Herbage Production and Grazing Capacity on Annual-Plant Range Pastures Fertilized with Sulfur

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Widespread tests over a period of years have shown a deficiency of sulfur in several soils derived from a variety of parent materials at many locations in California (Conrad, 1950). On foothill range with sulfur-deficient soil, fertilization offers a positive means of improving the natural annual-plant cover (Bentley, 1946; Bentley and Green, 1954). It is a low-cost treatment that, in plot tests, has given economical returns (Green and Bentley, 1954).

To determine how improvements in the vegetation from sulfur fertilization are reflected in range livestock production, a grazing test was started at the San Joaquin Experimental Range in 1949. A major objective was to learn how sulfur fertilization fits into year around management of foothill ranges. The experiment was conducted cooperatively by the California Forest and Range Experiment Station, U. S. Forest Service, and the Department of Animal Husbandry, University of California.

This article presents the herbage production, range stocking, and herbage utilization results obtained during the first 7 years in the experimental pastures. Gains, grazing habits, and diet of the steers will be covered in companion articles.

The Experiment

The experimental area is located at an elevation of about 1,100 feet in the Sierra Nevada foothills (Talbot, et al., 1942). Precipitation, averaging 19.4 inches annually for a 20-year period, ordinarily occurs as rain from October to May, with high-

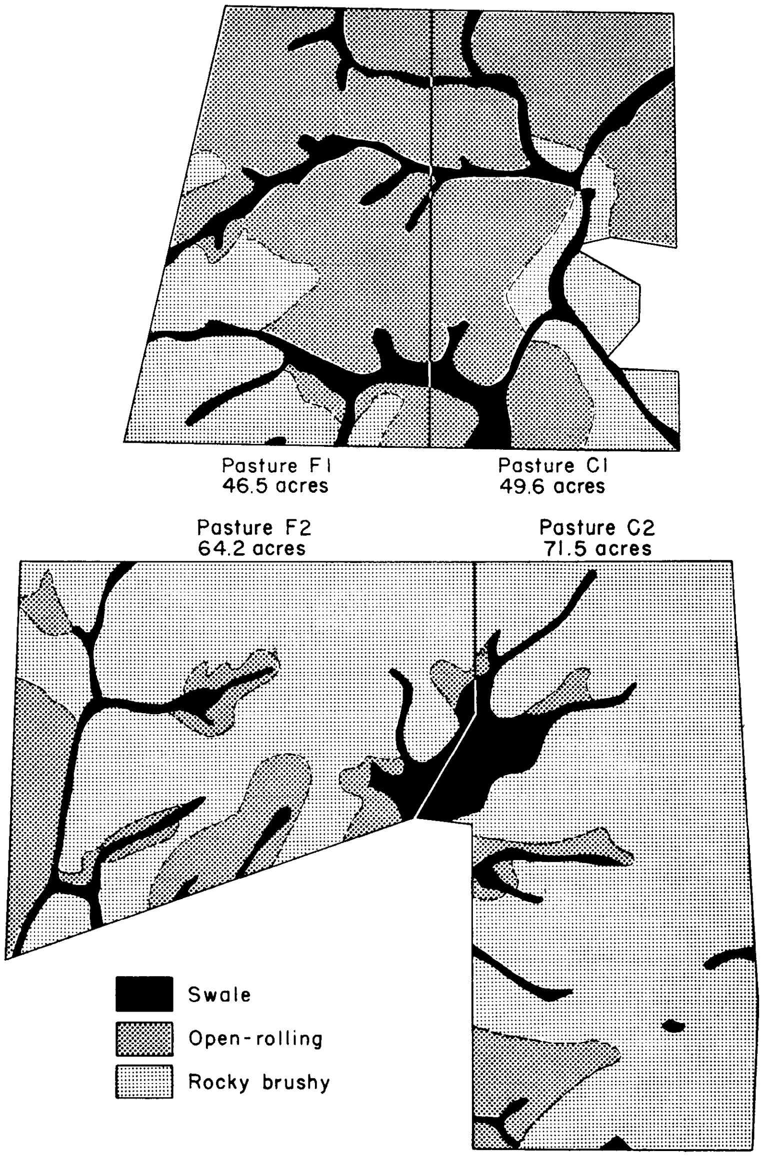

FIGURE 1. Two pairs of experimental pastures showing distribution of site classes; F1 and F2—fertilized, C1 and C2—unfertilized.

[1] *The California Forest and Range Experiment Station is maintained at Berkeley by the Forest Serivce, U. S. Department of Agriculture, in cooperation with the University of California.*

[2] *With the Agricultural Research Service for one year when this agency cooperated in the grazing trials.*

est amounts during the winter months. Herbaceous vegetation is a typical mixture of annual grasses and forbs including several legumes (Bentley and Talbot, 1951). The soil is predominately Vista sandy loam developed from granite bedrock. Soil depth is variable, mainly less than 2 feet, and rock outcrops are common.

The experiment was conducted in two pairs of pastures: F1 and F2—fertilized, control pastures C1 and C2—unfertilized (Fig. 1). The pastures were located and their approximate boundaries delineated from a range site map (Bentley and Talbot, 1951). Acreages of swale and slope sites and of nongrazable area covered by rock or brush were determined by line sampling, and pasture boundaries were adjusted to make the two pastures in each pair as comparable as possible.

At the time of fencing in 1948, the four pastures were judged approximately equal in grazing capacities, and each adequate for 10 yearling steers for 6 months. The smaller pair, pastures F1 and C1, contained considerable swale and open rolling slopes which were the most productive sites (Fig. 1). The larger pair, pastures F2 and C2, contained a high proportion of rocky, brushy slopes which were variable in productivity but generally poor. Pastures F1 and C1 proved closely paired but comparability of pastures F2 and C2 was somewhat less precise.

The fertilization practice followed had been developed in plot tests at the experimental range. Pasture F1 was first fertilized in January 1949, again in January 1953, and in December 1955. Pasture F2 was fertilized originally in February 1951, again at a low rate in October 1953, and at the regular rate in January 1956, to put its treatment on the same schedule as pasture F1. The rate of each application was 60 pounds elemental sulfur per acre except for 40 pounds per acre in pasture F2 in 1953. Gypsum was used as the carrier of sulfur except in pasture F1 in 1949, when a mixture of superphosphate and soil sulfur was applied. Both pit-run and agricultural gypsum were used.

Herbage yield in each pasture was sampled near plant maturity in May on temporary quadrats that were systematically spaced along permanent grid lines. Ungrazed vegetation was clipped at ½-inch stubble height on 50 to 70 square-foot quadrats per pasture. In pastures grazed during the green-forage season the quadrats were protected by cages made of 2-inch mesh poultry netting. The vegetation from an individual quadrat was placed in a paper bag and air-dried in a glass house. During periods of low humidity the plant material from each quadrat was weighed, and weights of individual species or plant groups were estimated for each.

One pair of pastures was stocked with two groups of weaner steers in July. The steers

Table 1. Herbage production in two pairs of pastures; one pasture in each pair was fertilized and the other pasture was an unfertilized control.

Pastures F1 and C1

Year and treatment	Grass	Legume	Other	Total
	Pounds per grazable acre[1], air dry			
1949:				
Fertilized[2]	826	79	449	1,354
Control	746	151	494	1,391
	80	—72	—45	—37
1950:				
Fertilized	928	1,147	1,247	3,322
Control	895	428	1,519	2,842
	33	719**	—272	480*
1951:				
Fertilized	3,089	612	572	4,273
Control	1,621	221	653	2,495
	1,468**	391**	—81	1,778**
1952:				
Fertilized	2,754	638	703	4,095
Control	1,482	258	822	2,562
	1,272**	380**	—119	1,533**
1953:				
Fertilized[2]	2,471	168	198	2,837
Control	1,580	59	317	1,956
	891**	109**	—119*	881**
1954:				
Fertilized	1,803	1,517	460	3,780
Control	1,490	441	653	2,584
	313*	1,076**	—193**	1,196**
1955:				
Fertilized	2,473	530	827	3,830
Control	1,165	176	840	2,181
	1,308**	354**	—13	1,649**
1956:				
Fertilized[2]	2,326	606	448	3,380
Control	1,058	201	711	1,970
	1,268**	405**	—263**	1,410**

Table 1. (Continued)

Pastures F2 and C2

Year and treatment	Grass	Legume	Other	Total
1949:				
Fertilized	697	136	341	1,174
Control	546	165	421	1,132
	151	—29	—80	42
1950:				
Fertilized	660	474	872	2,006
Control	591	275	922	1,788
	69	199	—50	218
1951:				
Fertilized[2]	2,835	161	428	3,424
Control	2,487	47	243	2,777
	348	114	185	647*
1952:				
Fertilized	1,359	1,126	540	3,025
Control	991	312	541	1,844
	368	814**	—1	1,181**
1953:				
Fertilized[2]	1,868	197	161	2,226
Control	1,173	174	145	1,492
	695**	23*	16	734**
1954:				
Fertilized	1,602	744	716	3,062
Control	1,220	179	783	2,182
	382	565**	—67	880**
1955:				
Fertilized	1,589	716	561	2,866
Control	1,010	229	510	1,749
	579**	487**	51	1,117**
1956:				
Fertilized[2]	1,468	396	327	2,191
Control	623	185	467	1,275
	845**	211**	—140**	916**

[1] Excludes rock outcrop and soil inaccessible to cattle.

[2] Pasture was fertilized during preceding fall or winter.

** Difference is significant at 1 percent level.

* Difference is significant at 5 percent level.

were in these two pastures during the remainder of the dry-forage season, utilizing vegetation that had grown during the preceding winter and spring. In some years the steers remained in these pastures during part or all of the winter season, which started with effective fall rains, utilizing some of the new plant growth. In other years the steers were moved to the second pair of pastures at the start of the winter season. The steers were in the second pair of pastures throughout the green-forage season utilizing current vegetation growth, and were removed in the summer after the vegetation had dried and the pastures had been moderately grazed. From 1949 to 1954 inclusive the steers were put in pastures F1-C1 in July and were moved later to the other pair of pastures. The grazing seasons were reversed in 1955 so that the steers were put in pastures F2 and C2 in July and later moved to pastures F1 and C1.

Notes were made on plant growth and utilization each year. Degree of utilization was recorded when the steers were removed. Photographic utilization standards (Hormay and Fausett, 1942) were used, but adaptations were necessary when final ratings were made in winter after heavy rains had occurred.

Herbage Production

The pattern of vegetation response to sulfur fertilization in the pastures (Table 1) was the same as that reported from plot tests (Bentley and Green, 1954). The first apparent effect was stimulation of legumes, mainly native annual clovers, during the year after fertilization—in 1950 for pasture F1 and in 1952 for pasture F2. In each pasture this initial response did not occur during the first season of fertilization because rainfall was insufficient for good legume growth.

The second effect of fertilization was increased production of grasses resulting from a buildup of soil nitrogen by the legumes. This increased grass yield first occurred in 1951 for pasture F1 and in 1953 for pasture F2. In subsequent years significant increases in production of grasses, legumes, and total herbage were maintained by repeat fertilization (Table 1), except that in 1954 yield of grasses in pasture F2 was not significantly greater than that in its control.

Production of forbs other than legumes generally decreased after fertilization became effective. Most of this decrease usually was in yield of broadleaf filaree, which composed the bulk of the other forbs. Reduction of filaree was plain in pasture F1; in 1949 it made up about the same percentage of the herbage

Table 2. Average herbage yield and response to fertilization by site class.

Site class, pasture, and treatment	Proportion of pasture acreage	Yield per grazable acre[1]	Increased yield
	Percent	*Pounds*	*Pounds*
Swale:			
C1 — Control	10.8	5,242	......
F1 — Fertilized	13.0	5,985	743
C2 — Control	8.9	4,224	......
F2 — Fertilized	12.3	5,689	1,465
Average difference[2]	......	......	1,014
Open, rolling slopes:			
C1 — Control	62.5	2,404	......
F1 — Fertilized	63.5	3,751	1,347
C2 — Control	34.6	1,971	......
F2 — Fertilized	33.5	3,082	1,111
Average difference[2]	......	......	1,259
Rocky or brushy slopes:			
C1 — Control	26.7	1,601	......
F1 — Fertilized	23.5	2,189	588
C2 — Control	56.5	1,312	......
F2 — Fertilized	54.2	1,635	323
Average difference	......	......	489

[1] Yields are averages for the years in which quadrats were classified by site class, after fertilization became effective: Pastures F1 and C1, 5 years, 1950-54; pastures F2 and C2, 3 years, 1952-54.

[2] Weighted average based on all quadrats in the site class.

in both pasture F1 and pasture C1, but in 1951 and later years its percentage in pasture F1 was only half that in pasture C1. Reduction of filaree in pasture F2 was less marked, but records since 1954 indicate it now composes a significantly lower percentage of the herbage in the fertilized pasture than in its control, pasture C2. This reduction in broadleaf filaree and the increases in grasses and legumes are improvements in the herbage composition on annual-plant ranges, particularly on range grazed during the dry-forage season.

Increased production of herbage resulting from sulfur fertilization was most marked in pasture F1, which contained a high proportion of the more productive sites (Fig. 1). For the 6-year period 1951-56, after fertilization was fully effective in pasture F1, its average yield was 1,408 pounds per acre greater than the average yield of the control pasture C1. This increase in grasses and legumes is considered a good measure of the effect of fertilization. In the low-production year of 1949, the clipped yields were the same in pasture C1 and pasture F1 and on a series of unfertilized strips in pasture F1. In 1950, when the first response from fertilization occurred, the yield of pasture F1 was greatly increased over yields of pasture C1 and the unfertilized strips (Fig. 2). The greater yield of pasture F1 over pasture C1 was clearly evident in succeeding years.

Increased production was less apparent in pasture F2. During the period 1952-56, when fertilization was effective in pasture F2, its yield averaged 966 pounds per acre more than the yield of control pasture C2. This greater production was caused primarily by fertilization but may have been influenced by site differences between the pastures. Increased production was evident in 1952 and subsequent years.

Effect of Site

Herbage sampling in the pastures clearly showed that best returns were obtained from fertilizing the most productive land

Table 3. Weight, density, and yield of vegetation in fertilized pasture F1 and control pasture C1 at different dates in 1951.

Date and pasture treatment	Average plant height	Average foliar density	Average dry weight
	Inches	*Percent*	*Lbs./acre*
February 22:			
Fertilized	2.1	63	[1]1,560
Unfertilized	1.6	59	1,100
	0.5	4	460
March 16:			
Fertilized	2.6	70	[2]2,004
Unfertilized	2.2	61	1,514
	0.4	9	490
May 12:			
Fertilized	([3])	([3])	[2]4,273
Unfertilized	([3])	([3])	2,495
	....	....	1,778

[1] Yield based on correlation with density x height developed in previous studies.

[2] Yield based on clipped samples.

[3] Not measured.

(Table 2). For a 5-year period in pastures F1 and C1, when the clipped quadrats were classified by site class, the average yields were greatest from the open, rolling slopes with few outcrops and less than half as great from rocky or brushy slopes with shallower soil.

Considering all quadrats in all pastures for a 3-year period, the yield of herbage in the fertilized pastures was greater than in the control pastures by 1,014 pounds per acre in the swales, by 1,259 pounds per acre on the open, rolling slopes, and by 489 pounds per acre on the rocky, brushy slopes. Yield figures for swales were based on few quadrats, but a large number were used in determining relative yields from the slope sites. Increased production from swales occurred mainly in the years of heaviest precipitation. The open, rolling slopes were consistently higher in all years in the fertilized pastures, but on rocky or brushy slopes the only impressive production from fertilization was in years with above-average rainfall.

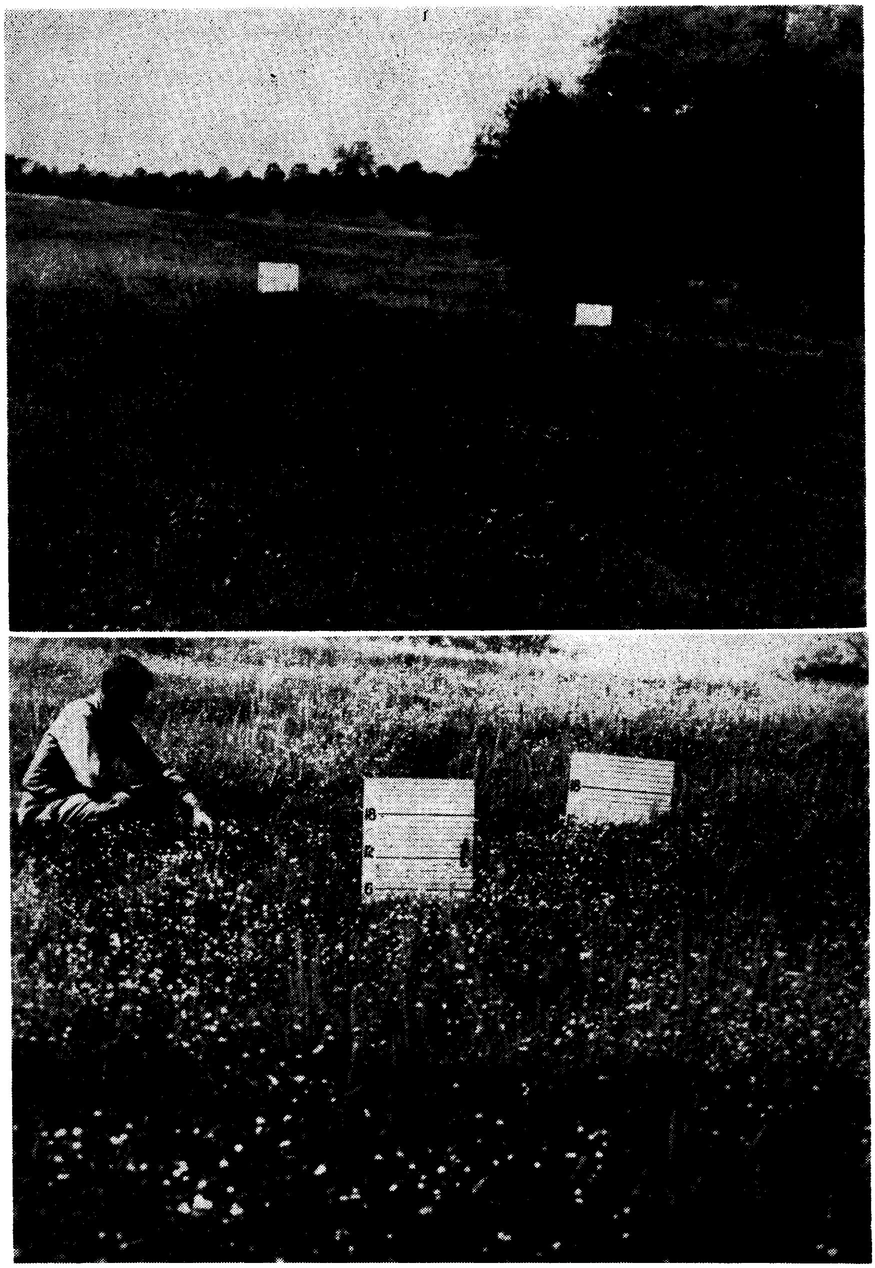

FIGURE 2. *Upper:* Initial heavy clover production on good site in sulfur fertilized pasture F1, April 1950. *Lower:* Good growth of clover after second fertilization compared with low growth on unfertilized strip in center of photo, pasture F1, April 1954.

Season of Growth

Most of the increased production under sulfur fertilization resulted from more rapid plant growth in April. Growth also was more vigorous during late winter and early spring in pasture F1 than in its control pasture, but the plants were only slightly taller. Production appeared much alike in the fertilized and control pastures in February and March during the years when pasture F1 was not being grazed at that time. Yet in later years, when it was grazed during late winter, the steers made materially better gains at that time than steers in the unfertilized pasture. Slight increases in production of available herbage during late winter months were more important than they appeared to be.

The value of such increases is illustrated by differences in plant growth in pasture F1 and its control during the late winter and spring of 1951 (Table 3). Both pastures had been closely grazed until December 27, 1950, but were not grazed during the remainder of the plant growing season. In February and March increases of only 0.4 to 0.5 inch in average height, along with slightly more foliar density, produced 460 to 490 pounds more available herbage per acre.

Earlier plant growth from fertilization was never apparent in pasture F2 and was not indicated by the steer gains. The reasons were not known; stimulation of legume growth seemed adequate to increase available soil nitrogen in some winters.

Yearly Fluctuations

Sulfur fertilization had little effect on yearly fluctuations in total herbage production. After

Table 4. Stocking and utilization of pastures grazed during the dry-forage season and into the winter season in some years, and estimates of increased grazing capacity of fertilized pasture over control pasture.

Year and pasture	Stocking of pastures: Dry-forage season	Stocking of pastures: Winter season	Utilization of pastures	Increase of fertilized pasture over control in— Total herbage yield[1]	Actual dry-season stocking	Estimated dry-season capacity[2]
	Steer-days	*Steer-days*	*Degree*[3]	*Percent*	*Percent*	*Percent*
1949:						
C1	1,050	0	C to M	—3	0	
F1	1,050	0	C to M			0
1950:						
C1	860	810	M			
F1	1,032	972	M to L	17	20	35
1951:						
C1	1,170	320	M to L			
F1	1,170	384	L to M	71	0	65
1952:						
C1	800	950	M			
F1	960	1,710	M to L	60	20	55
1953:						
C1	1,230	0	C to M			
F1	1,845	0	C to M	45	50	50
1954:						
C1	1,223	1,247	M			
F1	1,921	1,463	M	46	56	55
1955:						
C2	1,368	630	M			
F2	2,052	630	M	64	50	55

[1] Dry weight per grazable acre, from Table 1.

[2] Increase in stocking estimated from observation of actual stocking and utilization of the pastures, as that needed to obtain equal utilization of fertilized and control pastures at end of dry-forage season.

[3] Degree of utilization at time steers were removed from pasture: C, close; M, moderate; L, light; C to M on the moderate side of close; M to L on light side of moderate; etc.

fertilization had become fully effective, yields of the fertilized pastures fluctuated in about the same manner as yields of the control pastures (Table 1). Coefficients of variations were similar for the fertilized pastures and their control pastures. This is in contrast to results from nitrogen fertilization reported by Hoglund and co-workers (1952), who found that annual applications reduced fluctuations. Under periodic application of sulfur, legume stimulation and availability of organic soil nitrogen are greatly influenced by yearly weather conditions as well as by the level of soil sulfur supply.

After the soil nitrogen supply had been built up by growth of legumes, the total herbage production of the fertilized pastures in most years was more than 50 percent greater than in the control pastures. For pasture F1, 1951 to 1956 inclusive, the increase ranged from 45 to 76 percent; for pasture F2, 1953 to 1956 inclusive, from 40 to 72 percent. For the 5-year period 1952-56 when fertilization was fully effective in both pastures, herbage production of pasture F1 averaged 59 percent greater than its control. In pasture F2 it was 57 percent greater. These figures indicate that the base stocking level could be materially raised after fertilization and maintained at a high level without adding to the problem of adjusting to a fluctuating herbage supply.

Grazing Capacity

Grazing capacities of the fertilized pastures during the dry-forage season increased in about the same proportion as the herbage yields. But during the green-forage season in some years capacities were increased less than the herbage yield figures would indicate.

Fertilized pasture F1 was stocked below its capacity during the dry-forage season and was grazed rather lightly in each of the first 3 years after fertilization had become effective (1950-52, Table 4). In each of the next 3 years the fertilized pasture was stocked during the dry season well above stocking in its unfertilized control pasture; nevertheless degree of utilization was the same in both pastures. In some years extra steers were grazed in the fertilized pasture during the winter months to remove excess herbage that remained at the end of the dry season.

Averaged for several years, the increase in herbage resulting from fertilization was a reliable index of increase in grazing capacity during the dry season. Herbage yield increased 57 percent for the period 1951-55; grazing capacity, 56 percent.

During the green-forage season, results differed in the two pairs of experimental areas. Stocking and utilization records did not indicate much increased grazing capacity in the fertilized pasture when the steers were in pastures F2 and C2 (Table 5). Capacity appeared to be about the same in both pastures in 1950 and in 1951 even though herbage yield per acre, sampled under cages, was greater in the fertilized pasture. In 1953 and 1954, after the soil nitrogen level had been built up in the fertilized pastures, its increase in estimated capacity averaged only 25

Table 5. Stocking and utilization of pastures grazed during the green-forage season and during the preceding winter season in some years, and estimates of increased grazing capacity of fertilized pasture over control pasture.

	Stocking of pastures			Increase of fertilized pasture over control in—		
Year and pasture	Green-forage season	Winter season	Utilization of pastures	Total herbage yield[1]	Actual green-season stocking	Estimated green-season capacity[2]
	Steer-days	*Steer-days*	*Degrees*[3]	*Percent*	*Percent*	*Percent*
1950:						
C2	0	1,250	L to M			
F2	0	1,250	L to M	12	0	0
1951:						
C2	0	1,910	M to L			
F2	0	1,910	M to L	23	0	0
1952:						
C2	610	1,912	M			
F2	610	2,004	M	64	5	15
1953:						
C2	385	1,628	M to C			
F2	490	2,072	M to C	49	27	30
1954:						
C2	910	1,727	M to L			
F2	910	2,099	M to L	40	22	20
1955:						
C1	0	1,261	M			
F1	0	1,925	M to L	76	53	60
1956:						
C1	0	1,886	M			
F1	0	2,890	M to C	72	53	50

[1] Dry weight per grazable acre from Table 1.

[2] Increase in stocking estimated from observation of actual stocking and utilization of the pastures, as that needed to obtain equal utilization of fertilized and control pastures at end of dry-forage season.

[3] C, close; M, moderate; L, light; L to M on moderate side of light; M to L, on light side of moderate, etc.

percent while increase in herbage yield averaged 56 percent. In contrast, when pastures F1 and C1 were grazed during the green-forage season the estimated increase in capacity averaged 55 percent, the increase in herbage yield 53 percent. The reasons for the contrast were not apparent; when pasture F2 was grazed during the dry-forage season, the increases in capacity and yield agreed fairly well.

Discussion

Sulfur fertilization can be recommended for open, rolling land if the soil is deficient in this element. Fertilization of rocky or brushy, steeper slopes, which usually have shallower soil, is questionable or at least of lower priority. Returns are lower and fertilizing more difficult on these slopes. The productive swale areas should be fertilized, but plot tests indicated that better returns could be obtained if phosphorus also is applied on these sites. The good returns from fertilization in this experiment would have been even greater and more economical if the pastures had included only the better land.

The results show that after sulfur fertilization has become fully effective, the range can be stocked at a heavier level during both the green-forage and dry-forage season. This makes possible full utilization before the forage value of the herbage has been lowered by leaching. The heavier stocking rate cannot be maintained, however, during the winter season when cattle are grazing mainly on the slow-growing new vegetation. At this time of year the livestock should be on other kinds of range.

Sulfur fertilization changed the pattern of utilization on the range, particularly during the dry season. The herbage on the open slopes was more attractive on fertilized range. Consequently, the steers did not concentrate so heavily on the swales in the fertilized pastures, and grasses in the swales, especially Mediterranean barley, were less closely grazed. Better utilization might be obtained by a different kind of fertilization aimed at stimulating growth of clover on this productive site.

A desirable overall mixture of forbs and grasses was maintained on both the fertilized and unfertilized range under moderate grazing in both the green-forage and dry-forage seasons. The vegetation was better on the fertilized range, particularly if grazed during the dry season, because of the greater proportion of legumes and grasses and the lower amount of broadleaf filarees. With dry-season grazing and light utilization in pasture F1, ripgut brome increased more than is desirable. The increase was more rapid than observed in the past under similar grazing of natural range, apparently because of the higher fertility level in the fertilized pasture.

Dry-season grazing will be necessary each year on sulfur-fertilized range that is held back to round out the yearlong forage supply. To guard against possible undesirable changes in botanical composition of fertilized range, rotation of grazing between range units, so that no one unit is grazed continually during the dry summer and fall, should be a desirable practice even though the benefits to be obtained have not been thoroughly demonstrated.

Summary

On California annual plant range at the San Joaquin Experimental Range periodic sulfur fertilization increased herbage production in two range units above that in unfertilized controls by 59 and 57 percent during a 5-year period. Initial response was stimulation of native clovers. Production of grasses and legumes increased in subsequent years after soil nitrogen had been built up. Greatest returns were on the better range sites. Yearly yields fluctuated because of weather about the same on fertilized as on unfertilized range.

Grazing capacities were increased proportionally with yields, except for one pasture in the years when its was grazed during the green-forage season. Stocking of fertilized range could be raised materially above unfertilized range during the dry-forage and green-forage seasons but not during the winter season. Fertilization produced more grazable herbage during late winter in one pasture but not in the other. Most of the greater growth on fertilized range occurred during the spring months.

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