# Responses of Annual-Type Range Vegetation to Sulfur Fertilization

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The importance of remedying the prevalent soil deficiencies of nitrogen, phosphorus and sulfur on California range lands has been increasingly recognized over the past 25 years. Of these three nutritional elements sulfur has received the least attention in connection with its use to enhance growth of resident species of annual-type range vegetation. Recently, however, Martin (1958) indicated the extensiveness of sulfur-deficient areas.

Response of introduced annual legumes such as bur clover *(Medicago hispida)* and rose clover *(Trifolium hirtum)* to sulfur-containing materials has been reported by Conrad et al. (1948), Conrad (1950), Arkley et al. (1955) and McKell and Williams (1960). Response of native annual legumes, chiefly littlehead clover *(Trifolium microcephalum)* was reported by Bentley and Green (1954), Bently et al. (1958), and Woolfolk and Duncan (1962). In most instances growth of associated resident annual grasses has been stimulated, but it has been in the second or subsequent years after sulfur application.

Numerous sulfur-containing materials have been used on California range lands, both experimentally and on a commercial scale. The main materials are elemental sulfur, gypsum, single superphosphate and ammonium sulfate. The last two contain the elements phosphorus and nitrogen, respectively, which complicates the interpretation of results. Conrad (1950) found on bur clover that elemental sulfur gave yield increases about equal to those from gypsum-sulfur except when applied to the soil surface in areas where limited rainfall occurred only in the colder months. Under these conditions, response to gypsum exceeded the response to elemental sulfur. Elemental sulfur is oxidized to sulfuric acid by the action of certain soil bacteria, and rapid oxidation occurs only in warm, well-aerated, moist soil (Aldrich and Schoonover, 1951). Therefore, sulfur application in late fall or winter may have little or no effect until the following spring. McKell and Williams (1960) found from a lysimeter study that gypsum leached rapidly in a season of heavy rainfall.

A series of investigations was initiated in 1955 to study the effects of sulfur fertilization on annual-type range vegetation. The factors studied were (1) forage yield, (2) protein content and (3) sulfur content as influenced by several sources of sulfur and nitrogen applied in the autumn and winter. Nitrogen fertilization was included in all comparisons since it was known to be the primary nutrient deficiency of soils supporting annual-type vegetation (Martin and Berry, 1955).

### Description Of The Area

The study sites are located near Badger (Tulare Co.), California at 3,500 feet elevation in natural grassland areas surrounded by chaparral or woodland (Figure 1). These areas are adjacent to pioneer homesteads, and in the early decades of this century provided arable land for the production of cereal hay. The plant community is dominated by winter annual grasses, chiefly *Bromus mollis, B. rigidus, Avena fatua,* and *Festuca megalura* with a lesser component of forbs such as the

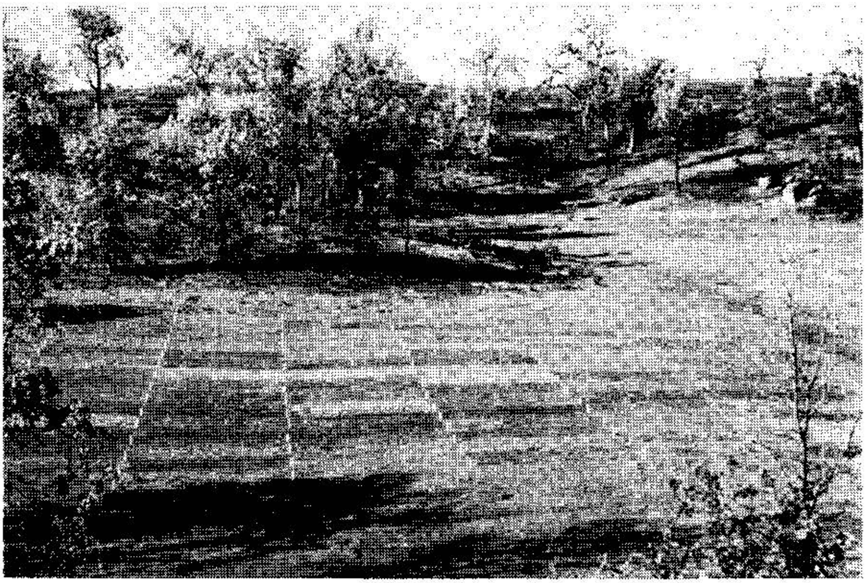

FIGURE 1. Site of experiment 3 showing evidence of response to September fertilizer applications. Photo taken February 1957.

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winter annual, *Erodium botrys,* and the summer annual tarweed, *Hemizonia virgata.*

The main soil of the experimental areas is represented by the Auberry series described as follows: grayish-brown, moderately deep, well-drained, slightly acid, moderately developed prairie soil, derived from crystalline, granular, acid, igneous rocks weathered in place.[2]

The climate is of the Mediterranean type or dry-summer subtropical (Koppen's Csa) and has the following characteristics: annual precipitation of 35 inches occurring mainly in the winter, summers essentially rainless; temperatures mild in winter and warm to hot in summer (Kesseli, 1942); mean annual temperature 56° F.

## Procedure

### Experiment 1

During February 1955 nitrogen, both as ammonium nitrate and ammonium sulfate, was applied at 33, 66 and 132 pounds of nitrogen per acre. The ammonium sulfate applications contained 37, 75 and 150 pounds of sulfur per acre, respectively. Plot size was 50 by 109 feet. In this and the following experiments, protein was determined by the macro-Kjeldahl method and sulfur by the method of Johnson and Nishita (1952).

### Experiment 2

In December 1955, ammonium nitrate, gypsum, and ammonium nitrate plus gypsum were applied at rates equivalent to 100 pounds of nitrogen, 107 pounds of sulfur, or both, per acre in eight replications.

### Experiment 3

Sulfur was applied in the materials gypsum, elemental sulfur and ammonium sulfate. Combinations of gypsum and elemental sulfur with ammonium nitrate and urea were also used as well as ammonium nitrate and urea alone. The rates of application were sulfur—120 pounds per acre and nitrogen—105 pounds per acre. The fertilizers were main plot treatments, and sub-plot treatments were times of application (September 1956 and February 1957) in a split-plot design. The size of sub-plots was 10 by 20 feet, and the treatments were replicated six times. A sample from each plot was hand separated by species after harvesting in May.

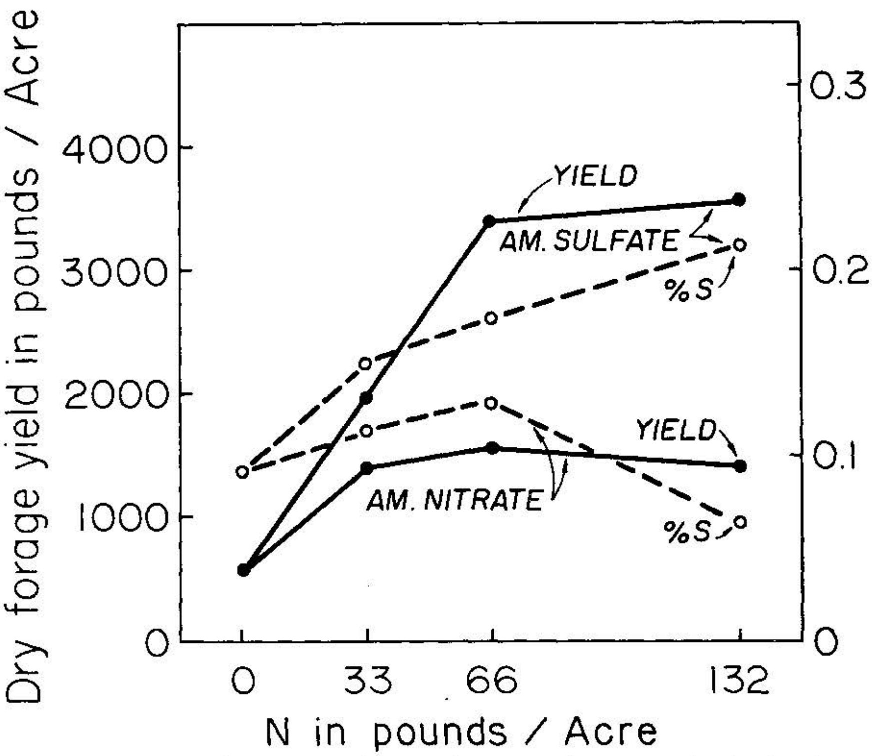


FIGURE 2. Yield of sulfur content of forage from annual-type range fertilized with ammonium sulfate and ammonium nitrate (equal nitrogen basis), Experiment 1.

### Experiment 4

Procedure was the same as for experiment 3 except that the times of application were September 1957 and February 1958, and a uniform application of an additional 66 pounds of nitrogen per acre was applied over the whole plot area in September 1958.

## Results

### Experiment 1

The results of the first experiment indicated soil deficiencies of both nitrogen and sulfur. Nitrogen alone applied as ammonium nitrate increased forage yield by a maximum of 880 pounds per acre (Figure 2). Sulfur plus nitrogen applied as ammonium sulfate was superior to nitrogen alone at all levels with a maximum additional increase over the best ammonium nitrate treatment of 2,110 pounds per acre. Visual observation before sampling indicated greener color of foliage on the plots receiving sulfur. Plots that received nitrogen only were not noticeably different in color from unfertilized plots.

Analyses showed that forage on the control plots and on the plots fertilized with ammonium nitrate contained less than 0.13 percent sulfur (Figure 2). Ammonium sulfate, by supplying both sulfur and nitrogen, increased the sulfur content of the forage to 0.21 percent at the highest rate of application. The yield response leveled off at 0.18 percent sulfur in the harvested forage.

Application of ammonium nitrate raised the crude protein

[2] *Huntington, G. L., personal communication.*

**Table 1. Crude protein content and N:S ratio of forage from annual-type range fertilized with ammonium sulfate and ammonium nitrate.**

| Fertilizer material | N | S | Crude Protein | | N:S ratio |
|---|---|---|---|---|---|
| | Pounds/acre | | Percent | Pounds/acre | |
| Control | 0 | 0 | 7.9 | 45 | 13.7 |
| Ammonium nitrate | 33 | 0 | 10.2 | 143 | 14.4 |
| Ammonium nitrate | 66 | 0 | 12.3 | 179 | 15.2 |
| Ammonium nitrate | 132 | 0 | 13.1 | 184 | 31.7 |
| Ammonium sulfate | 33 | 37 | 6.5 | 127 | 7.0 |
| Ammonium sulfate | 66 | 75 | 8.7 | 295 | 7.9 |
| Ammonium sulfate | 132 | 150 | 10.8 | 384 | 7.8 |

(nitrogen x 6.25) level of the forage from 7.9 percent for the control to 13.1 percent for the highest rate (Table 1). Ammonium sulfate applied at equivalent nitrogen rates depressed crude protein percentage by an average of 3.2 percent. However, the enhancement of yield by the sulfur in ammonium sulfate overbalanced the reduced protein concentration; thus, the crude protein production on an acre basis was increased at the higher rates of application. At the highest rate of application ammonium sulfate produced 384 pounds per acre crude protein whereas ammonium nitrate produced 184 pounds per acre.

The species in greatest abundance at the test site were soft chess *(Bromus mollis)* and broadleaf filaree *(Erodium botrys)*. After maturity was achieved by the winter annuals tarweed *(Hemizonia virgata)*, a summer annual, assumed dominance. Visual observaton indicated a reduction in the prevalence of tarweed was associated with certain fertilizer treatments. The reduction resulting from the ammonium sulfate treatments ranged from 30 to 60 percent with the greatest reduction occurring with the highest rate of application. Ammonium nitrate had no effect on tarweed abundance except a 10 percent reduction at the highest rate.

**Experiment 2**

To detect possible responses to sulfur alone as well as to a nitrogen and sulfur combination a second trial was established the following year using gypsum, ammonium nitrate and the combination of the two. A moderate increase in forage production was obtained following the ammonium nitrate treatment, but no increment resulted from gypsum applied with ammonium nitrate, nor did the gypsum-alone treatment differ from the control. Rain began the day after the applications were made, and 14 inches fell within a month. Gypsum is readily leached as shown by the lysimeter work of McKell and Williams (1960). Thus leaching would seem to be a most reasonable explanation for the lack of sulfur response in this particular season. This hypothesis is supported by tissue analysis which showed that very little additional sulfur was taken up by plants on the gypsum treated plots. This was in contrast to the marked increase in sulfur content the previous year when the response to ammonium sulfate was large.

**Experiment 3**

In experiment 3, several carriers of both nitrogen and sulfur were applied in the autumn and in the winter. The averages of the two times of application show that nitrogen alone from both ammonium nitrate and urea produced a large response in forage yield (Table 2). The several forms of sulfur in combination with nitrogen resulted in further significant increases in production.

Hand separation of forage samples for botanical composition showed that the most prevalent grass was soft chess *(Bromus mollis)*. Other grasses were principally *B. rigidus, Avena fatua* and *Festuca megalura*. The most important forbs were the filarees *Erodium botrys* and *E. cicutarium*. Other forbs included *Hemizonia virgata, Plagiobotrys northocarpus* and *Amsinkia testellate*. Legumes noted were, in very minor amounts, *Trifolium microcephalum, T. variegatum, Lupinus bicolor*, and *Lotus purshianus*. The botanical separation data were combined for both times of application of the two nitrogen carriers and the five nitrogen and sulfur combinations for presentation in Figure 3. Soft chess and filaree responded equally well to nitrogen; other grass produced a lesser response; and other forbs and legumes showed no response. Soft chess demonstrated a strong response to sulfur in combination with ni-

**Table 2. Forage production by annual-type range fertilized with various sources of nitrogen (105 pounds/acre) and sulfur (120 pounds/acre in the autumn or winter, Experiment 3.**

| Fertilizer material | Autumn applied | Winter applied | Ave. |
|---|---|---|---|
| | (pounds/acre) | | |
| Control | 1060 | 1060 | 1060 |
| Ammonium nitrate | 2970 | 2950 | 2960 |
| Ammonium nitrate and gypsum | 3610 | 3560 | 3580 |
| Ammonium nitrate and elemental sulfur | 3780 | 4000 | 3890 |
| Urea | 2850 | 2190 | 2520 |
| Urea and gypsum | 3050 | 3880 | 3460 |
| Urea and elemental sulfur | 3380 | 4330 | 3860 |
| Ammonium sulfate | 3160 | 4180 | 3670 |
| LSD 5% fertilizer | 770 | 770 | 480 |
| LSD 5% time | 850 | 850 | ...... |

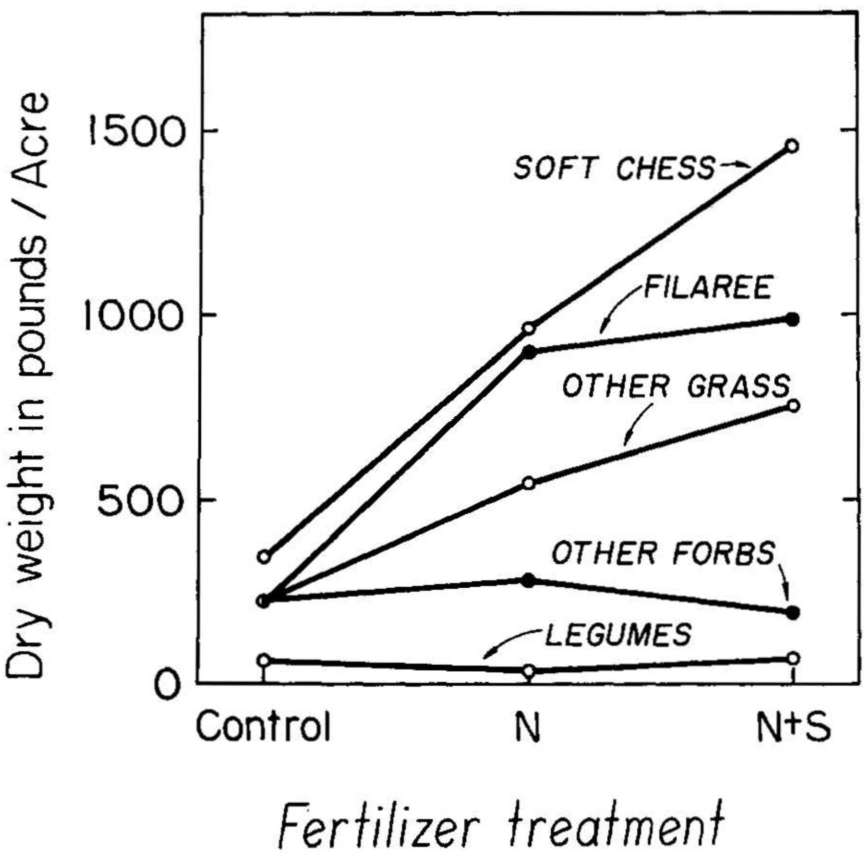


FIGURE 3. Botanical components of annual-type range fertilized with nitrogen (105 pounds/acre), and equivalent nitrogen plus sulfur (120 pounds/acre), Experiment 3.

trogen; other grass produced a lesser response and filaree, other forbs and legumes showed no response to sulfur.

The results of sulfur analyses revealed that the sulfur percentage of the whole forage was increased significantly from 0.12 for the control plots to 0.18 for the nitrogen-sulfur plots (Table 3). The increase in sulfur percentage of each of the forage components approached significance. The sulfur concentration in the plants fertilized with nitrogen only was not significantly different from the controls. The protein percentage of whole forage was not appreciably influenced by fertilization in this experiment, although filaree responded positively and the other forbs, negatively.

**Experiment 4**

In experiment 4 the treatments used in experiment 3 were repeated at a nearby location with substantially the same yield response at a slightly lower level of production over all in 1958 (Table 4). The annual grasses again responded strongly to nitrogen, with a further large increase in production occurring where sulfur was added to nitrogen (Figure 4). In this location and season the forbs responded to neither nitrogen nor sulfur.

A blanket application of urea was applied over experiment 4 in the autumn of 1958, and carry-over sulfur responses were measured in the subsequent year. The yields in 1959 showed a response from residual sulfur applied in the autumn of 1957, but there was no residual effect of sulfur applied in the winter of 1958. Apparently, residual response to the autumn application was the result of sulfur uptake by the plants and subsequent return during decomposition of plant residues between growing seasons, and then uptake by plants again in the 1958-59 growing season.

**Discussion**

Previous reports have attributed increases in production of winter annual range grasses resulting from sulfur fertilization to an initial stimulation of native or introduced legumes, followed in the subsequent year or years by increased grass production as a result of a nitrogen accumulation in the soil from the legumes (Conrad et al., 1948 and Bentley et al., 1958). However, in these

**Table 3. Sulfur and crude protein content of various botanical components and the N:S ratio of whole forage from annual-type range fertilized with nitrogen (105 pounds/acre) and equivalent nitrogen plus sulfur (120 pounds/acre), sources combined, Experiment 3.**

| | Fertilizer treatment | | | |
|---|---|---|---|---|
| Forage component* | Control | Nitrogen | Nitrogen-Sulfur | LSD 5% |
| | | Sulfur (Percent) | | |
| Soft chess | 0.11 | 0.08 | 0.14 | 0.05 |
| Other grass | .11 | .10 | .18 | .05 |
| Filaree | .13 | .09 | .20 | .09 |
| Other forbs | .16 | .14 | .28 | .14 |
| Average (weighted) | .12 | .09 | .18 | .06 |
| | | Protein (Percent) | | |
| Soft chess | 9.8 | 12.1 | 8.6 | NS |
| Other grass | 7.4 | 8.2 | 7.8 | NS |
| Filaree | 7.4 | 10.8 | 9.4 | 1.5 |
| Other forbs | 16.3 | 14.9 | 12.6 | 3.1 |
| Average (weighted) | 10.2 | 11.1 | 8.9 | 1.8 |
| | | N:S ratio | | |
| Whole Forage | 12.8 | 19.0 | 8.1 | ...... |

*Legume component inadequate for chemical analysis.

**Table 4. Forage production by annual-type range fertilized with various sources of nitrogen (105 pounds/acre) and sulfur (120 pounds/acre) in the autumn or winter and with the residual the succeeding year. Experiment 4.**

| Fertilizer material | 1958 | | | 1959 | | |
|---|---|---|---|---|---|---|
| | Autumn applied | Winter applied | Ave. | Autumn applied residual | Winter applied residual | Ave. |
| | (Pounds/Acre) | | | | | |
| Control | 960 | 960 | 960 | 1420 | 1420 | 1420 |
| Ammonium nitrate | 2260 | 2160 | 2210 | 1500 | 1560 | 1530 |
| Ammonium nitrate and gypsum | 3490 | 2820 | 3160 | 2030 | 1640 | 1840 |
| Ammonium nitrate and elemental sulfur | 2920 | 3000 | 2960 | 2040 | 1720 | 1880 |
| Urea | 2370 | 2150 | 2260 | 1500 | 1730 | 1620 |
| Urea and gypsum | 2840 | 2860 | 2850 | 1660 | 1610 | 1640 |
| Urea and elemental sulfur | 3100 | 2650 | 2880 | 2100 | 1640 | 1870 |
| Ammonium sulfate | 3230 | 2670 | 2950 | 2280 | 1430 | 1860 |
| LSD 5% fertilizer | 680 | 680 | 530 | 560 | 560 | 470 |
| LSD 5% time | 600 | 600 | ...... | 460 | 460 | ...... |

experiments there was a direct effect of the sulfur on the grass production with legumes participating in no obvious manner. A direct response to sulfur fertilization in cereal grain production has been reported by Harder and Baker (1961).

Walker and Adams (1958) have reported that perennial grasses have the ability to compete successfully with Trifolium species for the available sulfur in the soil. In our experiment, increase in percent sulfur in the filaree and forbs in the presence of applied sulfur was at least as great as that in the soft chess and other grass (Table 3). Hence, competition for sulfur does not seem to explain the increased growth of grasses. Rather it appears that the grasses may require a higher level of sulfur than the other components of the plant community. Alternately, it may be that the competitive interaction was indirect, i.e. that the taller growing grasses were able to shade the forbs by the advantage in growth obtained from more adequate sulfur nutrition.

Loosli (952) has proposed a critical ratio of nitrogen to sulfur of 15 in feedstuffs for ruminants. Forages having ratios greater than this are considered to contain inadequate sulfur. Ratios for the whole forage were calculated from the nitrogen and sulfur analyses conducted in experiments 1 and 3. Ratios for nitrogen-only treatments varied from 14.4 to 31.7 indicating marginal to very inadequate sulfur levels from the standpoint of ruminant nutrition. The range of ratios of 7.0 to 8.1 for the various nitrogen-sulfur treatments is evidence of adequate sulfur levels in the forage produced (Tables 1 and 3).

There were no significant differences among the sources of nitrogen or sulfur in experiments 3 or 4 (Tables 2 and 4). Time of application had a statistically significant effect, on the average,

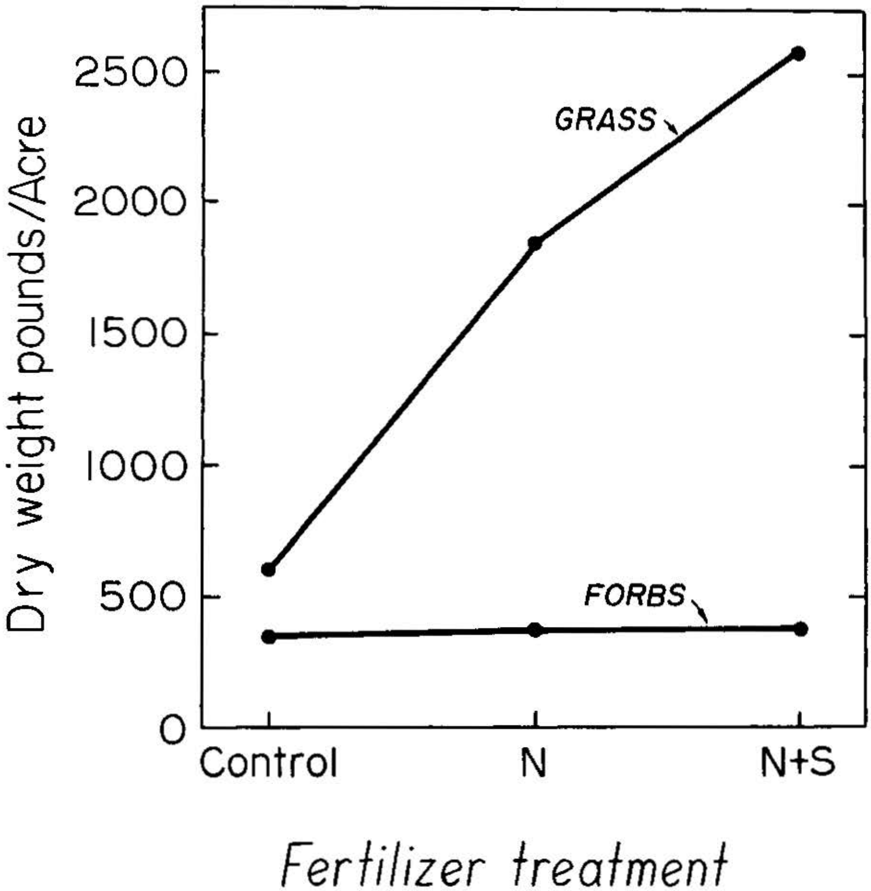


FIGURE 4. Botanical components of annual-type range fertilized with nitrogen (105 pounds/acre) and equivalent nitrogen plus sulfur (120 pounds/acre), Experiment 4.

**Table 5. Monthly precipitation during growing season, Badger (Tulare Co.) California.**

| | 1954-55 | 1955-56 | 1956-57 | 1957-58 | 1958-59 | Ave. |
|---|---|---|---|---|---|---|
| | | | (Inches) | | | |
| September | 0 | 0 | 0 | 1.50 | 2.15 | |
| October | 0 | 0 | 2.16 | .87 | .30 | |
| November | 3.85 | 3.10 | 0 | 2.96 | 0 | |
| December | 3.65 | 16.05 | 2.35 | 6.13 | .85 | |
| January | 4.50 | 6.70 | 2.91 | 6.30 | 5.10 | |
| February | 7.90 | 2.20 | 6.91 | 10.25 | 7.20 | |
| March | .30 | 0 | 5.12 | 16.27 | 0 | |
| April | 3.95 | 3.65 | 6.29 | 5.20 | 1.55 | |
| May | 1.25 | 2.97 | 1.47 | 1.90 | 0 | |
| Seasonal Total to Feb. 1 | 12.00 | 25.85 | 7.42 | 17.76 | 8.40 | |
| Total | 25.40 | 34.67 | 27.21 | 51.38 | 17.15 | 31.16 |

but it was not consistent among materials applied in the two successive years and is somewhat difficult to interpret. Where differences were apparent, winter application was superior to autumn application in experiment 3 and autumn application was superior to winter application in experiment 4. Precipitation was sparse in the fall of 1956, since only 7.4 inches of rain was recorded to February 1957, and it is assumed that soil moisture was inadequate for optimum utilization of autumn application in experiment 3 (Table 5). A more adequate rainfall of 17.8 inches was recorded by February during the 1957-58 season, but excessive rain of 16.3 inches fell during the four weeks immediately after the winter application in experiment 4. In this instance undue leaching probably was an unfavorable factor.

Cattle were allowed to graze all plots after sampling. In all cases the cattle grazed the fertilized plots more heavily than they grazed the controls.

## Summary

Previously reported increases in annual grass production following sulfur fertilization have been attributed to an initial stimulation of native or introduced legumes, followed in subsequent years by increased grass production as a result of nitrogen build-up in the soil by the legumes. In the experiments reported here various sources of nitrogen and sulfur were applied in the autumn and winter seasons to resident annual-range type vegetation. Combinations of sulfur and nitrogen materials resulted in increased forage production over nitrogen applications alone. The increased yield due to sulfur fertilization occurred consistently in the annual grass component, with no perceptible response by the forbs. Possibly superior competitive ability of the grass for sulfur *per se* does not explain their response, as the sulfur content of the forbs was equal to or greater than the grasses in all treatments. The nitrogen-sulfur ratio was affected by fertilization, being widened by nitrogen applications and narrowed by sulfur and nitrogen combinations. It is concluded that sulfur can be an important fertilizer element on annual-type range, and can enhance directly, the growth of common annual-range grass species when their need for nitrogen is satisfied.

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