Sulfur or Sulfur Plus Nitrogen Increases Beef Production on California Annual Range

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Abstract

A 6-year study was conducted to evaluate the response of California annual range to triennial applications of sulfur only and sulfur plus nitrogen fertilizer. Range response was evaluated in terms of length of the green season, steer weight gain, total beef production and steer days of grazing/ha. Neither fertilization treatment consistently lengthened the green season nor influenced steer weight gain compared to nonfertilized range. Steer days of grazing and total beef production/ha were greatest on sulfur plus nitrogen-treated range, intermediate on sulfur only-fertilized range and least on nonfertilized range. Sulfur only-fertilized range increased beef production about 60 kg/ha compared to nonfertilized range, and range fertilized with sulfur plus nitrogen increased beef production nearly 50 kg/ha more than sulfur only-fertilized range.

On California's annual range, most of the herbage is produced between early February and mid-April, when soil moisture is generally abundant and rising temperatures foster rapid plant growth. Forage selected by cattle during this time of the year is well balanced nutritionally and produces the most rapid animal weight gains. However, as annual herbage matures and dries, generally during mid-June, the rate of animal weight gain drops rapidly. Wagnon et al. (1958) found that without supplements, weaner and yearling steers gained weight only during the green season; they maintained weight through the dry-forage season and lost weight during the winter season.

Conrad (1950) and Martin (1958) reported a widespread sulfur deficiency in several soils derived from a wide variety of parent materials at many locations throughout California. Bentley (1946) found that pit-run gypsum increased herbage production on the San Joaquin Experimental Range. Fertilization with sulfur every third year increased annual herbage yields, grazing capacities (Bentley et al. 1958), and steer gains (Wagnon et al. 1958) over those on nonfertilized range. Bentley and Green (1954) noted the first marked response to sulfur fertilization was a stimulation of legume growth. Grass production increased the year after stimulation of legumes and the beneficial effects held over for a few years after sulfur fertilization.

Martin (1958) reported that soil nitrogen deficiency was at least as widespread in California as sulfur deficiency. The first year after treatment, cattle weight gains were greater on nitrogen-fertilized range than on nonfertilized range, but less than where both nitrogen and sulfur had been provided (Martin and Berry 1970). Similar though reduced responses were reported the second year after treatment. Triennial applications of sulfur or sulfur plus nitrogen increased herbage yields and grazing capacity of annual ranges (Conrad et al. 1966). Woolfolk and Duncan (1962) reported that herbage production, grazing use, and animal weight gain were greatest on annual range fertilized with sulfur and nitrogen. Fertilization with sulfur alone was less beneficial. Benefits of range fertilization included earlier range readiness, increased herbage production, and increased herbage protein content (McKell et al. 1960).

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This paper reports the effects of sulfur and sulfur plus nitrogen fertilizers on length of the green season, range stocking rate, beef production and steer weight response on annual range at the San Joaquin Experimental Range, Madera County, California.

Study Area

The Experimental Range is located approximately 32 km north of Fresno, Calif., in the low foothills on the Sierra Nevada Mountains. The climate is Mediterranean, with mild, rainy winters and hot, dry summers (Bentley and Green 1954). Precipitation, primarily rain, averages about 48 cm annually, 98% occurs from October through May.

From June through September, daily temperature averages 24° C, and daily maximum temperature averages 32° C. Soil is primarily Ahwahnee, coarse, sandy loam, (Alfisol, Mollic Haploxeralf), of granitic origin, and generally less than 76 cm deep. The vegetation includes about 400 introduced species of annual plants, (Bentley and Talbot 1951, Biswell 1956, Talbot and Biswell 1942). The more abundant species are soft chess *(Bromus mollis),* ripgut brome *(B. rigidus),* red brome *(B. rubens),* slender oat *(Avena barbata),* wild oat *(A. fatua),* broadleaf filaree *(Erodium botrys),* red-stem filaree *(E. cicutarium)* and bur clover *(Medicago hispida).*

Methods

Range Units

The 12 range units used in the present study were used in earlier studies cited above (Woolfolk and Duncan 1962, Conrad et al. 1966). Residual effects from previous studies, if present, were considered innocuous. The units were judged as having nearly equal grazing capacities. Each range unit would carry a minimum of 10 yearling steers throughout an average green season and have 730 ± 170 kg/ha residual forage at the end of the grazing season.

Area of the units ranged from 7.3 to 31.8 ha. Disparity in unit size was needed to equalize grazing capacity because of differences in soil depth and topography. Two blocks of three range units were established on soil generally less than 10 cm deep with slopes generally greater than 25%, hereafter referred to as shallow-soil units. Two blocks of 3 units were established on soil which averaged about 60 cm deep with 10 to 25% slope, referred to as the deep-soil units.

Range units were stocked annually during the green season from 1969 to 1974, based on forage availability and range readiness. The green season within each range unit was judged independently. Each range unit was considered ready and was stocked when soft chess and broadleaf filaree were 6.4 and 3.8 cm tall, respectively. After a unit was stocked, test animals remained within the unit until the end of the green season for that unit. The green season was considered ended when cattle concentrated on soft chess and red-stem filaree on the lower slopes, on the summer-growing Spanish-clover *(Lotus americanus),* and on green plants under trees as described by Bentley and Talbot (1951).

Treatments

Sulfur and sulfur plus nitrogen were applied to designated range units in the fall of 1968; treatments were repeated on the same units in 1971. Four units served as nonfertilized controls. One replication of the control and each fertilizer treatment was randomly assigned to the units in each of the 4 blocks. On the sulfur only

Table 1. Length of the green season and annual precipitation on California annual range from 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Green season, days							
Sulfur + Nitrogen	156a[1]	138a	144a	108a	160a	202a	151a
Sulfur only	156a	133a	116b	80b	135b	201a	137a
Non-fertilized	156a	134a	134ab	87b	141b	202a	142a
Average	156±0.3[2]	135+5.5	131±10.1	92+9.9	145+8.1	201+0.3	143+8.1
Precipitation, cm	82	45	40	27	61	58	52

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

treatment, sulfur was applied at the rate of 67 kg/ha, in the form of gypsum. The sulfur plus nitrogen treatment consisted of a 3 to 1 mixture, by weight, of ammonium sulfate and ammonium nitrate. The mixture, as applied, provided 67 and 90 kg/ha of sulfur and nitrogen, respectively.

Animals

Three hundred short yearling weaned steers, averaging about 190 kg, were purchased annually, just prior to range readiness. The animals, most with predominately Hereford lineage, were weighed and 120 steers of medium weight were selected as test animals. The 120 steers were separated by weight into 12 groups of 10 animals each so that total weight of test steers was equalized between groups. One group was randomly assigned to each range unit. All test groups were held in a common nontest unit until forage within each unit was judged ready for grazing. When forage within each test unit was ready for grazing, the preassigned test group of animals was released in the respective test unit.

Test animals were weighed at the beginning and end of the green season within the assigned range unit. Test animal weights were used to calculate average daily weight gain and seasonal weight gain per steer. When more herbage was available during the green season than test animals could consume, nontest animals were placed in range units as needed, to equalize use between units and to provide uniform use of herbage throughout the grazing season. Days of grazing by both test and nontest animals were used to calculate total steer days of grazing. Beef production was calculated from total steer days of grazing and the average daily weight gain of test steers.

Data were analyzed, following analysis of variance procedures, for a two-factor split-plot design. The 6-year average treatment means were compared by Gaines' and Howell's T-modification (Keselman and Rogan 1978). Differences were tested for significance at the 5% probability level.

Results and Discussion

Green Season

On nonfertilized range, average date of range readiness was 18 January, although during the 6 years of study, readiness occurred as early as 7 December and as late as 14 February. Range readiness occurred 2 to 4 weeks earlier in 1972 and 1973 on units fertilized with sulfur plus nitrogen than on nonfertilized or sulfur-treated units. Since range readiness was not influenced the first and second years after treatment in 1969 and 1970 as it was in 1972 and 1973, the response apparently was due to unique environmental conditions combined with supplemental nitrogen. Supplemental sulfur from ammonium sulfate may also have contributed to earlier range readiness on the sulfur plus nitrogen units. Range readiness was not influenced by the sulfur only treatment, apparently because sulfur in gypsum is released at a slower rate than sulfur in ammonium sulfate. Martin and Berry (1970) reported nitrogenous fertilizers stimulated early and continued winter and early spring growth of annual grasses, but supplemental nitrogen appeared effective only if adequate phosphorus and sulfur were present. McKell et al. (1960) also reported earlier range readiness on California annual range with sulfur plus nitrogen, but the present findings agree with those of Conrad et al. (1966), who found range readiness inconsistently influenced by sulfur plus nitrogen on the San Joaquin Experimental Range. Inconsistent findings were perhaps related to low soil fertility. Germination and growth of annual range plants were also dependent upon adequate soil moisture and temperature; when either was deficient, range readiness was delayed.

Fertilization did not affect the end of the annual plant range green season (plant maturity). Bentley and Talbot (1951) reported that most herbage does not dry until temperatures rise sharply and the upper soil dries. Adequate soil moisture delayed plant maturity and annual plants matured earlier in years with droughts.

Length of the green season was variable, depending upon the dates of range readiness and plant maturity. On nonfertilized range the green season averaged 142 days and was not different from the length of season on fertilized range (Table 1). The shortest green season (87 days) on nonfertilized range occurred in 1972, and the longest green season (202 days) occurred in 1974. Talbot and Biswell (1942) also reported considerable year-to-year variation in length of green season. Bentley and Talbot (1951) found the period of most dependable green forage to be approximately 4 months long, from January or February into June. In the present study, the cumulative precipitation during the months of October, December, March, and June gave the best fit between precipitation and length of season. The relationship between precipitation and length of the grazing season was described by the linear equation: $Y = 7.53 + 6.72X$, in which Y = length of the green season in days, and X = sum of October, December, March, and June precipitation in centimeters. The equation explained 80% of the variation in length of the season, standard error of the estimate = 16.4 days and $N = 24$. However, as a predictive tool the equation is inadequate and additional research is needed before the equation is useful to managers.

Table 2. Steer days of grazing on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Days of grazing/ha							
Sulfur + nitrogen	368a[1]	258a	221a	258a	303a	295a	283a
Sulfur only	215b	168b	162b	114b	204b	250a	190b
Non-fertilized	132b	96c	87c	66c	106c	145b	108c
Average	238±69[2]	174±45	157±46	146±58	204±57	230±49	192±21

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

Length of the green season was generally not influenced by fertilization treatment. Sulfur plus nitrogen increased the length of the green season compared with nonfertilized range only in 1972 and 1973, and length of the green season was similar all years on sulfur only and nonfertilized range. Sulfur plus nitrogen-treated range was green longer in 1971, 1972, and 1973 than sulfur only-treated range due to range readiness, which occurred up to a month earlier on sulfur plus nitrogen range. However, average length of green season during the 6-year study was similar on all treatments.

Range Stocking Rate

Steer days of grazing/ha varied substantially within and between fertilizer treatments (Table 2). For example, annual days of grazing/ha were the least on both sulfur only and nonfertilized range in the extremely dry year of 1972, and days of grazing more than doubled on both treatments in the moderately high precipitation year of 1974. Within treatment variation was less on the sulfur plus nitrogen treatment. The difference in maximum and minimum days of grazing, 1969 and 1971 respectively, on sulfur plus nitrogen-treated range was approximately 30%.

Sulfur plus nitrogen-fertilized units produced more days of grazing than sulfur only units every year except 1974, and sulfur only-fertilized units produced more days of grazing than non-fertilized units every year except 1969. These 2 exceptions, however, may have been due to a Type II error as described by Steele and Torrie (1960), since similar treatment means within years varied by as much as 45 to 83 grazing days. On an average annual basis, sulfur plus nitrogen produced over 90 days of grazing/ ha more than sulfur only-treated range and the sulfur only treatment produced nearly 90 days of grazing/ha more than non-fertilized range. The increase in days of grazing/per ha was apparently due to increased herbage production. A direct estimate of herbage production by treatment was not made although the days of grazing/ha were dependent upon the amount of herbage available for use. Bentley and Green (1954) and Bentley et al. (1958) also reported increased herbage production on annual range following sulfur fertilization. The first apparent effect was a stimulation of legumes; in subsequent years increased production of grasses was attributed to a build-up of soil nitrogen by the legumes. Conrad et al. (1966) reported herbage production and animal days of grazing were generally greater on sulfur plus nitrogen-treated range than on either sulfur only or nonfertilized range.

During 1971 and 1972, steer days of grazing per ha were influenced by treatment-soil depth interactions (Fig. 1). Steer days of grazing were the least on nonfertilized range both years regardless of soil depth. In 1971, the third growing season after fertilization, sulfur only and sulfur plus nitrogen treatments produced more days of grazing than nonfertilized range. Days of grazing were similar with sulfur only and sulfur plus nitrogen on shallow soil, but sulfur plus nitrogen produced more days of grazing on deep soil than sulfur only. In 1972, the first green season after fertilization, sulfur plus nitrogen produced more days of grazing than the other treatments regardless of soil depth. On the shallow soil, sulfur only produced more days of grazing than nonfertilized range.

Fig. 1. *Steer days of grazing response to soil depth and fertilizer treatment in 1971 and 1972.*

Steer Weight Gain

The 6-year average steer weight gain was not enhanced by range fertilization (Table 3). Except for the drought year of 1972, steer gain on nonfertilized range equaled or exceeded the gain on sulfur- or sulfur plus nitrogen-fertilized range.

During 1969 and 1971, treatment-soil depth interactions influenced seasonal steer gains (Fig. 2). For example, in 1969 the largest steer gains on deep soil were produced on nonfertilized range, the smallest gains were obtained on sulfur plus nitrogen-fertilized range, and intermediate gains were obtained on sulfur only range.

Table 3. Average seasonal steer weight gain on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Steer gain, kg							
Sulfur + nitrogen	93b[1]	91a	75a	84a	96a	121a	93a
Sulfur only	101a	101a	73b	60b	99a	134a	95a
Non-fertilized	99a	102a	86a	60b	95a	128a	95a
Average	98±6[2]	98±6	78±6	68±8	97±4	128±53	94±9

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

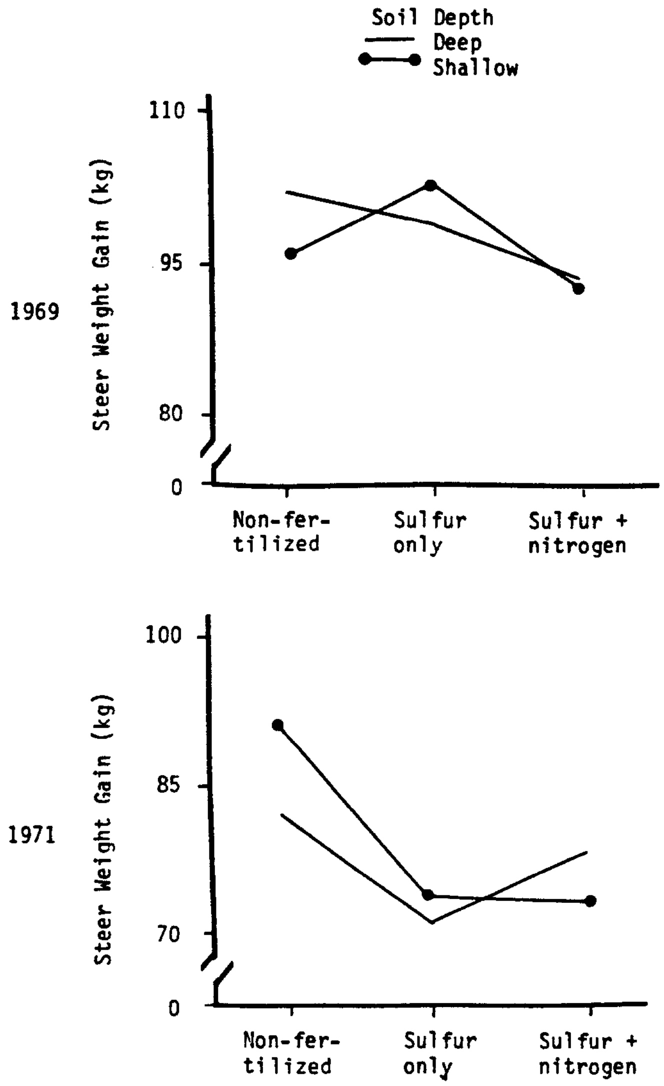

Fig. 2. *Steer weight gain response to soil depth and fertilizer treatment in 1969 and 1971.*

On shallow soil the greatest gains were obtained on sulfur only-treated range, while sulfur plus nitrogen and nonfertilized range produced similar but smaller seasonal steer gains. In 1971, steer gains produced on nonfertilized and sulfur plus nitrogen-fertilized deep soils were similar and both produced greater gains than sulfur only-fertilized range. Steer gains were larger on nonfertilized shallow soil than on fertilized shallow soil.

Within-year seasonal steer gains were influenced by a complex interrelationship between soil depth, treatment, length of green season, herbage nutritional value, days of grazing/ha, herbage production, timing of use, and perhaps other factors. However, from a practical management viewpoint, treatment influences tended to be nonconsequential since average seasonal steer gains during the 6-year study were similar on all treatments. Bentley and Talbot (1951) and Hart et al. (1945) reported heavy stocking, on annual ranges, even for only part of the year, resulted in lower production of a breeding-cow herd. As discussed earlier, the number of steers/unit of land was greater on sulfur plus nitrogen range than on sulfur-treated range, and sulfur only treatment supported more animals/ha than nonfertilized range. However, all units were stocked to obtain a uniform degree of use and there was no direct evidence to suggest an imbalance in forage/steer due to treatment. In fact, the similarity of within-year seasonal gains, as well as the similarity in the 6-year average gains, suggests that allocation of quality forage/steer was generally uniform across treatments.

Beef Production

The 6-year average production of beef was greater on sulfur-fertilized range than on nonfertilized range, and beef production was greater on sulfur plus nitrogen range than on sulfur fertilized range (Table 4). Sulfur alone increased beef production/ha nearly 80% and sulfur plus nitrogen increased production nearly 150% compared to non-fertilized range. These findings are in general agreement with those of Conrad et al. (1966), who reported increased herbage and cattle production on sulfur plus nitrogen-fertilized range; sulfur only also increased production but by a smaller amount.

Within-year beef production/ha of range was consistently enhanced by fertilization except in 1969. In 1969, production was similar on sulfur-fertilized and nonfertilized range. Sulfur applied as gypsum apparently was essentially unavailable for plant assimilation the first year after application due to a slow rate of release.

Beef production within treatments varied substantially over time, and in general, the trends appeared to be similar across treatments. For example, during 1969, 1970, and 1971 beef production declined annually regardless of treatment. Precipitation also declined annually (Table 1) although timing of precipitation may have been most limiting. In 1971, precipitation from early January through April was only 35% of normal, and precipitation during February was only about 10% of normal. Thus, the reduction in herbage and beef production was attributed to a reduction in the amount and frequency of precipitation. Beef production was also greater on deep soil (91 kg/ha) than shallow soil (80 kg/ha) in 1971. The deep-soil advantage may have been due to its ability to lengthen the growing season by storing additional amounts of water and nutrients available for plant growth. Beef production on non-fertilized range continued to decline with reduced precipitation in 1972, although the trend was reversed on fertilized range, particularly on sulfur plus nitrogen-treated range. The change in trend of beef production was probably due to an increase in herbage production. Conrad et al. (1966) also reported an increase in herbage production during a drought year on sulfur plus nitrogen-fertilized range. Beef production/ha was slightly above average in 1973 and 1974, as was precipitation, although factors other than precipitation may have also influenced beef production.

Table 4. Beef production on California annual range during the green seasons of 1969 through 1974 on three fertilizer treatments.

Item	1969	1970	1971	1972	1973	1974	Average
Production/ha, kg							
Sulfur + nitrogen	229a[1]	180a	103a	215a	190a	170a	181a
Sulfur only	140b	131b	95a	112b	149b	165a	132b
Non-fertilized	88b	75c	59b	49c	71c	101b	74c
Average	152±41[2]	128±32	85±16	125±51	137±34	145±26	129±14

[1]Values within columns followed by the same letter are not significantly different ($P<.05$).
[2]Mean ± confidence limits ($P<.05$).

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