SO_4$-S concentration in each of the species on the same date is shown in Figure 1. The curve for soft chess had no sharp break or clearly defined critical value, and the $SO_4$-S values were generally higher for soft chess than for the other four species. Subclover was lowest in $SO_4$-S compared to the other species at the 0-, 5-, and 10-pound S rates and about equal to soft chess at the 30-pound S rate. This resulted in the curve for subclover having a relatively sharp break, and giving a critical value of slightly less than the 170 ppm previously established for subclover (6). The $SO_4$-S values of ripgut, medusahead, and filaree gave curves intermediate between soft chess and subclover.

If $SO_4$-S concentration in plant tissue is to be used to indicate the S status of a pasture, the relation of $SO_4$-S concentration in the plants at various stages of maturity to total production at the final harvest must be considered. The $SO_4$-S values for subclover at 3 dates as related to combined production of all species at the final harvest is given in Figure 2. Subclover was chosen to illustrate this relationship because N was not limiting, and $SO_4$-S concentration in this plant was considered to be the best indicator of the S status of the soil when the plants were at the flowering stage. Where no S was applied the $SO_4$-S concentration was 100 ppm on February 14, indicating low S at an early date, and decreased by only 60 ppm by April 19. However, subclover that had a $SO_4$-S concentration of 1400 ppm on February 14 became deficient by April 19 when the $SO_4$-S concentration dropped to 140 ppm. The total yield at this level of $SO_4$-S in the subclover was 42 g. per pot compared to 45 g. where S was not limiting. From Table 2 it may be determined that where 10 pounds S per acre were applied the $SO_4$-S concentration in subclover decreased at the rate of 28 ppm per day between February 14 and March 23. Under greenhouse conditions it would be difficult to tell what the level of $SO_4$-S should be at any given date early in the season to prevent S deficiency at maturity because the values were changing so rapidly. Under the variables of climate, soils, and grazing pressures found under field conditions, the problem is even more difficult.

It was concluded that $SO_4$-S concentration in the plant indicates the S status of that plant at the time the sample is taken. Work is now under way to extend this information into the field. From the practical view point it now appears that a low-producing stand of subclover should be sampled when it is flowering. If S is low, the field should be fertilized the next autumn. Samples taken from pastures very low in S early in the season would have low $SO_4$-S values, but from pastures where S supplies were just below critical levels samples taken early in the season appear to have little value. In the subclover producing area of California most pastures are too wet to get equipment on them during the winter months, and best responses to fertilization have resulted from early fall applications.

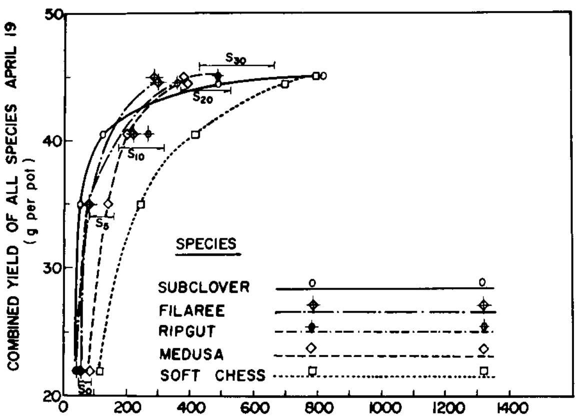


Figure 1—Relation of the $SO_4$-S concentrations in 5 annual grassland species April 19 to the combined yield of all the species on the same date. Statistical significance for $SO_4$-S concentration at the 5% level for each S rate is indicated by the horizontal arrows.

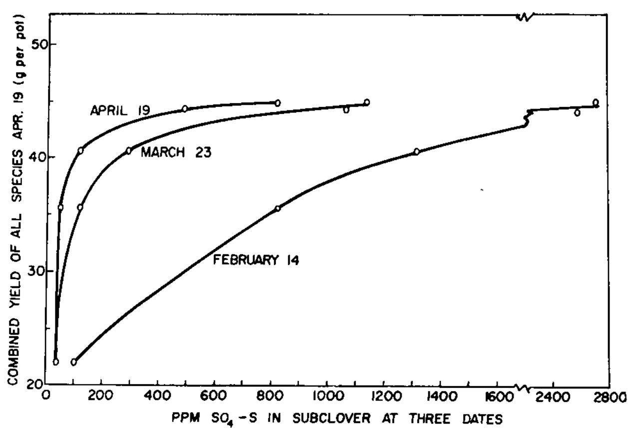


Figure 2—Relation of the $SO_4$-S concentration in subclover at 3 dates to the combined production of all species at the last harvest.

The fact that subclover is a relatively poor competitor for S when supplies are low was indicated by low subclover yields, low $SO_4$-S, and low organic S concentrations where no S was applied. In contrast, subclover had the capacity to absorb and utilize more S than the grasses when it was available, as indicated by its greater percentage increase in yield and S uptake as the rate of S applied increased. Application of 30 pounds S per acre increased ripgut yield by 72% at the first harvest. No other species increased significantly at this date. At the third harvest 30 pounds S per acre increased the yield of ripgut 129% and that of subclover 313% compared to the no-S rate. The combined yield of the five species was increased at each harvest date by the application of S. However, the 20- and 30-pound S rates inhibited total growth early in the season, but not at the last harvest.

Under field conditions equal space for each species would not be provided initially as it was in this case; however, the fact that subclover continued to increase in yield with increasing S even though the pot was dominated by ripgut is significant. Perhaps the grasses became deficient in N at the higher levels of S. If so, they would have been unable to utilize the S, thus giving subclover an advantage, since the latter was well nodulated and apparently fixing N. Walker (10) pointed out that in the absence of outside sources of S, grasses in a grass-legume association would be almost completely dominant as they compete intensively with legumes for S and could utilize almost all the mineral N and S made available by the mineralization of the organic matter. If a little S is applied grasses may respond within the limit imposed by nitrogen deficiency. Anderson and Spencer (1) indicated that in the case of clover S deficiency greatly restricts growth and N fixation, but as the supply of S is increased the growth is not restricted by the lack of N as in the case with the grasses. Thus the $SO_4$-S concentration remains low in the clover until some factor other than N limits growth. Other workers have shown that where S levels are satisfied, pasture legumes have a competitive advantage over the grasses. Hilder and Spencer (3) found that *Medicago* accounted for less than half of an unfertilized stand; after fertilization with S and P the proportion of *Medicago* increased to 85%. Grazing also has been shown to be advantageous to subclover and soft chess, but detrimental to ripgut and medusahead (4, 6). Grazing, plus the addition of S where it is needed, could be helpful in establishing a proper balance among these species.

## SUMMARY

Five annual grassland species were grown competitively in the same pots at different levels of available S, and were harvested at 3 stages of maturity. There were differences in yield responses, $SO_4$-S concentrations, and total S uptake among the five species at different dates. Yield response of subclover, soft chess, and ripgut to S fertilization increased as the season advanced, but this increase was most outstanding in subclover.

The concentration of total S and $SO_4$-S decreased as the season advanced. These decreases were very small where no

S was applied and were large at the higher rates of S. The $SO_4$-S concentration in each of the species where no S was applied was indicative of S deficiency. However, the $SO_4$-S concentration in subclover at flowering appeared to be the best single indicator of S status when all levels of available S were considered.

Where no S was applied there was little or no uptake of S after the first harvest date, but where S was applied it continued to be absorbed up to the third harvest by subclover, soft chess, and ripgut. The increase over the check was much greater for subclover than for any of the other species.