Stimulation of Native Annual Clovers Through Application of Sulfur on California Foothill Range

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The use of fertilizers to stimulate growth of legumes and thus build up soil fertility—long accepted as a sound grassland practice—is being studied intensively on California foothill ranges. Most of the studies involve use of winter-growing annual legumes which are particularly well adapted to the mild, rainy winters and hot, dry summers. Considerable progress has been made in developing fertilizer practices to increase production of these annuals, including both introduced and native species.

Introduced annuals, such as the widely naturalized bur-clover (*Medicago hispida*) and the more recently introduced rose clover (*Trifolium hirtum*), subterranean clover (*T. subterraneum*), and crimson clover (*T. incarnatum*) have proved to be very valuable for grassland improvement (Love, 1952 and Love and Sumner, 1952). The native annuals also have an important place in an improvement program on foothill range. Most areas contain several native legumes growing on sites where they are well adapted. Growth of certain species, particularly the clovers, can be increased greatly through fertilization to correct mineral deficiencies in the soils. The use of sulfur-bearing fertilizers to stimulate native clovers on sandy loam soils has been demonstrated at the San Joaquin Experimental Range.

The forage on this Experimental Range is a typical mixture of many native and naturalized annual plants (Bentley and Talbot, 1951). Legumes make up some 2 to 15 percent of the total herbage on most of the unfertilized range, the amount depending upon weather conditions of the year. Most of this production is from native clovers; the introduced bur-clover occurs but sparingly. Since 1941 a series of plot studies has been conducted using fertilizers containing nitrogen, phosphorus, sulfur, or combinations of these elements on various sites to determine the conditions under which each produced definite response in plant growth. Observations from these studies are summarized here, together with 4 years measurement of herbage production on a set of plots treated in 1949 with several sulfur-bearing fertilizers.

Response to Sulfur Fertilization

A deficiency of sulfur in the foothill range soils of granitic origin was indicated by the first tests started in 1941. On the plots where soil sulfur had been applied and on the plots receiving single superphosphate, a carrier of sulfur, growth of legumes was much greater than on plots which did not receive these fertilizers. In subsequent exploratory trials an increase in legume production from application of sulfur-bearing fertilizers was observed on all kinds of sites on the Experimental Range, including the residual soils on slopes and the secondary soils in the swales. The residual soil is Vista sandy loam, usually between 1 and 2 feet deep, although depth is quite variable. The most impressive increase in legume production was at the transition between slopes and swales and on slope soils with a gentle north exposure. Apparently, deficiency of sulfur was less of a limiting factor in the heavier swale soils, which have a higher organic matter content.

A deficiency of soil sulfur has been reported at many other locations on California foothill lands. In trials conducted between 1940 and 1943, Conrad, Hall and Chaugule (1947) found that bur-clover responded markedly to sulfur fertilization on an Altamont soil derived from old sedimentary materials. In later tests with the California Agricultural Extension Service, Conrad (1950) found sulfur responses on several other soils derived from a wide variety of parent materials.

The response of the annual-plant range to application of sulfur fertilizers followed fairly closely the same pattern in all tests. The first marked response was stimulation of legume growth, but this response did not always occur during the season of application. The year after stimulation of legumes, production of grasses as well as legumes increased. The effects on grasses and legumes held over for a few years following a single fertilization.

These responses are shown by the plant yields measured on plots fertilized in January, 1949. This test included 10 plots fertilized with sulfur, gypsum, superphosphate and two combinations, each application at the rate of 60 pounds of sulfur per acre. Six other plots were not fertilized. Each plot was 10 x 200 feet in size and was sampled with 10 quadrats, 1 square foot in size, located along the center line of the plot. The ungrazed herbage was clipped at ½-inch stubble height when most species were near maturity in May, dried in a greenhouse, and weighed. The weight of each important species or plant

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group in each quadrat sample was carefully estimated at the time the sample was weighed; certain quadrat samples were separated and component parts weighed as a check on the estimates. Mean yields obtained by this method are essentially the same as those from complete separation of every quadrat sample. The plots were grazed by cattle after all of the forage had dried. Utilization on the fertilized plots was somewhat heavier than on the unfertilized plots.

The design of the experiment and the intensity of sampling did not prove adequate for certain comparisons of different sulfur fertilizers, but consistent differences were obtained between fertilized and unfertilized plots. There were, however, indications that the magnitude of the differences was reduced by lateral movement of plant nutrients from fertilized to unfertilized plots.

First-Season Response is Often Poor

A very limited effect from application of sulfur was noted during the first season on the plots fertilized in January, 1949 (Table 1). A slight stimulation of legumes occurred by April, but at plant maturity there was no observable effect of sulfur fertilization. The average yield and composition of herbage from the fertilized plots was similar to that from unfertilized plots. The insignificant effect of fertilization was attributed to a prolonged spring drought and low total rainfall of that season.

This poor first-season response is typical of results from other plots that were established in seasons of low total precipitation. Growth of legumes was limited by periods of drought or cold weather during the growing season or by early drying of the vegetation. A poor stand of legumes also can limit the first-year effects of sulfur fertilization. Where the stand of native legumes on the Experimental Range had been thinned by cultivation in preparing a seedbed for introduced species, sulfur fertilization had little visible effect on plant growth until the stand of legumes had thickened.

Initial Response is in Legumes

On the plots fertilized in January 1949, the first marked effects of fertilization were recorded during 1950. Clovers were noticeably stimulated during the entire spring of 1950 on the plots receiving sulfur in any of the various fertilizer combinations that were used. At plant maturity the contrast in growth of clover was very distinct at most boundaries between treated and untreated plots. The yield of clovers, mainly littlehead clover (*T. microcephalum*) but including tree clover (*T. ciliatum*) averaged 1,308 pounds per acre greater on the 10 fertilized plots than on the 6 unfertilized plots (Table 1). Because of a decrease in filaree and some other species on the fertilized plots, the average increase in total herbage production was 923 pounds per acre—4,453 pounds per acre dry weight on fertilized plots compared to 3,530 pounds on untreated plots.

Marked stimulation of legumes the second year after application of sulfur fertilizers was also recorded in earlier tests. For example, on a gypsum plot and a superphosphate plot first fertilized in February 1944, response was barely apparent in 1944, but very impressive in 1945 (Bentley, 1946). Clipped samples showed that the increase in dry herbage yield over an adjacent untreated plot was about 1,300 pounds from gypsum, and about 1,000 pounds per acre from superphosphate. The increases were estimated to be almost entirely in legumes, mainly littlehead clover.

The addition of sulfur as an essential element in plant nutrition appears to be the major reason for the stimulation of legumes, which require appreciable quantities of sulfur. Several workers have reported the importance of adding sulfur on deficient soils to promote growth of legumes; the sulfur serves to increase production of amino acids and total protein in the leggumes (Nightingale, *et al.*, 1932; Eaton, 1941; Thomas, *et al.*, 1950; Anderson and Spencer, 1949; Crocker, 1945; and Tisdale, *et al.*,

Table 1. Average herbage production during each of four years for 10 plots fertilized in January, 1949* and for 6 unfertilized plots

Year and Plot Treatment	Grass	Filaree	Clover	Other Legumes	Misc. Forbs	Total
	Pounds per acre, air dry					
1949						
Fertilized	924	634	48	37	28	1671
Unfertilized	870	681	26	34	37	1648
Difference	54	−47	22	3	−9	23
1950						
Fertilized	1748	740	1694	143	128	4453
Unfertilized	1642	1080	386	274	148	3530
Difference	106	−340	1308	−131	−20	923
1951						
Fertilized	4545	214	495	18	84	5356
Unfertilized	3804	302	277	24	47	4454
Difference	741	−88	218	−6	37	902
1952						
Fertilized	3389	201	1414	75	410	5489
Unfertilized	3058	412	583	173	311	4537
Difference	331	−211	831	−98	99	952

* The fertilizer treatments consisted of two replications of soil sulfur, gypsum, superphosphate, gypsum-sulfur mixture, and superphosphate-sulfur mixture, each at the rate of 60 pounds sulfur per acre.

1950). The darker color of legumes on fertilized plots (Conrad, 1950) indicates an effect of sulfur on chlorophyll formation (Powers, 1930).

Second Response is in Grasses

On the fertilized plots where heavy production of clover was obtained in 1950, growth of grass in 1951 was 741 pounds per acre greater than on unfertilized plots (Table 1). The contrast in growth of grass at the boundaries between fertilized and unfertilized plots was not impressive. For one reason, in 1951 grass grew well on both fertilized and unfertilized plots as a result of unusually favorable fall and winter weather. Also, there appeared to be some lateral movement of nitrates across portions of the narrow plots. This movement erased sharp contrasts at plot borders and probably reduced the measured differences in grass production between plots.

Greater vigor of clovers was very apparent during April, 1951 on the fertilized plots, but clovers made little growth after that date because of dry spring weather, the average yield being only 218 pounds greater than on unfertilized plots. Total herbage yield was 902 pounds per acre greater on the fertilized plots, about the same increase over unfertilized plots as obtained in 1950.

A more striking increase in growth of grass following heavy clover production was observed in an earlier test. On gypsum and superphosphate plots, which produced heavy crops of clover in 1945, there was a tall growth of soft chess in 1946 (Fig. 1). Clovers were also stimulated in 1946. The increase in total herbage production was measured as about 1,300 pounds per acre on the gypsum plot and 800 pounds per acre on the superphosphate plots, as contrasted with an adjacent unfertilized plot.

Stimulation of grass production after heavy growth of clover on plots fertilized with sulfur has been one of the most important results from the studies. This increase in grass is clearly a response to increased soil nitrogen fixed by bacteria on the roots of the legumes. Root systems were always larger and nodules were large and abundant on legume plants during the season of first marked response to sulfur. During succeeding seasons the nodules decreased in size and abundance until, after three or four years, the level of nodule production was only slightly above that on unfertilized legumes. These observations are in agreement with work of others who have reported increases in legume roots and nodules following fertilization with sulfur (Anderson and Spencer, 1949; Gilbert, 1951; and Ivanoff, 1948).

The need for additional soil nitrogen to increase grass production has been indicated by responses to nitrogen fertilizer on all sites at the Experimental Range. This nitrogen deficiency is typical of foothill soils and has been reported on other areas (Dickey, *et al.*, 1948; Chapman, *et al.*, 1949). Response to added nitrogen has been impressive and consistent on some fairly deep, heavy soils and a program of nitrogen fertilization has been recommended for some foothill areas (Hoglund, *et al.*, 1952). On the shallow, light soils at the Experimental Range, studies to date have been concentrated on the use of sulfur-bearing fertilizers to build up soil nitrogen through stimulation of legumes. Use of nitrogen along with sulfur fertilizers will be studied in more detail.

Hold-Over Response in Grasses and Legumes

A hold-over response in both grasses and legumes was obtained on the fertilized plots during 1952 (Table 1). The production of clovers, averaging 1,414 pounds per acre on the fertilized plots, was heavier than expected. Over a larger area fertilized at the same time, the proportion of legumes in the forage during 1952 was much less.

The increase of only 331 pounds per acre of grass on the fertilized plots as compared to the unfertilized plots was less than expected and was less than the increase which occurred in 1952 on the larger fertilized area. There was considerable evidence that the limited contrast in production of grass on the plots was caused by lateral seepage of nitrates from fertilized plots into portions of the unfertilized plots.

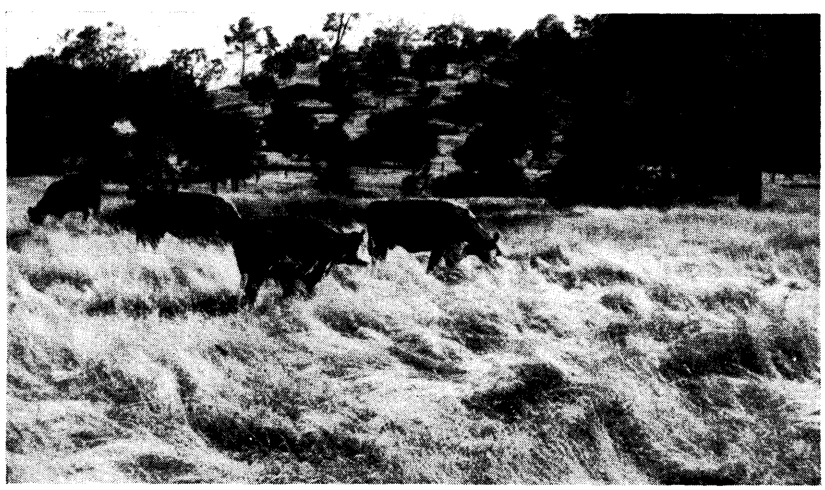

FIGURE 1. The luxuriant crop of lodged vegetation in the foreground, dominated by soft chess and littlehead clover, is on a plot fertilized with gypsum. The tall growth of grass occurred in 1946 as a result of marked stimulation of legumes in 1945. The grass is much shorter on an unfertilized plot immediately in front of the background trees. Photo taken at the San Joaquin Experimental Range, August 1946.

The narrow plots, while excellent for observation of the early effects of sulfur fertilization, are not suited for long-time comparisons of fertilization practices.

Plant responses for at least three years from a single application of sulfur-bearing fertilizers have occurred in all plots where records were maintained for that length of time. The proportion of grasses and legumes during the third year was not the same on all plots; probably the proportion will vary from site to site and from year to year.

Discussion

Application of sulfur fertilizers has proved to be a positive method of range improvement for the kind of range land on the experimental area. The nature of plant responses obtained in the plot studies show that sulfur fertilization has improved both quality and quantity of forage (Fig. 2) through stimulation of legume growth. The decrease in filaree and the slight increase in "others" on the plots are about the same as the changes in these species which have occurred on larger fertilized areas. These plots do show, however, relatively greater increase in legumes and less increase in grass and total forage production than on larger fertilized areas.

Fertilization has brought about a greater improvement in the natural forage cover than that obtained by any grazing management practice. Increase in legumes at the expense of broadleaf filarees (*Erodium botrys* and *E. botrys* f. *montanum*) is considered an upward step in condition class on annual-plant range.

The improvement in forage quality has been indicated by the preference of cattle for forage on plots where sulfur has been applied as soil sulfur, gypsum or superphosphate. The preference has been very apparent during the summer when cattle have grazed the dry forage on fertilized plots to the ground before grazing materially on unfertilized forage. More clovers, which are the best of the native forage plants, and greater palatability of the forage would indicate livestock should make better gains on fertilized range. And the greater total yields of forage will result in greater grazing capacity.

Sulfur-bearing fertilizers have produced definite responses in forage growth at the Experimental Range when applied at rates equivalent to 10 to 120 pounds of sulfur per acre. The response was not very apparent and was not uniform on plots where fertilizers were applied at only 10 pounds of sulfur, but was usually quite apparent where the fertilizers contained 20 pounds of sulfur per acre. Better initial response and greater hold-over effects were observed, however, from fertilizers applied at heavier rates. Fertilization at a rate equivalent to 60 pounds of sulfur per acre, applied every three years, has consistently increased forage growth.

Either gypsum at approximately 350 pounds per acre or soil sulfur at approximately 60 pounds per acre, applied at three-year intervals. can be recommended for trial until better practices have been developed. A single application of either costs about $2.50 to $4.00 per acre for the fertilizer and spreading. Extensive use of these fertilizers should not be made on a range until tests have shown that sulfur is deficient. Results for four years on the plots fertilized in 1949 (Fig. 3) indicate that either gypsum or soil sulfur will produce increased forage at a low cost of about $3.00 per ton. Replication and sampling was not adequate to determine whether there was significant difference between the returns from these two fertilizers. Comparison of the returns from gypsum and soil sulfur will be continued.

Addition of elements other than sulfur may prove to be beneficial on some sites. For example, legumes responded to application of phosphorus on swale soils. Single superphosphate, to supply both phosphorus and sulfur, can be recommended for swales. On slope soils, which make up most of the area, treblephosphate added to gypsum showed no advantage over gypsum alone, even though application of single superphosphate consistently has given greater observa-

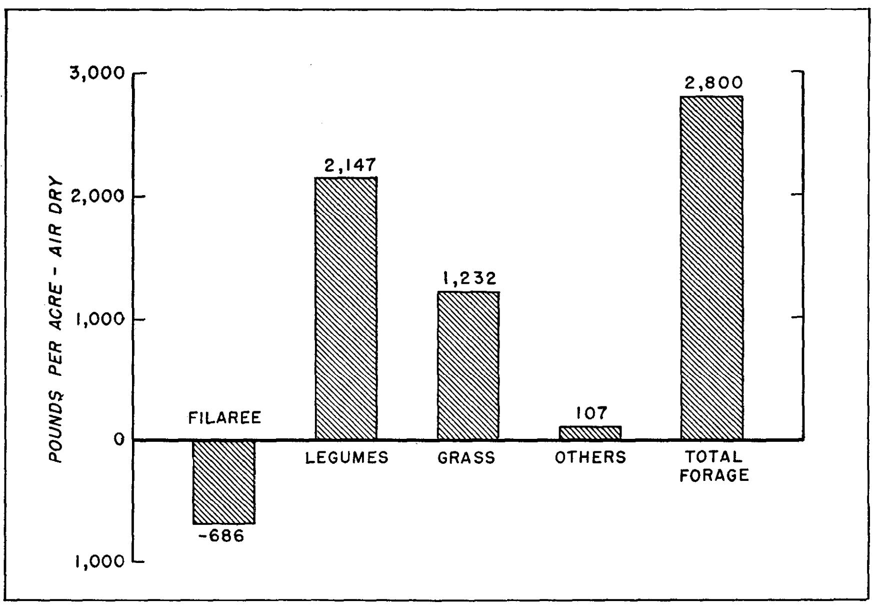

FIGURE 2. Change in composition and yield of forage after application of sulfur fertilizers. Based on yields for four years on 10 plots fertilized in January 1949, compared with yields from 6 unfertilized plots.

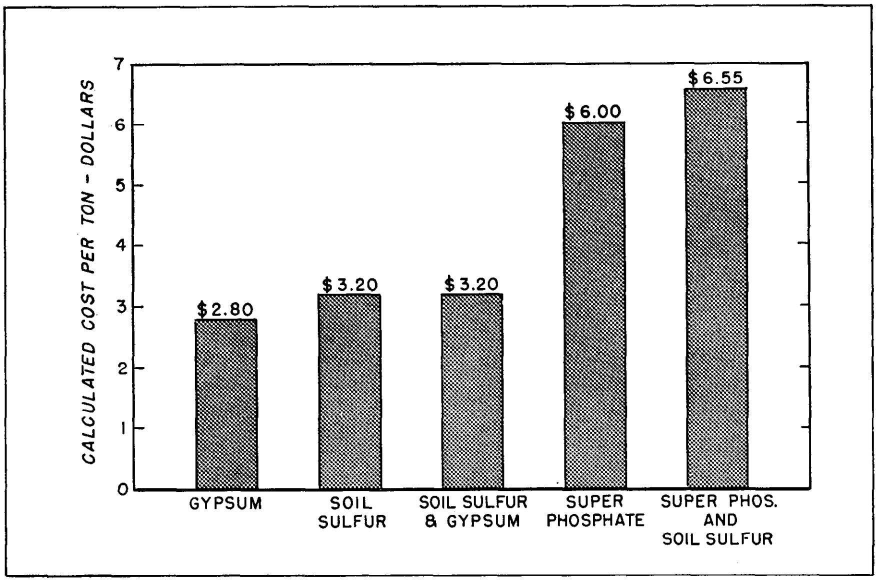

FIGURE 3. Cost per ton of increased forage production from different fertilizer treatments, each containing an equivalent of 60 pounds sulfur per acre. Based on four-year yields from 2 plots in each treatment compared with yields from adjoining unfertilized plots.

able effect than has an equivalent amount of sulfur in gypsum or soil sulfur. Because of the higher price of superphosphate, however, the increased forage yields have always cost more than have increases obtained with soil sulfur or gypsum.

That forage yields can be maintained at a consistently higher level on fertilized range is suggested by results on the plots fertilized in 1949, where total herbage production was increased 900 pounds in each of three successive years. Observations in other tests, however, indicate that the effects of fertilization may vary on shallow, sandy loam soils if unfavorable years are encountered. For example, the returns from fertilization were very limited during two dry years, 1948 and 1949, which followed two other years of low precipitation. There is some question as to whether stimulation of forage growth by fertilization in favorable years will make more variable an already fluctuating forage crop.

Cooperative studies on larger grazed areas have been started with the University of California to learn more about the practical problems of utilizing the increased natural forage obtained by sulfur fertilization on foothill ranges. Studies will be continued to determine the sites where additional practical benefits can be obtained from establishment of introduced legumes along with the natives.

Summary

The use of commercial fertilizers to improve California foothill ranges has been studied on plots at the San Joaquin Experimental Range since 1941. Stimulation of native clovers through application of sulfur-bearing fertilizers has proved to be a positive method of improving the annual-plant forage on the soils of granitic origin.

The response to sulfur fertilization was delayed for one season if the weather was unfavorable for legume growth during the year of application. Stimulation of legumes, particularly native annual clovers, was the first marked response to fertilizers containing sulfur. Increased production of both grasses and clovers occurred during the year after heavy legume growth, and there was a hold-over response in these plants during the third year. Improvement in both quality and quantity of forage as a result of increasing legume production has been very striking.

Fertilization at three-year intervals is now being tested on larger range areas, with each application at a rate equivalent to 60 pounds sulfur per acre. Either gypsum or soil sulfur is used on slope soils, at a cost of $2.50 to $4.00 per acre for a single application. Single superphosphate, a more expensive fertilizer, is recommended for swale soils where plot studies have indicated a deficiency of phosphorus as well as sulfur.

The problems involved in utilizing the improved forage are being studied on grazed range to learn more about practical operation in dry years as well as in favorable seasons.

LITERATURE CITED

ANDERSON, A. J. AND D. SPENCER. 1949. Molybdenum and sulphur in symbiotic nitrogen fixation. Nature (London) 164: 273–274.

BENTLEY, J. R. 1946. Range fertilization—one means of improving range forage. California Cattleman, September, pp. 6, 24.

BENTLEY, J. R. AND M. W. TALBOT. 1951. Efficient use of annual plants on cattle ranges in the California foothills. U. S. Dept. Agr. Cir. 870, 52 pp.

CHAPMAN, H. D., G. F. LIEBIG, AND D. S. RAYNER. 1949. A lysimeter investigation of nitrogen gains and losses under various systems of cover cropping and fertilization, and a discussion of error sources. Hilgardia 19: 57–128.

CONRAD, JOHN P. 1950. Sulfur fertilization in California and some related factors. Soil Science 70: 43–54.

CONRAD, JOHN P., H. L. HALL, AND B. A. CHAUGULE. 1947. Sulfur fertilization of legumes in the Upper Ojai Valley, California, and the resulting effects on the following non-legumes. Soil Science Soc. of Amer. Proc. 12: 275–277.

CROCKER, WILLIAM. 1945. Sulfur deficiency in soils. Soil Sci. 60: 149–155.

DICKEY, PAUL B., O. K. HOGLUND, AND B. A. MADSON. 1948. Effect of fertilizers on the production and season of use of annual grass range in California. Agron. Jour. 40: 186–188.

EATON, SCOTT V. 1941. Influence of sulphur deficiency on metabolism of the sunflower. Bot. Gaz. 102: 536–556.

GILBERT, FRANK A. 1951. The place of sulfur in plant nutrition. Bot. Review 17: 671–691.

HOGLUND, O. K., H. W. MILLER AND A. L. HAFENRICHTER. 1952. Application of fertilizers to aid conservation on annual range forage. Jour. Range Mangt. 5: 55–61.

IVANOFF, S. S. 1948. Chlorosis and nodulation of cowpeas as affected by trial sulfur applications to calcareous soil in the greenhouse. Plant Physiol. 23: 162–164.

NIGHTINGALE, G. T., L. G. SCHERMERHORN AND W. R. ROBBINS. 1932. effects of sulphur deficiency on metabolism in tomato. Plant Physiol. 7: 565–595.

LOVE, R. MERTON. 1952. Range improvement experiments on the Arthur E. Brown Ranch, California. Jour. Range Mangt. 5: 120–123.

LOVE, R. MERTON AND DORMAN C. SUMNER. 1952. Rose clover—a new winter legume. Calif. Agr. Ext. Serv. Cir. 407.

POWERS, W. L. 1930. The role of sulfur in plant nutrition. Oregon Agr. Exp. Sta. Bien. Rep. 1929–30.

THOMAS, MOYER D., RUSSEL H. HENDRICKS AND GEO. R. HILL. 1950. Sulfur metabolism in alfalfa. Soil Sci. 70: 19–26.

TISDALE, S. L., R. L. DAVIS, A. F. KINGSLEY AND E. T. WERTZ. 1950. Methionine and cystine content of two strains of alfalfa as influenced by different concentrations of the sulfate ion. Agron. Jour. 42: 221–225.

MID-CENTURY CONFERENCE ON RESOURCES FOR THE FUTURE

The Nation's range lands formed an important topic of discussion at the Mid-Century Conference on Resources for the Future held in Washington, D. C., December 2–4, 1953.

The conference, attended by 1,472 representatives from industry, labor, social and physical sciences, farm and conservation organizations, officials of local, state and federal governments, and foreign observers, was financed by a grant from the Ford Foundation.

The purpose of the Conference, which was greeted by President Eisenhower, was to permit free discussion of issues and for compilation of facts and opinions on which public and private agencies and groups might chart their plans and policies. The Conference reached no conclusion—there were no resolutions and no votes.

In order to facilitate effective consideration and group discussion, the Conference was divided into eight major sections on the subjects of: (1) Competing Demands for Use of the Land; (2) Utilization and Development of Land Resources; (3) Water Resource Problems; (4) Domestic Problems of Non-Fuel Minerals; (5) Energy Resource Problems; (6) U. S. Concern with World Resources; (7) Resources Research; and (8) Patterns of Cooperation, i.e., the interrelationships of citizens, organizations and governments at all levels. Topics discussed in Section 1 and especially in Section 2 are of greatest interest to range management people.

Two major speeches were made on the subject "The Public Lands—Who Should Control Them?" One advocated firm federal control, by Judge Robert W. Sawyer of Bend, Oregon, the other urged greater assurance to permittees of continuity of grazing use, by Representative Wesley A. D'Ewart of Montana. In the open discussions, agreement was found that the present public ownership of range lands is the most desirable arrangement for upbuilding and protection. There was also agreement that all federal activities relating to federal lands not in specialized use should be combined into a single agency in order to provide more effective and efficient administration.

Aspects of range resources touched upon in the discussions included: the history of their use; importance for the production of livestock and wildlife; watershed, timber and recreation values; past, present and possible future trends in condition; possibilities for improvement through management, reseeding, noxious plant control and fertilization; and research needs. Fred G. Renner, former President of the American Society of Range Management, voiced the opinion that "the 759 million acres of private and publicly-owned ranges in the 17 Western States can still be improved from 150 to 300 per cent." Dr. A. W. Sampson and Dr. Harold G. Wilm served as steering committee members. C. L. Forsling, former Director of the Bureau of Land Management, discussed policies of the various land management agencies. Other Range Society members presenting papers or otherwise participating were: Dr. H. C. Hanson, C. J. Olsen, M. L. Baker, Edward P. Cliff, W. L. Dutton, E. J. Dyksterhuis, C. R. Gutermuth and R. M. Salter.—*Kenneth W. Parker*, U. S. Forest Service, Washington, D. C.