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EFFECTS OF NITROGENOUS FERTILIZERS ON CALIFORNIA RANGE AS MEASURED BY WEIGHT GAINS OF GRAZING CATTLE

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This report summarizes the results of 54 field experiments designed to evaluate the effects of nitrogenous fertilization of California rangeland as measured by weight gains of grazing cattle. Carried out over a 15-year period, the tests involved 7,650 animals grazing on 16,781 acres on 28 ranches in 20 counties. Weight gains of cattle grazing on fertilized and unfertilized fields during the same period were compared. Grazing income per acre was calculated by using the 15-year average price of stocker and feeder cattle and deducting costs of fertilization, stocking, and interest.

From fertilizer effects the first year of application, the average range carrying-capacity was increased from 38 to 92 head days per acre, and the average live-weight gain of cattle was increased from 60 to 170 pounds per acre. Greater first-year benefits were observed where nitrogen plus sulfur or nitrogen plus phosphorus were required than where nitrogen alone was needed. Second-year or carryover effects, measured at 13 locations, were much greater from nitrogen plus sulfur and nitrogen plus phosphorus than from nitrogen alone. In two years, total extra beef production from each pound of nitrogen was 1.17 pounds; from nitrogen plus sulfur, it was 2.75 pounds, and from nitrogen plus phosphorus, 2.54 pounds.

Economic evaluation of first-year nitrogen fertilization showed that the average grazing income was increased from $9.95 on the check to $15.05 per acre, with a fertilizer cost of $13.92. This represented a return of 39 per cent in 122 days of grazing. Maximum profits from use of nitrogenous fertilizers were found in the 13- to 30-inch rainfall zone. Losses usually occurred with drought conditions (less than 12 inches rain) or with excess leaching associated with over 30 inches of seasonal rainfall. Profit from sites where nitrogen plus sulfur or nitrogen plus phosphorus were initially required were much greater than from sites where only nitrogen was needed.

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EFFECTS OF NITROGENOUS FERTILIZERS ON CALIFORNIA RANGE AS MEASURED BY WEIGHT GAINS OF GRAZING CATTLE[1]

THE PROBLEM

Rangeland makes up slightly over one-third of California. It includes about 10 million acres of open, treeless grassland and about 25 million acres of oak-grass woodland and brushy areas used primarily for grazing. Little of this has been fertilized, although it has been grazed by cattle or sheep for at least a century. Present forage is composed principally of annual grasses and forbs, including clovers and afilaria. Perennial forage species make up only a small percentage of California range.

Most of the open range and low-lying portions of the oak-grass woodland are used for the production of green feed in the winter and spring. At higher elevations and along the north coast where rains continue longer, range provides some winter feed, but green feed comes principally during the spring and early summer months. Over most of California range, summer and fall feed is from dry grasses and legumes produced during the spring flush of growth.

Forage production on California rangeland has been limited by:

Feast or famine. The growth of feed is slow during the winter months because temperatures are low, and annual grasses and legumes grow slowly under existing fertility levels—even though adequate soil moisture is present. The major production of forage comes in a great flush in the spring when soil and air temperatures have increased, and soil moisture is still adequate. Feed dries up quickly in the late spring as soon as rains cease.

Poor forage production. In many areas, low fertility limits the growth of forage even when temperature and moisture are favorable. In these areas, soils are acutely deficient in phosphorus (P) or sulfur (S) or both, as well as in nitrogen (N). In other areas, soils are severely compacted from years of grazing, and growth is poor because neither water nor plant roots penetrate the soil readily.

Poor-quality forage for animal use. Most winter- and spring-growing annual grasses make good feed while green or approaching maturity. When mature and dry, however, many of these species are of low nutritive quality, unpalatable, and often injurious. In some areas of low fertility, annual grasses fail to extract the available soil moisture, allowing non-palatable summer weeds, such as star thistle and tarweed, to grow vigorously and reduce the overall quality of the dry forage.

[1] Submitted for publication July 3, 1969.

CLIPPING STUDIES—A PRELUDE TO GRAZING TRIALS

For many years, the University of California Agricultural Extension Service farm advisors, working in cooperation with the Department of Agronomy at Davis carried out field studies with nitrogenous fertilizers in which results were measured in terms of forage clipped from the experimental areas. The principal purpose was to stimulate the grasses directly and thus increase forage available for animal use. These tests showed responses to N in nearly every case, but several patterns of responses were observed. On soils well supplied with P, nitrogen treatments alone produced as good early and total growth as did N plus P(NP) treatments. On soils acutely deficient in P, little benefit was obtained from N in any season, unless P was also applied. Many soils showed a winter deficiency of P. On such soils, NP treatments greatly increased winter and spring growth, while N alone produced little growth in the winter but reasonably good production in the spring after soil temperatures had increased. On S-deficient soils, ammonium sulfate applications to provide both N and S made better growth than did equivalent amounts of N alone from ammonium nitrate as shown by Walker and Williams (1963) and by Martin (1958).

Rate- and source-of-N experiments. Clipping studies by the Soil Conservation Service showed the average production for six successive years to be increased by approximately 2,900 pounds per acre per year over the control where annual applications of 200 pounds of ammonium phosphate sulfate (16-20-0-12S) had been applied.

Studies were carried out by the Department of Agronomy at the University of California at two principal locations.

1. Brown Ranch in Sacramento County: On a very P-deficient soil, clippings over a two-year period showed that 4,555 pounds of extra forage were produced from a single application of 600 pounds of ammonium phosphate sulfate (16-20-0-12S), providing 96 pounds of N and 120 P_2O_5 (52 actual P). Eighty-two per cent of the increased forage production came during the first season (Conrad, 1951).

2. University of California Hopland Field Station: There is normally little winter growth, although rainfall is usually adequate. Test strips were laid out on seeded legume and perennial grass pastures in the winter of 1953–1954. Feed production through March 30, 1954, was increased from 540 pounds per acre on the control strips to 3,944 pounds by 400 pounds of ammonium sulfate supplying 84 pounds N. Production increased to 6,349 pounds from 519 pounds of ammonium phosphate sulfate providing 83 pounds of N and 104 P_2O_5 (45P). (Love and Murphy, 1955; Love and Williams, 1956.)

The most striking and consistent fact that emerged from the entire series of tests and demonstrations measured by clipping has been that supplemental N stimulated early and continued winter and early spring growth of annual grasses. These responses occurred during the cold season, when little growth would normally be expected. Nitrogenous fertilizers appeared to be the key to early growth, but they were found effective only if adequate P and S were present in the soil or applied in the fertilizers.

Influence of temperature, rainfall, and nutrient supply

Throughout California, rainfall usually comes during the winter months when temperatures are at their lowest. The bulk

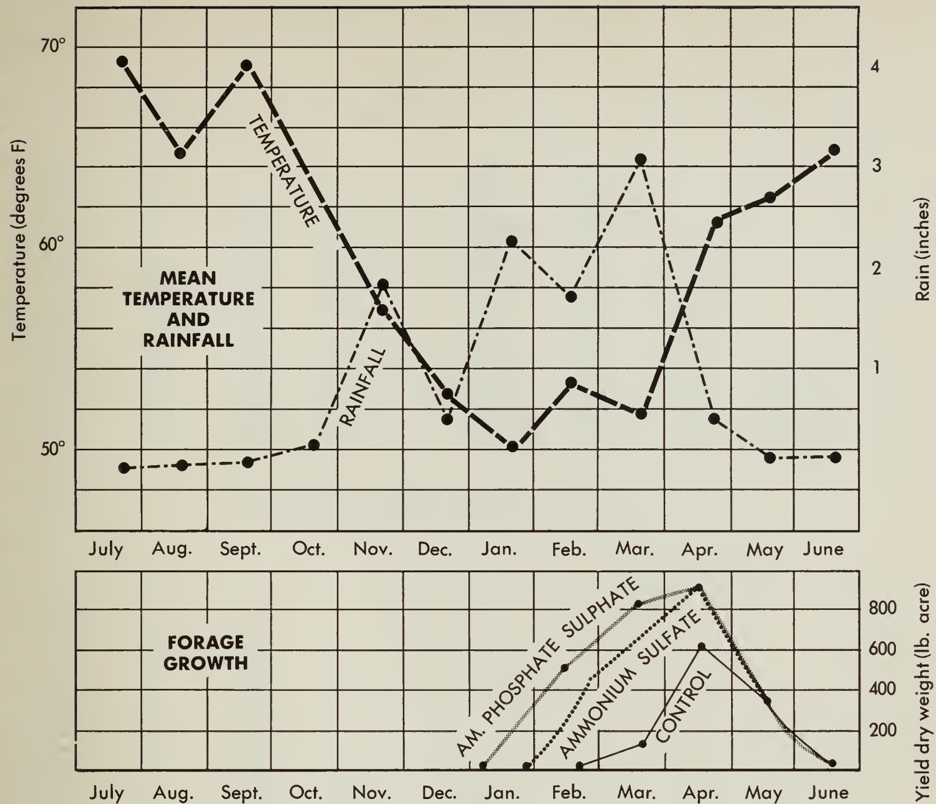
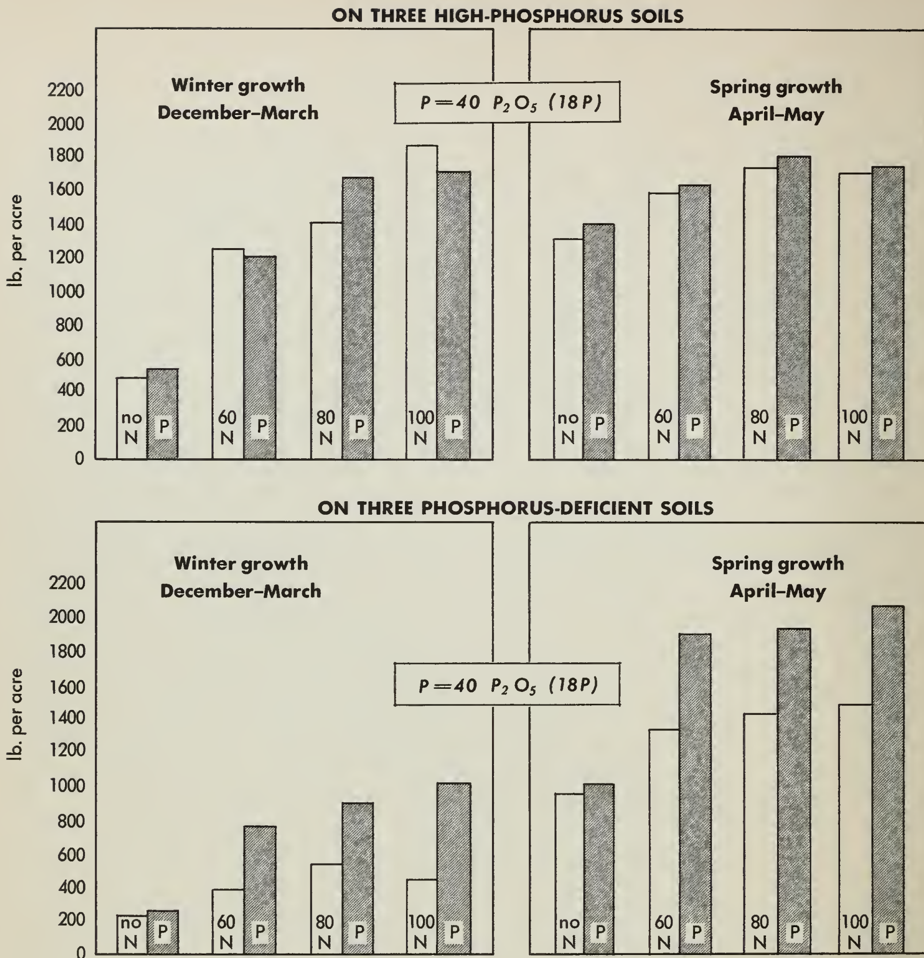


Fig. 1. Seasonal growth of forage as related to fertilization, rainfall, and temperature. Santa Clara County. 1953–1954.

of forage production, however, does not come until spring, when soil temperatures have increased and moisture is still adequate. As spring approaches, the warming of the soil liberates nitrogen from organic reserves and crop residues. The nutrient supply thus increased permits forage to grow in a great flush of spring growth as temperatures become more favorable. As rains cease, this growth slows to a stop; forage matures and dries as summer approaches.

It is ironic that the most favorable temperatures occur when there is little rain, and that good moisture conditions occur when soil temperatures are usually too low for normal growth of range plants. Winter temperatures are apparently too low for the soil bacterial processes that bring about decomposition or mineralization of organic matter and crop residues. These same winter temperatures, however, are high enough on much of California rangeland to permit winter growth of annual grasses, afilaria, and other forage plants if adequate nutrients are present in available form.

The relationship between temperature, rainfall, and fertilizer treatments upon the seasonal growth of forage is shown in figure 1. In this Santa Clara County study (Martin and Berry, 1954) the soil was clearly deficient in both N and P. Clippings were made at monthly intervals from both the fertilized and unfertilized areas. Yields of unfertilized plots showed that growth occurred only when temperatures were rising, rainfall was decreasing, and moisture was still present and decreased rapidly as rain ceased. Yields



from the plot treated with ammonium sulfate showed that growth was hastened and took place well in advance of the untreated area, but not as early as where N, P, and S were applied in ammonium phosphate sulfate. Both early and total forage were increased by nitrogenous fertilizers, and the grazing season was thus hastened by supplying N and P at a time of year when moisture conditions were favorable but when low soil temperatures caused naturally-occurring mineral nutrients to be insufficient. Figure 1 illustrates the potential in much of our California rangeland for making plants grow during the winter when moisture supplies are normally adequate.

Nitrogenous fertilizer effects on high- and low-P soils

Figure 2 shows results of N and P treatments on winter and spring forage from three high-P and three low-P soils. These clipping tests, carried out concurrently with grazing experiments, were reported by Martin and Berry (1956).

On the high-P soils, P fertilizers had no significant effect when added alone or with N. On these same soils, forage yield was almost directly proportional to the

Table 1

EFFECT OF DIFFERENT N AND P RATES ON FORAGE YIELD AND RECOVERY OF N

Treatment*	Seasonal yield forage (dry weight) from: 3 low-P soils				3 high-P soils			
	Total	Increase	Per 1 lb. N	N recovery	Total	Increase	Per 1 lb. N	N recovery
	lb./acre	*lb./acre*	*lb.*	*per cent*	*lb./acre*	*lb./acre*	*lb.*	*per cent*
Check	1,213	.....	....	..	1,735	.....	....	..
$40P_2O_5$†	1,302	89	....	..	1,978	243	....	..
60 N	1,723	510	8.5	15	2,881	1,046	17.4	39
80 N	2,000	787	9.8	16	3,188	1,453	18.2	39
100 N	1,976	763	7.6	12	3,677	1,942	19.4	43
60 N, $40P_2O_5$†	2,665	1,452	24.2	31	2,909	1,174	19.6	38
80 N, $40P_2O_5$†	2,860	1,647	20.5	30	3,555	1,826	22.7	37
100 N, $40P_2O_5$†	3,306	2,090	20.9	35	3,518	1,783	17.8	25
L.S.D. (5%)	521	521	....		488	488	....	

* As lb. of N and P per acre from ammonium sulfate (21–0–0–24S) and normal superphosphate (0–21–0–12S).
† $40P_2O_5$ = 17 P.

rate of N applied in both winter and spring growth periods. Most "extra forage" from N treatment came during the winter.

On the low-P (P-deficient) soils, P fertilizer alone did not increase total forage in either the winter or spring cuttings. Native legumes responded somewhat to added P, but not enough to appreciably affect yields. In the winter period, P was clearly effective *only* when applied with N, and responses were proportionate to the amount of N applied. In the spring period, N alone did increase grass growth on these low-P soils, but to a much lesser degree than where P was also added.

Why NP combinations failed to produce as much winter forage on low-P soils as they did on high-P soils is not known. The delayed response may have been related to the water-logged soils at these locations during the winter "flood" periods. A summary of the total seasonal yield on high- and low-P soils is shown in table 1.

The apparent recovery of fertilizer N as measured by the total N content of the forage was only 12 to 16 per cent on low-P soils where no P had been supplied, but was generally 30 to 40 per cent of applied N on high-P soils and on low-P soils after P had been applied. The yield of dry matter per pound of N applied was constant at 18 to 20 pounds per pound N on all rates of N, and on both groups of soil if native P was high or P had been applied.

GRAZING TESTS—THE PURPOSE OF THIS REPORT

Nitrogenous fertilizers have been shown to increase range forage production as measured by clipping, drying, and weighing the vegetation cut at intervals or near the end of the green-feed period. Such studies, however, have not established that these forage gains would be reflected in increased cattle gains, if the forage was grazed continuously during the green-feed period.

The purpose of this report is to gather together the results of grazing tests over a 15-year period (1953 to 1968) in which weight gains of 7,650 animals grazing on 8,051 fertilized acres and 8,730 unfertilized acres were compared. An effort was made to measure the effectiveness of specific fertilizer treatments and to determine under what conditions the use of nitrogenous fertilizers would appear feasible.

These field-scale grazing tests were initiated in 1953 by the University of California Agricultural Extension Service in cooperation with ranchers and commercial fertilizer manufacturers. Four annual progress reports were made by Martin and Berry (1954, 1955, 1956) and Martin, Berry, and Williams (1957). In 36 of these tests, weight gains of grazing cattle during the green-feed period were used to evaluate results of fertilizer applications. Eighteen similar field experiments were carried out by farm advisors from 1958 to 1968, but reports on them were disseminated only locally. In each test, earlier winter feed was produced on N-fertilized fields; carrying capacity was greatly increased; and beef production during the green-feed period was increased two to four times. Results from year to year varied greatly with seasonal rainfall and growing conditions, as will be shown later in this report.

A similar series of demonstrations, sponsored by a commercial fertilizer distributor were carried out in cooperation with several Soil Conservation districts and California State Polytechnic College at San Luis Obispo. These tests reported by the California Fertilizer Association (1957) showed that winter growth was greatly hastened, overall beef production was increased, and "profits" as measured by value of beef production over cost of fertilizer were achieved in most cases.

In a six-year study by Wagnon, Bentley, and Green (1958), cattle gains were used to measure the results of fertilizer treatments at the San Joaquin Experimental Range in Madera County. Sulfur alone applied to stimulate annual legumes and associated grasses increased annual beef production from 20.4 to 64.2 pounds per acre. Later studies at the same location (Woolfolk and Duncan, 1962) compared cattle gains on pastures fertilized with S with gains on pastures fertilized with N plus S. This three-year study indicated that N fertilization increased beef production in both the green- and dry-feed periods. Liveweight gains of cattle from NS treatment amounted to 108 pounds per acre as compared with 65 pounds per acre from S treatment alone, and 32 pounds per acre with no treatment. Data from a study of the residual effects the year after treatment indicated that gains from previously applied S and NS were about equal but double those obtained on the untreated fields.

EXPERIMENTAL METHODS FOR GRAZING TESTS

Site selection

Grazing trials were laid out on land selected as typical of extensive areas of range in each locality under study. Some tests were set up on productive rangeland, while others were on poorer areas depleted by years of grazing, or on areas of known low productive capacity. Some of these latter were known to be acutely deficient in P or S; some were set up at locations thought to be well supplied with nutrients other than N.

Relatively large experimental fields were used in order to get a fair cross section of the area under study and to accommodate sufficient cattle to obtain reliable results. Field size was often dictated by the size of existing fields which could be subdivided for treatment, as well as by the location of stock water facilities. Fifty- to 60-acre fields were usually used for fertilizer treatments. The untreated fields were often 100 to 300 acres in size, so that roughly the same number of animals might be grazed on both fertilized and unfertilized fields in each test.

Treatment

One control field and one or more adjacent fertilizer fields at each location comprised the basic plan. Fertilizers were applied in October or November just before the winter rains began. In some instances, N-rate experiments were set up; in others, N-source tests were made in which results of N alone were compared with those from NP and NPS. Also, studies were carried out at several locations on the use of supplemental feeding of cattle with hay or hay and barley on both fertilized and unfertilized areas. At 13 locations, second-year residual effects of nitrogenous fertilizer on beef production were measured.

Fertilizer materials were applied by ground rig where possible, or by airplane where terrain was too rough or inaccessible for ground equipment. Actual costs of fertilizer materials and their application (whether by air or ground rig) were recorded at the prevailing market prices when tests were started.

Stocking and grazing

Grazing was carried out as close to normal operations as possible; young animals, usually Hereford or Angus steers or heifers weighing 350 to 600 pounds each, were used in most tests. In a few experiments, Holstein steers or heifers were employed. The fertilized fields were stocked at rates estimated as proper for the available feed. Untreated fields were stocked on the same date at rates selected by the rancher as the normal carrying-capacity of his range. Both control and fertilized fields were grazed during the same period. Stocking rates were changed as the condition of the range indicated, and animals were added or removed as needed to utilize the available forage. All animals were removed and tests terminated by mutual agreement when nearly all of the green feed had been utilized, leaving enough growth to provide dry feed for normal fall use. Every effort was made to utilize available feed, but not to overgraze or abuse the range.

Measurement of results

All animals were weighed when placed in the field and again when removed. In some tests, periodic weighings were made to determine progress. Results have been expressed as (1) grazing days per acre, (2) average daily gain per animal, (3) liveweight gain per acre, and (4) beef per pound of N applied.

EFFECTS OF RANGE FERTILIZATION ON CATTLE WEIGHT

The 54 field grazing tests which comprise the body of this report involved several types of experiments. The majority were simple two-field experiments comparing the beef production from an untreated field with that from a N-fertilized field—with S or P, or both, added in the nitrogenous fertilizer where thought necessary. At a number of locations where three or more comparable fields were available, N-rate or N-source experiments were carried out.

At a few locations, owing to drought, it was necessary to provide hay or barley to all test animals to keep them from losing excessive weight. At such locations, effects of supplements masked results of fertilizer applications. At some locations, four fields were available where it was possible to compare cattle gains on the fertilized and control fields, each with and without hay or barley supplements.

Tests were continued a second year at some locations to measure the residual effect of nitrogenous fertilizers. At a number of locations, grazing tests were carried out for three to five successive years, providing information on the influence of rainfall per se on the production of beef on the unfertilized field at each site.

N-rate experiments

These tests were conducted to determine whether cattle gains reflected the results observed in the small-scale clipping experiments described in the preceding sections. Using three fields at each of five separate locations, a high rate (80 to 100 lb. N/acre) was compared with a low rate (40 to 60 lb. N/acre), and to an untreated field. Results of these experiments are summarized in figure 3. Beef production was increased at about the same rate in each of the five experi-

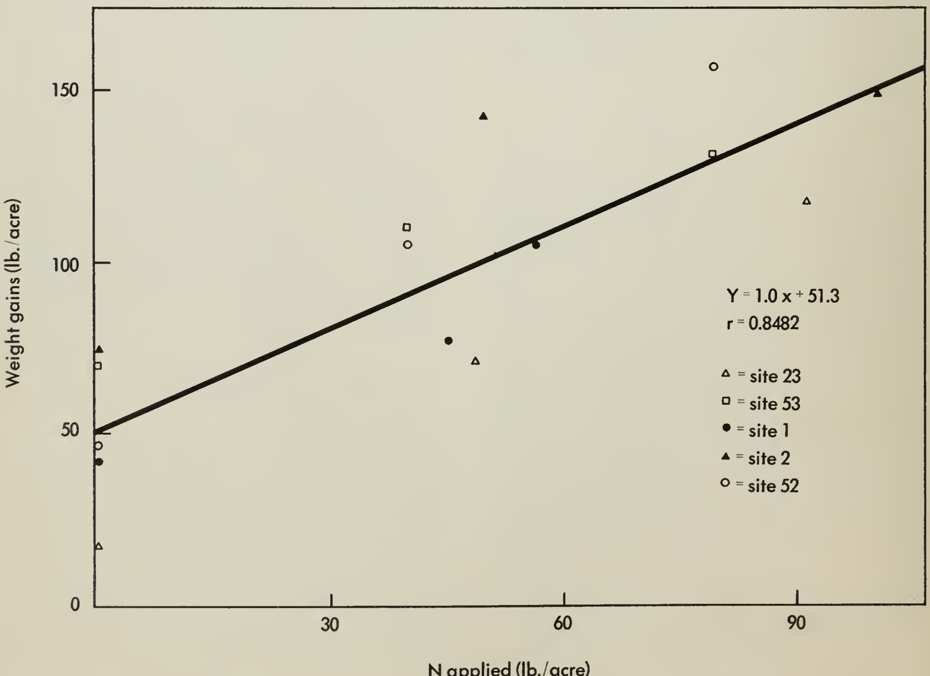


Fig. 3. The effects of rates of N on cattle weight gains at five locations.

TABLE 2

CATTLE WEIGHT GAINS RELATED TO NITROGEN AND NITROGEN-PHOSPHOROUS FERTILIZERS

Average N treatment	Weight gains by site and year				Average gain	Fert. effect	Average beef per lb. N
	3–'56	15–'55	18–'55	20–'54			
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Check	60.4	56.9	126.9	52.7	74.2	.....	....
90 N	128.0	134.6	175.7	150.3	147.2	73.0	.81
90 N (25P) 58 P_2O_5	156.0	221.0	395.5	224.8	249.3	175.1	1.94
Actual rates:							
N	80	73	144	64			
P_2O_5	40(17)	49(21)	64(28)	80(35)			

TABLE 3

FIRST-YEAR EFFECTS OF DIFFERENT NUTRIENTS ON CATTLE GAINS

Nutrient required	Average treatment			Number of grazing days		Avg. daily gain		Liveweight gain		Gain per 1 lb. N	No. of tests
	N	P_2O_5	S	Check	Fert.	Check	Fert.	Check	Fert.		
	lb./acre			*head days/acre*		*lb./head*		*lb./acre*		*lb.*	
N	57	..	..	56.8	86.4	1.36	1.63	73.7	141.5	1.19	7
NS	71	..	64	30.0	89.3	1.95	1.84	52.8	157.4	1.48	10
NP	69	58*	36	33.2	97.5	1.69	1.96	58.2	195.1	2.00	13
Average	66.5	..	..	37.7	92.0	1.70	1.85	60.0	170.0	1.65	30
Increase due to fertilization:					54.3		.15		110.0		

*$58 P_2O_5$ = 26P.

ments. The slope of the regression line and correlation coefficient ($r = .848$) indicate a highly significent linear relationship with approximately one pound of liveweight gain for each pound of N applied. Since four of the five tests summarized in this group were on soils believed to be adequately supplied with both P and S, the responses are believed to be due principally to N alone.

N-source experiments

The effects of N alone were compared with those of equal quantities of N plus P in four trials (table 2). Production from N alone was significantly higher than for the untreated field in each case, but obviously much less than when both N and P had been provided.

First-year responses to nitrogenous fertilization

Thirty tests were carried out on lands not previously fertilized. Data in table 3 are grouped to show where N alone, NS, and NP were thought to be responsible for forage growth differences. In the NP group, some S was also applied along with P where materials such as ammonium phosphate sulfate (16-20-0-12S) were used as the P source. Individual data from all 30 experiments are grouped by nutrient response and in order of increasing rainfall within each group. (See appendix table 1.)

Table 3 shows that the average carrying-capacity was increased from approximately 38 to 92 grazing days per acre.

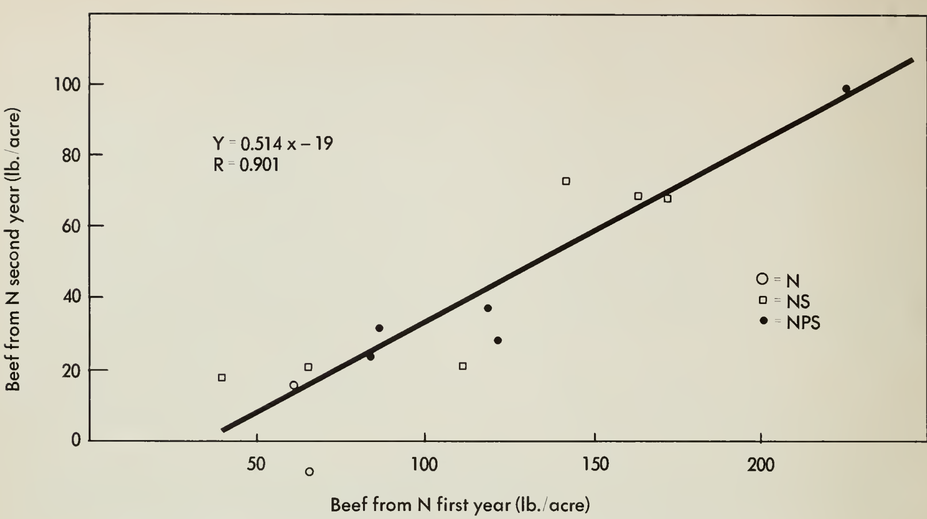
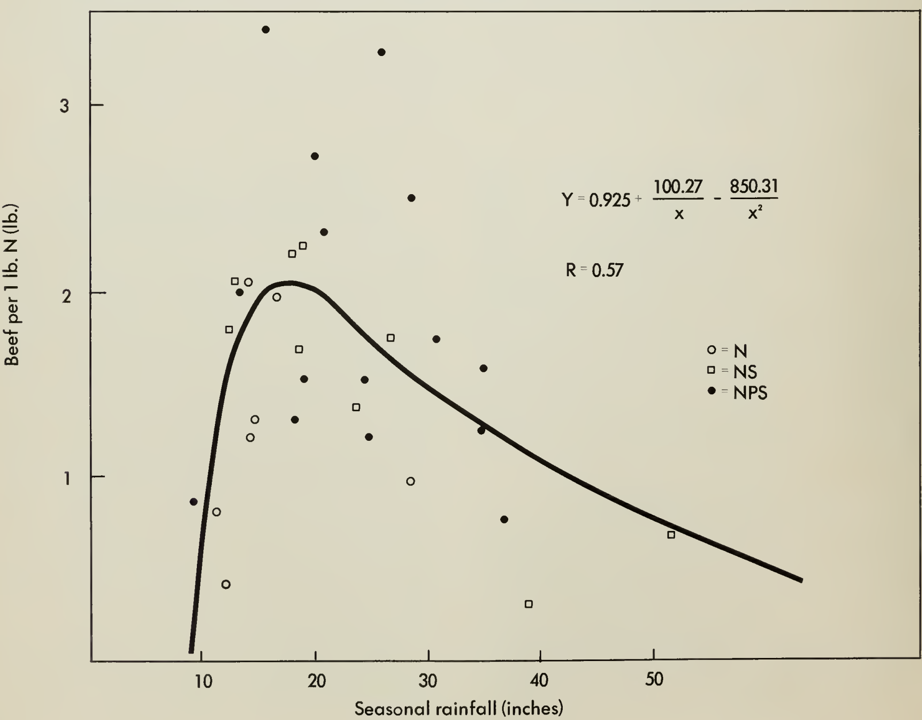


Fig. 4. The relationship between first- and second-year meat production to fertilizer treatment.

Fig. 5. Beef per pound of N as related to seasonal rainfall and source of N.



The mean average daily gain per head was slightly greater on the fertilized fields than on the control fields. Appendix table 1 shows that in 24 out of 30 tests the average daily gains were slightly greater on fertilized than on control fields. This indicates that the fertilized fields were not overstocked in relation to control fields. Beef production, or liveweight gain per acre, was greatly increased in every test. Average beef production per acre was increased from 56 to 159 pounds where nitrogenous fertilizers were used. This average increase amounted to 1.65 pounds of beef for each pound of N applied. The increase in production per pound of N was greater where NP was applied than where NS, or N alone, were applied. The greater increased production from NS or NPS than from N alone is to be expected, since a dual or multiple deficiency was corrected. A portion of the benefits must be attributed to the S and P applied with the nitrogenous fertilizers.

Second-year residual effects

Experiments were continued a second year without further treatment to measure the residual effects of fertilization at 13 locations (appendix table 2). In figure 4, beef yields attributed to N fertilization for the second year are plotted against first-year beef production. In every case but one, an appreciable residual effect of nitrogenous fertilizer was observed. The second-year results were found to be proportionate to the initial first-year production, and the correlation coefficient ($r = .901$) indicates a highly significant relationship. Residual or carryover gain was approximately 50 per cent of the first-year effects of nitrogenous fertilization. The data does not make clear whether these second-year effects are attributable to (a) residual N from the first-year's application, (b) recycled N in manure or urine, or (c) P and S remaining to stimulate resident legumes which make up a portion of the vegetation at some locations. Grazing data from the study carried out at the San Joaquin Experimental Range by Woolfolk (1962) showed that carryover effects of S were equal to those of NS. Carryover effects according to their study, therefore, were due to the influence of S rather than recycled N.

Seasonal rainfall influences beef production

Records of seasonal rainfall from the official rainfall station nearest each experimental field were recorded along with the pounds of beef per acre produced on both the fertilized and unfertilized fields at each location.

On N-fertilized range. Figure 5 shows seasonal rainfall effects on beef production per pound of N, and appendix table 1 lists the effects according to the nutrient response. The amount of beef per pound of N was low where the seasonal rainfall was below 12 inches or above 30 inches. The maximum response occurred at about 17 inches seasonal rainfall, according to the regression curve calculated from the data (fig. 5). The highest yield of beef per pound of N generally was observed where NP or NPS were used. These first-year effects of seasonal rainfall upon N response indicated that either low or high rainfall conditions may be expected to reduce the efficiency of conversion of N into beef. In high-rainfall areas of 30 inches or over, losses of N by leaching make fertilization impractical in most years. Similarly, where rainfall is less than 12 inches, it is drought conditions, rather than N deficiency, that tend to limit forage growth. Few data were available to relate actual cattle gains to N fertilization where seasonal rainfall was below 12 inches—since supplemental rations had to be supplied and it was not possible to measure the effects of N alone.

On unfertilized range. Cattle gain and

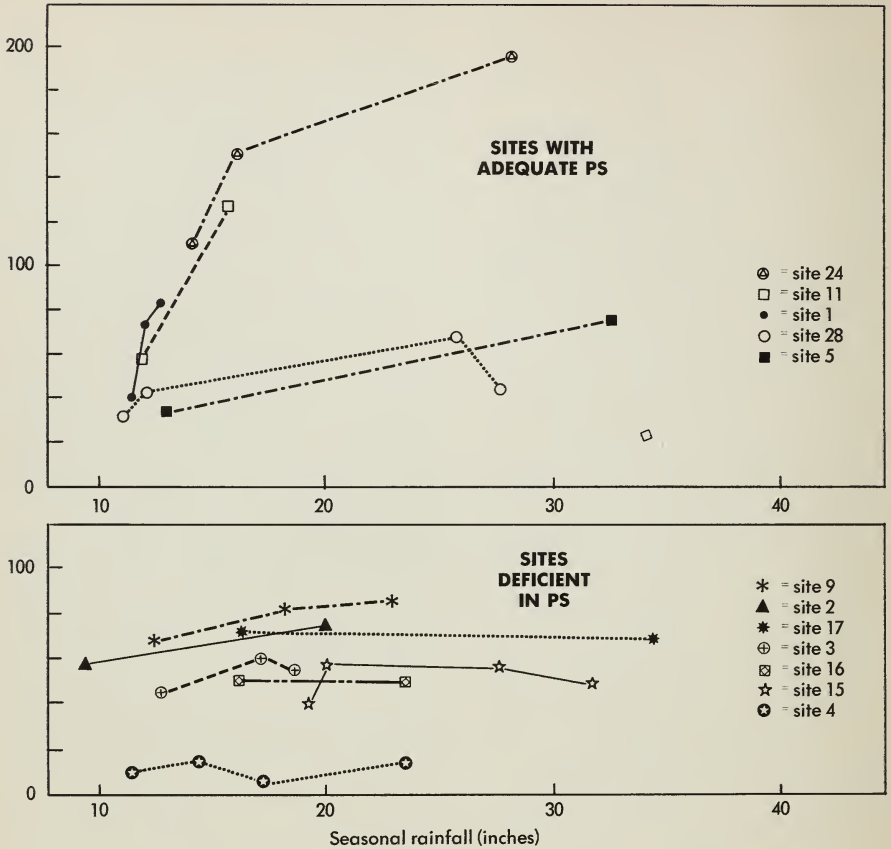


Fig. 6. Influence of rainfall and nutrient status on beef production on unfertilized range.

rainfall records were available for two or more successive years at 12 unfertilized locations. Figure 6 shows two distinct types of response. On soils known to be deficient in S, P, or both, differences in beef production were very slight for successive years, even though rainfall showed a two- to three-fold variation. On the other hand, at locations known to be well supplied with P and S (where N alone had been effective), beef gains on the control field were, in most cases, markedly increased by increasing seasonal rainfall. Where P and S were acutely deficient, the supply of these nutrients, rather than rainfall, limited forage and, consequently, beef production on unfertilized range. This observation is contrary to the popular conception that wet years are usually good feed years.

ECONOMIC EVALUATION OF RESULTS

Nitrogenous fertilizers, some containing S and P in addition to N, have been shown in the preceding section to offer a potent means of increasing meat production. However, the results of grazing experiments are meaningful only as they relate the value of the additional liveweight gain produced to the costs of the fertilizer and the costs of stocking the fields for the duration of the experiment.

Roughly, each pound N applied per acre produce one and one-half to two pounds of extra beef per acre. Applied N costs varied from 10 to 20 cents per pound, depending upon the kind of N, cost of application, and whether or not the materials contain additional nutrients, such as S and P. Cattle as removed from the range currently have a liveweight value of 24 to 28 cents per pound.

Evaluation method

The following steps were used to determine the profitability of range fertilization in each test:

Gross grazing income per acre was calculated as the value of cattle removed for sale at termination of the test.

Net grazing income per acre was calculated by deducting from the gross grazing income the cost of animals used in stocking each acre, the cost of applied fertilizers and/or supplements when used, and interest on these costs for the duration of the experiment.

Fertilizer profit per acre was then calculated as the difference between the net grazing income on the fertilized as compared to the net grazing income for the control field.

California rangelands are usually stocked with calves purchased in the fall or early winter. After a grazing period of several months (the green feed period) these animals are removed and placed either in a feedlot or on irrigated pastures. The price of the animals used for stocking is usually somewhat higher than the price per pound at which the animal is sold at the termination of the green feed period. Records for the 15-year study period from the Stockton Livestock Market show that 400-pound animals cost 24.25 cents per pound in the fall, and that 600-pound animals, after a 200-pound gain, sold in the spring for 22.20 cents per pound. These average values, including the "negative margin" were employed in the calculations used in evaluating the tests in this study.

Fertilizer costs used in profit calculations were actual costs of the fertilizer at time of treatment, plus actual cost of application, according to each experiment. Costs of ground application were one dollar per acre, while air costs were much higher giving an obvious economic advantage to tests where ground application was employed. Interest on stocking and fertilizer costs were charged at the rate of 6 per cent per annum, or .5 per cent per month for the duration for each test. This interest was approximately that prevailing during the 15 years of the study.

An illustration of the method of cost evaluation is shown on page 16. In this example, we have used the average weights and gains of animals as found in the overall average of all experiments in this study.

30 first-year fertilization tests

Table 4 shows the amounts of extra beef produced as a result of fertilization, along with fertilizer costs. Net grazing income value and fertilizer profit were calculated for each of the several classes of fertilizer response described in the preceding sections. These data for the 30 first-year tests show the highest fertilizer profit and the highest increase in beef production per acre occurred in the group of tests where both N and P were used. Lower fertilizer profits were obtained in the tests where NS was employed, and the least profit occurred where N alone was used. However, since the N and NS costs were less than for the NP treatments, the per cent profit on the fertilizer investment was nearly the same. It is important that nine of the 30 plots included in this study failed to show a profit, as indicated in appendix table 1, probably because most of these were in either the high- or low-rainfall zones in which beef production per pound of N was markedly reduced.

A GRAZING TEST EVALUATION

Factor	Check	Fertilized
Average inweight/head	367 lb.	370 lb.
Average stocking rates:		
inweight/acre	147 lb.	370 lb.
acre/head	2.5	1
head/acre	.4	1
Average gain/acre during test	60 lb.	170 lb.
Outweight/acre	207 lb.	540 lb.
Gross grazing income/acre (outweight @$22.20 cwt)	$45.97	$120.10
Less stocking cost (inweight @$24.25 cwt)	$35.65	$ 89.00
Less fertilizer cost	....	$ 13.92
Less interest 124 days–2.07% 6% (.0167%/day)	$ .73	$ 2.13
Net grazing income/acre	$ 9.59	$ 15.05
Average profit from fertilization	....	$ 5.46

Second-year residual effects

Fertilizer carryover effects must be considered if an accurate evaluation is to be made. It was shown in an earlier section that in 12 of the 13 carryover tests the previously fertilized fields produced more beef than did the controls the second year. This second-year effect was about 40 to 50 per cent of the gain from fertilization for the initial year or season of application. Table 5 compares the first- and second-year results on these same sites. Note that the average fertilizer profit the first year of the test was $7.34 per acre

TABLE 4

ECONOMIC EVALUATION OF 30 FIRST-YEAR GRAZING TESTS WITH NITROGEN FERTILIZERS

Number of tests	Average treatment				Extra beef		Grazing income per acre		Profit per acre from fertilizers	
	N	P_2O_5	S	Cost	Per acre	Per 1 lb. N	Check	Fert.		
	lb./acre			*dollars*	*lb.*	*lb.*	*dollars*		*dollars*	*per cent*
7	57	..	..	$ 8.68	67.8	1.19	$11.66	$15.02	$3.36	38
10	69	58*	..	16.91	136.9	2.00	9.52	16.67	7.15	42
13	71	..	64	13.69	104.7	1.48	8.24	12.97	4.73	35
Average:	67	..	..	$13.92	110.0	1.63	$ 9.59	$15.05	$5.46	39

* $58P_2O_5 = 26P$.

TABLE 5
FIRST-YEAR AND RESIDUAL EFFECTS OF NITROGEN FERTILIZER ON CATTLE GAINS

Year	Average treatment		Average liveweight gains			Beef/ 1 lb. N	Average grazing income		Fertilizer profit
	N	Cost	Check	Fert.	Increase		Check	Fert.	
	lb./acre	*$/acre*	*lb./acre*			*lb.*	*lb./acre*		*$/acre*
Treatment year	67	12.11	63.9	175.6	111.7	1.67	10.61	17.95	7.34
Residual year	..	.....	56.4	102.6	46.2	.69	9.09	15.03	5.94
Two-year total	67	12.11	120.3	278.2	157.9	2.36	19.70	32.98	13.28

with 1.67 pounds of beef for each pound of N fertilizer. The residual response obtained at no additional fertilizer cost gave an additional fertilizer profit of $5.94 per acre and an additional .69 pound of beef per pound N from the original application. This raised the fertilizer profit per acre to $13.28 after deducting the original average fertilizer cost of $12.11, and it raised the average beef production per pound of N to 2.36 pounds. Whether the carryover effects were due to recycling of N fertilizer through manure or urine, or to stimulation from P and S added initially with N cannot be determined. The fact remains, however, that carryover responses with NS and NPS originally applied were of greater magnitude than those where straight N had been used the initial year.

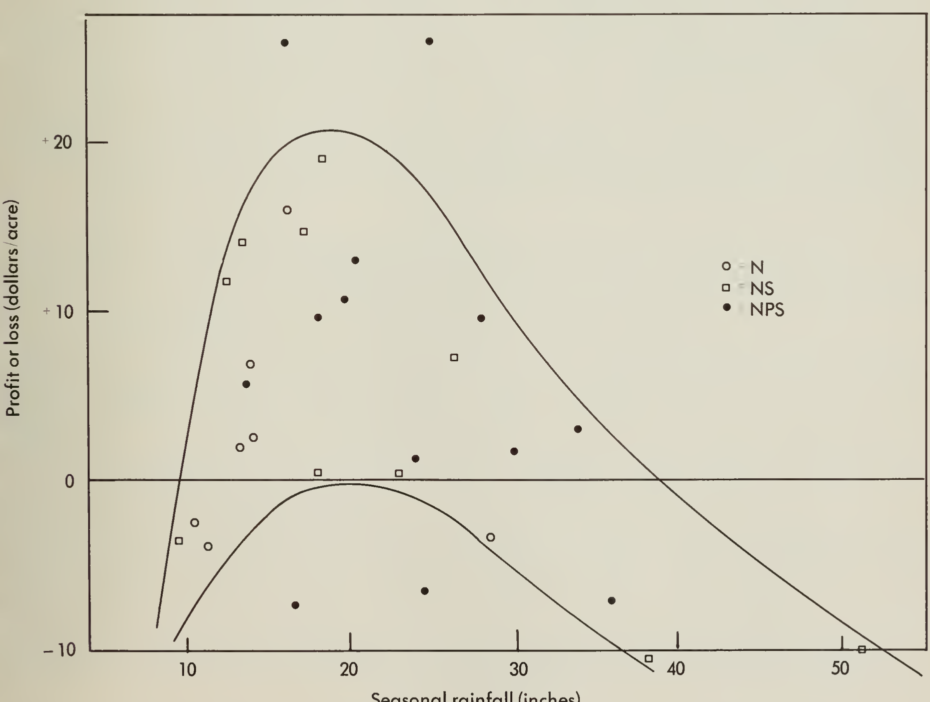


Fig. 7. First-year profit from fertilization as related to seasonal rainfall and nutrient response.

Effects of seasonal rainfall on profitability of nitrogenous fertilization

Beef production attributable to nitrogenous fertilizer was low where rainfall was below 12 inches or where rainfall exceeded 30 inches seasonally. Fertilizer profits per acre for each of the 30 first-year grazing tests were calculated and related to seasonal rainfall (fig. 7 and app. table 1). The greatest likelihood of profit from the use of nitrogenous materials appear to be in the 13- to 25-inch rainfall zone. Nitrogen fertilization should probably be avoided in areas with rainfall outside this range. Nine of the 30 first-year tests in this study showed a "fertilizer loss," using the evaluation method described earlier. Most of these tests were at areas of low rainfall, high rainfall, or on rocky soil with little real grazing potential.

Grazing tests with both supplemental feed and fertilizers

Grazing tests were carried out at five locations in an effort to compare the relative effects of supplemental feed and nitrogen fertilizers, alone and in combination. Beef production per acre and net grazing income from each of the treatments are shown in table 6. The use of supplemental feed increased grazing income over that of the control in four of the five tests; so also did the use of nitrogenous fertilizers. Fertilizers were more profitable than supplements in four cases out of five. In three of the four tests where both supplements and fertilizers were used, grazing income was less than where either fertilizer or supplement had been employed. Data here are too limited for any far-reaching conclusions.

Certainly, fertilizers are no substitute for rainfall, but where adequate growth has been stimulated by supplemental N, it would seem economically undesirable to provide supplemental feed as well. However, at locations where rainfall was below 10 inches, or deficient enough so that little growth of vegetation occurred, supplements had to be provided to maintain grazing animals. In the several cases where substantial amounts of hay had to be fed in the early portion of the grazing season because of drought, no meaningful data could be obtained on the profitability of range fertilization with N.

TABLE 6

NITROGENOUS FERTILIZATION AND/OR SUPPLEMENTAL FEED: COMPARISON OF CATTLE GAINS AND INCOME

Site	Year	Liveweight gains during grazing period				Net grazing income*			
		Check	Supplement	Fertilizer	Fertilizer + supplement	Check	Supplement	Fertilizer	Fertilizer + supplement
		lb./acre				dollars/acre			
15	1956	53.2	96.7	181.2	.....	$ 9.11	13.80	14.35	.....
15	1957	39.2	84.2	150.0	127.2	5.92	7.59	8.89	0.15
15	1958	49.4	90.5	141.8	176.2	7.98	10.60	5.80	5.01
2	1958	79.9	100.3	200.5	226.8	11.33	12.37	18.75	18.20
3	1958	50.9	89.5	165.0	184.0	6.71	1.13	9.32	7.40

* Net grazing income derived from cost of fertilizer, supplement, stocking and interest deducted from gross income from outweights of cattle from each plot at end of test period.

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DATA FOR EVALUATION OF NITROGENOUS FERTILIZATION OF RANGE FORAG

(A) Locations with response to N only

Test no.	Year (19–)	Seasonal rain	Treatment				Stocking rate	
			N	P_2O_5(P)	S	Cost	Check	Fert.
		inches	*lb./acre*			*dollars/acre*	*lb./acre*	
1	54	10.5	45	......	54	$ 7.42	176.8	295.2
12	68	11.4	59	......	..	4.01	218.2	302.4
14	57	13.3	65	......	..	10.63	57.2	192.5
43	54	14.0	47	......	..	9.75	230.2	358.9
43	54	14.0	42	......	60	6.34	230.2	329.4
24	67	16.3	60	......	50	5.93	196.9	270.1
51	56	28.3	82	......	94	13.71	188.0	361.1
Average:		15.4	57	......	37	$ 8.68	185.3	301.4
(B) Locations with response to both N and S — no P effect								
4	57	9.5	60	......	70	10.01	164.2	387.8
21	57	12.2	80	......	96	11.94	117.2	355.2
19	55	13.3	80	......	96	14.89	164.5	528.0
18	58	17.5	80	......	96	11.75	137.5	550.0
10	54	18.0	48	26(11)	15	13.52	48.8	234.3
20	56	18.2	80	......	96	12.00	146.9	44[illegible].0
12	56	23.0	64	20(9)	15	23.00	57.3	229.5
17	56	26.4	60	......	73	8.50	59.4	319.0
47	58	38.0	74	29(13)	12	13.48	273.0	328.8
41	56	51.7	80	50(22)	68	17.82	178.1	350.0
Average:		22.8	71		64	$13.69	134.7	372.3
(C) Locations with response to both N and P								
16	56	13.8	80	100(44)	64	22.74	85.5	323.6
36	57	16.0	65	55(24)	..	14.18	144.7	439.7
40	55	16.7	64	20(88)	70	13.92	155.6	546.4
6	56	18.2	80	68(30)	70	18.11	142.9	404.9
39	54	19.5	64	80(35)	62	18.00	139.7	479.9
30	55	20.3	70	49(21)	..	16.88	103.9	295.2
23	55	24.0	48	60(26)	36	15.35	53.5	187.0
34	56	24.0	80	38(17)	40	17.04	148.4	463.3
38	55	25.2	72	64(28)	..	18.32	197.7	430.5
42	67	28.0	64	80(35)	48	18.10	143.6	377.0
28	56	30.2	70	49(21)	31	18.01	207.8	478.9
37	58	34.4	74	59(26)	..	16.00	152.6	360.0
46	56	36.1	59	33(14)	53	13.18	100.8	246.4
Average:		23.6	69	58(31)	37	$16.91	136.7	387.1
Average of all plots:		21.4	67			$13.92	147.4	362.3

ABLE 1

S MEASURED BY CATTLEWEIGHT GAINS AND DOLLAR RETURNS (1954 TO 1968)

uration of test	Grazing days/acre		Liveweight gains				Beef/lb. N	Grazing income		Fert. profit
	Check	Fert.	Av. daily		Total			Check	Fert.	
			Check	Fert.	Check	Fert.				
days	*days*		*lb./day*		*lb./acre*		*lb.*	*dollars/acre*		*dollars*
86	29	48	1.63	1.81	40.7	77.8	.82	$ 4.80	$ 2.14	—$ 2.14
130	58	82	.93	.97	54.1	80.1	.44	6.40	2.81	— 3.59
160	22	66	1.62	1.69	34.9	111.9	1.18	6.21	8.74	2.53
108	75	109	1.44	1.85	108.7	201.7	1.98	18.42	25.93	7.51
108	75	85	1.44	1.78	108.7	161.5	1.26	18.42	21.21	2.79
163	102	145	1.26	1.66	129.0	240.7	1.95	23.30	40.03	16.73
128	37	70	1.23	1.66	40.1	117.1	.94	4.07	3.74	— .33
126	57	87	1.36	1.63	73.7	141.5	1.19	$11.66	$15.02	$ 3.36
–										
62	17	38	3.37	2.98	56.0	109.0	.88	8.67	5.20	— 3.47
118	39	118	1.67	1.73	65.9	203.5	1.72	11.67	24.25	12.58
128	37	127	1.21	1.63	44.3	207.3	2.04	5.61	20.50	14.89
141	35	141	1.62	1.62	57.2	229.0	2.15	9.10	24.68	15.58
98	10	54	2.08	1.87	21.2	100.8	1.65	3.52	4.14	0.62
136	45	136	1.75	1.86	79.4	255.9	2.20	13.81	33.83	20.02
154	20	70	1.53	1.63	29.9	114.6	1.32	5.07	5.41	0.34
121	15	70	2.54	2.03	37.1	141.1	1.73	6.73	14.55	7.82
179	57	69	1.37	1.43	78.8	99.2	.28	9.92	— .98	—10.90
108	25	70	2.33	1.63	57.4	113.5	.70	8.31	— 1.82	—10.13
125	30.0	89	1.95	1.84	52.8	157.4	1.48	$ 8.24	$12.97	$ 4.73
113	21	88	1.49	2.16	30.1	189.2	1.99	4.54	10.73	6.19
129	42	120	1.74	2.41	72.9	299.7	3.49	12.47	40.10	27.63
91	18	69	.96	1.41	17.4	97.5	1.25	— .26	— 7.91	— 7.65
140	36	94	1.66	1.93	60.4	182.3	1.52	9.67	19.84	10.17
90	23	94	2.30	2.40	52.7	224.8	2.69	8.54	19.82	11.28
173	41	123	1.40	1.80	56.9	221.0	2.34	9.77	23.58	13.81
130	11	37	1.43	1.87	15.2	70.0	1.14	2.06	— 4.67	— 6.73
86	27	86	1.68	1.77	50.3	169.4	1.49	7.54	9.25	1.71
148	47	117	2.69	3.17	126.9	368.9	3.36	24.12	51.72	27.60
151	57	151	1.64	1.65	92.6	249.8	2.46	16.73	26.87	10.14
94	40	117	2.02	1.72	81.0	202.0	1.73	12.93	14.91	1.98
147	49	117	1.40	1.56	68.0	183.0	1.55	11.06	14.72	3.66
122	20	48	1.60	1.63	32.1	78.5	.79	4.56	— 2.29	— 6.85
122	33	98	1.69	1.96	58.2	195.1	2.00	$ 9.52	$16.67	$ 7.15
124	38	92	1.70	1.84	60.0	170.0	1.63	$ 9.59	$15.05	$ 5.46

ECONOMIC EVALUATION OF FIRST-YEAR AND SECOND-YEAR

Test no.	Year (19–)	Rainfall	Treatment			
			N	P_2O_5(P)	S	Cost
		inches	*lb./acre*			*dollars/acre*
6–3	56	18.3	80	68(30)	70	$18.11
7–3	57	12.2	..	......	..	.....
10–4	54	18.0	48	26(11)	16	13.52
11–4	55	15.8	..	......	..	.....
11–4	55	15.8	60	0	0	9.75
12–4	56	23.0	..	......	..	.....
12–4	56	23.0	64	20(9)	15	12.59
13–4	57	10.9	..	......	..	.....
19–9	55	13.3	80	0	96	11.71
20–9	56	18.2	..	......	..	.....
20–9	56	18.2	80	0	96	12.00
21–9	57	12.2	..	......	..	.....
21–9	57	12.2	80	0	91	11.94
22–9	58	22.7	..	......	..	.....
24–11	67	16.3	60	0	50	5.93
25–11	68	11.4	..	......	..	.....
34–16	56	24.0	80	38(14)	40	17.04
35–16	57	16.7	..	......	..	.....
36–17	57	15.9	65	59(26)	0	14.81
37–17	58	34.4	58	......	..	.....
43–24	54	14.0	42	29(13)	95	9.39
44–24	55	16.2	..	......	..	.....
53–28	58	27.0	42	0	68	6.95
54–28	59	10.5	..	......	..	.....
53–28	58	27.0	85	0	96	13.66
54–28	59	10.5	..	......	..	.....
Average for fertilized year:						$12.11
Average for carryover year:						.....

RYOVER EFFECTS OF RANGE FERTILIZATION WITH N MATERIALS

Liveweight gains			Grazing income		Fertilizer profit		
eck	Fert.	Increase	Check	Fert.	First year	2-year total	Per fertilizer dollar
lb./acre			*dollars/acre*		*dollars/acre*		
0.4	182.3	121.9	9.67	19.84	10.17	14.05	$1.78
8.4	79.0	30.6	7.58	11.46	3.88	.....	....
1.2	100.9	79.7	3.52	4.14	.62	3.17	1.23
0.5	64.0	33.5	5.00	7.55	2.55	.....	....
0.5	91.8	61.3	5.00	1.64	−3.36	−1.25	.87
9.9	45.4	15.5	5.07	7.18	2.11	.....	....
9.9	114.6	84.7	5.07	5.41	.34	3.83	1.30
8.2	50.5	22.3	4.26	7.75	3.49	.....	....
4.3	207.3	163.0	5.61	20.50	14.89	26.48	3.26
9.4	150.1	70.7	13.81	25.40	11.59	.....	....
9.4	255.9	176.5	13.81	33.83	20.02	31.38	3.62
5.9	134.5	68.6	11.67	23.03	11.36	.....	....
5.9	203.5	137.6	11.67	24.25	12.58	23.45	2.96
0.4	133.5	73.1	10.68	21.55	10.87	.....	....
9.0	240.7	111.7	23.30	40.03	16.73	19.72	4.32
9.0	82.5	23.5	7.59	10.58	2.99	.....	....
0.3	169.4	119.1	7.54	9.25	1.71	7.15	1.42
0.2	87.4	37.2	7.22	12.66	5.44	.....	....
2.9	299.7	226.8	12.47	40.10	27.63	44.93	4.03
8.0	166.0	98.0	11.06	28.36	17.30	.....	....
8.7	172.0	63.3	18.42	20.05	1.67	−1.25	.87
3.0	134.0	−14.0	27.04	24.12	−2.92	.....	....
9.0	110.2	41.2	10.95	9.26	−1.69	2.11	1.30
2.4	49.5	17.1	3.62	7.42	3.80	.....	....
).0	134.0	65.0	10.95	5.05	−5.91	−1.23	.91
2.4	54.5	22.1	3.62	8.30	4.68	.....	....
3.9	175.6	111.7	$10.61	$17.95	$7.34	$13.28	$2.10
6.4	102.6	46.2	$9.09	$15.03	$5.94	.....	....

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* Retired.
† Resigned.
‡ Transferred.
§ Deceased.

ABSTRACT

The effects of nitrogenous fertilization were measured by weight gains of 7,6 cattle grazing on 16,800 acres of California rangeland. Carrying capacity was increased from 38 to 92 head days per acre, and beef production was increased from 60 to 170 pounds per acre by fertilization. Both first- and second-year benefits were greater where NS or NP were needed than where N alone was required. In two years, total extra beef per pound of N applied was 1.75 pounds from N alone, 2.75 pounds from NS and 2.54 pounds from NP. Average grazing income per acre was increased from $9.95 to $15.05 by fertilization in the first year. Greatest profit occurred in the 13 to 30-inch rainfall zone.

10m-9,'70(N7912L)P.A.V.