The effect of *Rhizobium* on clover growth was evident five months after seeding. All plots received phosphorus and sulfur fertilizer. Only the plot with lush clover received an effective *Rhizobium* strain; the others received an ineffective strain or no *Rhizobium*.

TABLE 3. Fertilization and clipping effects on forage dry weight and crude protein

Treatment	Total forage: Dry weight	Total forage: Crude protein	Crude protein concentration
	...... *lb/ac*		%
Unfertilized			
One harvest	3,030	419	13.8
Two harvests	1,900**	318	16.7
Fertilized with P + S			
One harvest	5,940 b	921 b	15.5
Two harvests	3,110*** b	771* b	24.8*** a

NOTES:
Values were averaged across the three range sites reported in table 2, and data from two clippings were summed for the two-harvest total.
Mean values followed by *, **, or *** show a harvest effect that is significant at $P \leq 0.05$, 0.01, or 0.001, respectively.
Mean values followed by the letters a or b show a fertilizer effect that is significant at $P \leq 0.05$ or 0.001, respectively.

production and thereby allows higher stocking rates and, second, it permits the plants to respond to grazing pressure by increasing the crude protein concentration in the young growing shoots. This two-fold response to fertilization allows more profitable production of lambs.

Conclusion

Planting clover seeds inoculated with *Rhizobium* bacteria and fertilizing with adequate phosphorus and sulfur can significantly increase forage production on numerous rangeland soils. The phosphorus and sulfur promote total plant growth, and the clover uses *Rhizobium* to fix nitrogen, a source of low-cost nitrogen fertilizer.

Specific recommendations for the species of clover and the amount of phosphorus and sulfur vary with climate and soil type. Information for each locality is available from UC Cooperative Extension farm advisors, but general recommendations for annual rangelands would be as follows: (1) Plant a minimum of 10 pounds per acre of subclover (*Trifolium subterraneum* L.), rose clover (*T. hirtum* L.), or both in areas that receive more than 10 inches of annual precipitation. Both clovers use a special *Rhizobium* inoculum, which is available commercially. (2) Fertilize at planting with 200 pounds per acre of 0-38-0-20, a mixture produced by combining treble superphosphate and elemental sulfur. The same fertilizer treatment normally will be required every other year to provide optimum phosphorus and sulfur, but with proper grazing management, the clover should persist indefinitely, and the *Rhizobium* will keep on fixing nitrogen.

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Fertilization increases profitability of lamb production on small pastures

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A grazing experiment conducted in conjunction with research reported in the previous article yielded encouraging economic results for phosphorus and sulfur fertilization and suggested that small-scale pasture management may be profitable for sheep producers. The goal of the experiment reported here was to determine the effect of phosphorus and sulfur fertilization on forage quality and on lamb weight gain.

Because of the costs, fertilizers are usually applied where nutrients produce large responses in productivity. Lamb production is particularly sensitive to nutrient intake and forage quality. Lambs are small-bodied ruminants with high nutrient requirements per unit of body weight relative to those of mature sheep. As body weight increases, the total metabolic requirement per animal also rises, but the increase per unit of body weight decreases. Since total metabolic requirement is a major factor determining how much an animal eats, total feed intake should increase, but intake per pound of body weight should decrease as the animal grows. Small and large ruminants have the same proportion of their body weights in rumen contents, but small ruminants, eating more per unit of body weight, have a faster turnover of rumen contents. Since the digestion of a given forage occurs at a constant rate, the amount of forage digested per unit of intake is proportional to the length of time the forage spends in the rumen.

One possible response to this constraint of digestive capacity is for small ruminants to eat more, but two factors limit the extent to which they can compensate in this way. First, ruminants control turnover by ruminating particles to smaller sizes that can be passed from the rumen. The rumination rate often limits intake on low-quality diets, because plant cell walls restrict their physical breakdown. Second, high intake rates increase the loss of microbial bodies from the rumen and large intestine to the feces. At these rates, ingested forage is passed quickly, and there is less time for reabsorption in the hind gut of nutrients contained in the microbes. For small animals on low-quality diets, this nutrient loss may cause a negative nutrient balance.

Small animals respond to these limitations by feeding on high-quality forages if possible. The low cell-wall and high nutrient concentrations of these forages allow rapid digestion. The faster assimilation of nutrients compensates for the short time forage spends in the rumen.

Animal growth rate is proportional to the assimilated nutrients acquired above those needed for maintenance. The increase in intake required to maintain a high growth rate in lambs further reduces the time forage is retained in the rumen and can magnify the limitations of their small rumen volume. As the previous article indicates, fertilization can enhance nutrient concentration, especially when forage is grazed. Increased nutrient concentrations usually accompany reduction in the cell wall component and therefore should increase the potential for rapid growth in lambs.

Grazing experiment

To evaluate the effects of fertilization, we applied four treatments to replicated 1-acre pastures: sulfur, phosphorus, sulfur plus phosphorus, and an unfertilized control. The pastures were burned, disked, and sown with 50 pounds of subclover seed per acre in October 1982. Potassium chloride at 100 pounds per acre was applied to all pastures in October of 1982 and 1983. The sulfur treatment consisted of 88 pounds per acre in October 1982 and 100 pounds per acre as elemental sulfur in October 1984, while the phosphorus treatment at 50 pounds per acre was applied only in 1982. The sulfur plus phosphorus application was a combination of the sulfur and phosphorus treatment schedules.

In 1982 and 1983, lambs used for the experiments were the offspring of Targhee rams and, in 1984, of Suffolk rams and white-faced cross-breed ewes. Lambs were weaned at about 40 pounds and put on experimental pasture on March 8, 1983, March 1, 1984, and February 12, 1985. We adjusted lamb numbers each month by adding or removing nontest animals to maintain a constant herbage allowance (standing crop of forage per lamb) across treatments. Determinations and species compositional measurements were taken at approximately monthly intervals through the seasons. Data considered here are averages of values taken over 84 days from the date lambs entered the pasture.

Results and discussion

The most important effect of fertilization was a significant increase in cumulative lamb gain per acre (1983 + 1984 + 1985): 61 percent with sulfur, 42 percent with phosphorus, and 87 percent with sulfur plus phosphorus (table 1). While sulfur alone produced more gain per acre than phosphorus alone, the difference was not significant. Sulfur plus phosphorus produced significantly more gain than either element did when applied alone.

In all cases, fertilization more than paid for itself. These gains over three years translated into increases in gross profits of 56 percent with sulfur, 25 percent with phosphorus, and 73 percent with sulfur plus phosphorus. Gross profit is the difference between the costs of the treatment and the revenue generated by the lamb gain. Although it does not reflect the full range of expenses involved in a ranching operation (such as the cost of year-round maintenance for the ewes), gross profit does indicate the likely increment in profit if these other expenses do not increase with the introduction of a fertilizer treatment.

While fertilization with sulfur plus phosphorus produced the highest gross profit and the largest profit margin over controls (column 3, 4, table 1), sulfur fertilization provided the best rate of return on the investment ($4.43 per $1.00 invested). The specific comparison between fertilizer treatments, while appropriate for the Hopland site, may not be generalizable. We suspect that, without site-specific knowledge of soil nutrient availability, the sulfur plus phosphorus treatment is most appropriate, as a general rule. Because our economic analysis is specific for rainfall, costs, and prices that prevailed at the site and during the years of the study, extrapolation to other areas and years must be done cautiously.

Fertilization increased nutrient concentrations in the forage. Statistical analysis showed that sulfur fertilization increased forage nitrogen, sulfur, and phosphorus; phosphorus fertilization increased only phosphorus forage concentration; and sulfur plus phosphorus increased concentrations of sulfur and phosphorus. Based on the National Research Council tables for nutrient requirements for lambs, all nutrient concentrations measured through the season were adequate (fig. 1). Forage nitrogen in the late season, however, was probably low enough to limit growth.

If these nutrients and other forage characteristics are examined for their

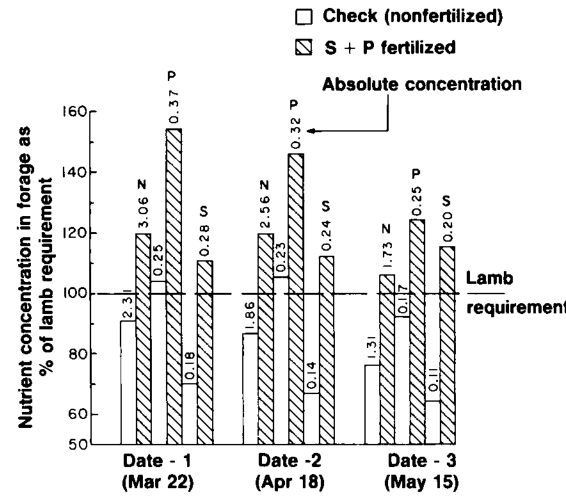

Fig. 1. Fertilization with sulfur and phosphorus increased nutrient concentrations to levels adequate for lamb growth. Values are averages of three years.

ability to predict gain per head and gain per acre, forage nitrogen concentration is the only one of the three elements that significantly predicts the gains per acre in all three years. No forage measures predicted gain per head in 1983, but neutral detergent fiber (total cell wall content), acid detergent fiber (cellulose and lignin), and the nitrogen percentage were significant predictors in the following two years.

The neutral detergent fiber content of forages has been shown to be the best predictor of intake under conditions where forage availability is not limited. This relationship occurs because the cell wall concentration of forages probably is related to its fill characteristics in the gut and to the rate at which ingested forages are ruminated to small particles for passage from the rumen. The relationship is much stronger with grasses than with legumes because of the greater cell wall content in grasses. Without early-season grazing, the grass component of the pastures increased through the years of the experiment, and consequently the ability of the neutral detergent fiber content to predict gain per head also increased.

Since the growth of individual animals depends on the amount and quality of what they eat, our results suggest that the differences in fiber content among the pastures within years controlled intake levels, and nitrogen concentrations of the forage best described the quality factors. Because available forage was used to adjust stocking rates, its high correlation with lamb gain per acre was expected and reflects in a general way the difference between growth rate of the plants and forage removal by the lambs. The 60 percent increase in crude protein concentrations (percent nitrogen x 6.25) caused by simulated grazing (clipping) of fertilized plots, as described in the previous article, is important. Since lambs can eat more of the high-quality forage, the growth rate of the plants in those treatments must be much greater to support greater numbers of animals yet maintain an equal forage allowance (pounds forage per animal). Because the forage allowance was kept constant across treatments, animal gain per head did not respond as dramatically to the increased productivity of the pastures as did lamb gain per acre. The major effect of fertilization, therefore, was to allow an increase in stocking rate.

Nitrogen was not applied as a fertilizer in this study; it entered the pasture system primarily through nitrogen fixation by *Rhizobium* bacteria in a symbiotic relationship with clover. The addition of sulfur and phosphorus increases the clover component, which in turn provides most of the nitrogen. In the competitive interaction with grasses, clover increases when nitrogen availability is low and when grazing removes the taller grasses. In our pastures, the decline of subclover and increase in grasses through the years can be explained by the likely increases in soil nitrogen, favoring the non-nitrogen-fixing grasses, and the lack of intensive grazing early in the season. With proper timing and intensity of grazing, the clover component can be maintained indefinitely.

While fertilization produces greater gains per acre, it may also result in higher prices per pound by producing high yield grade carcasses. Lambs in this experiment were weaned early, reached market weight at a young age, and were sold for slaughter as "spring" lambs. Young, rapidly growing lambs have low levels of fat within the muscle and thus provide low-fat cuts. A recent New Zealand advertising campaign in the United States stressed the low fat and high nutritional quality of this type of lamb. With consumers increasingly sensitive to fat levels in meats, a ranching operation producing large quantities of lean meats per acre may be suited in the future to supply this expanding market.

Our study suggests the great potential that exists in rangeland if managed intensively. The pasture management employed in the experiment produced a high efficiency of conversion from forage to animal gain and relatively uniform use of the range. In a previous study at Hopland (*California Agriculture* 11(5):12-13; 1957) on improved pastures fertilized with 400 pounds per acre of 12-38-0, lamb production was 86 pounds per acre. Since ewes were maintained on the pastures with the lambs in that study, the three- to eight-fold greater lamb production per acre measured in our study does not reflect completely the differences in pasture productivity. Our results do suggest, however, that improved range can be very efficiently used by young, small, fast-growing animals whose growth is sensitive to nutrient concentrations. Because larger bodied ewes can tolerate much lower nutrient and higher fiber concentrations, management schemes that allow ewes to use unimproved pasture and concentrate growing animals on the improved range may convert more of the forage base and capital input into animal gain.

The amount of forage consumed may also be affected by pasture size. The use of small pastures created more even grazing and prevented the higher level of patchy use that is often typical of this range. The development of patchiness can be a particular problem with lambs, which are highly selective and intolerant of more mature forages.

TABLE 1. Cumulative lamb weight and projected financial gains from fertilizer treatments, 1984-85

Fertilizer applied	Rate	Cumulative lamb gain	Lamb gain increment	(1) Seed + fertilizer cost	(2) Gross income	(3) Gross profit	(4) Profit margin over control	(5) Rate of return*
	lb/ac	*lb/ac*	*lb/ac*	*$*	*$*	*$*	*$*	*$*
Control	0	817	0	50.67	519.19	468.52	0	
S	188	1,313	496	109.65	839.30	729.65	261.13	4.43
P	50	1,162	345	149.37	736.42	587.05	118.53	1.20
S + P	188 + 50	1,528	711	162.15	971.45	809.30	340.78	3.06
LSD 5%		195	195					

NOTE: Lamb weight gains are based on 84 days of pasture grazing each year. Lamb prices used in the calculation were $59.50, $61.00, and $69.00 per 100 lb for 1983, '84, and '85, respectively. Gain for the control treatments were subtracted from the gains on fertilized pastures. The costs of seeding (subclover seeds, 50 pounds per acre (lb/ac), $81.24; inoculation $11.50; sowing $6.00) were amortized over 15 years as follows:

$$\text{annual cost} = \frac{(\text{total cost})\,(i)\,(1+i)^n}{(1+i)^n - 1} = \$16.89$$

where i = 15% interest rate and n = 15 years. Sulfur (S) and phosphorus (P) costs were amortized over two and three years, respectively, as follows:

S 88 lb/ac $200/ton = 8.80
Amortized costs = 7.26 + 3.00 (application cost) = $10.26
S 100 lb/ac $200/ton = 10.00
Amortized cost = 8.00 + 3.00 = $11.00
P 50 lb/ac applied as 0-45-0 254 lb/ac $321/ton =$40.80
Amortized cost = 20.50 + 3.00 = $23.50

All treatments received 48 lb of potassium (K)/ac as 0-0-62, 94 lb/ac $200/ton = $9.40. The application costs of fertilizer were estimated at $6.00/ac and, when more than one fertilizer was applied at once, the cost was divided between different applications so the total for any one year was never more than $6.00/ac. The cost of K was not added to the unfertilized control. Gross profit (3) is (2) − (1). Profit margin over control (4) is gross profit for treatment minus profit for control. Col (5) is (4) divided by the difference between the cost of the fertilizer treatment and the cost of the control in col. (1).
* Increment in gross profit per increment in cost (over control).

Conclusion

Fertilization of small pastures increased profits in lamb production. While the greatest return on investment was realized with the application of sulfur alone, we recommend that both sulfur and phosphorus be applied together unless knowledge of the soils is detailed. The early weaning and rapid growth in this experiment resulted in spring lambs, which are likely to produce high-grade, low-fat carcasses popular with consumers.

Fertilization of the small pastures used in this experiment produced improvements for the following reasons. First, fertilization stimulated plant growth rate while increasing nutrient and decreasing fiber concentrations in the forage. These responses markedly increased the number of lambs that could be supported per acre. Second, unlike the 1957 study at Hopland, our study concentrated the lambs without ewes on the pastures, so that a high proportion of the energy harvested by the animals could be converted to gain. Third, small pastures spread evenly the use of the range, prevented the development of patches of mature vegetation, and probably increased the amount of plant production consumed by lambs.

Although breed differences and 30 years of selection may have contributed to the results, lamb production in our study was three to eight times greater than that recorded in the 1957 study. Fertilization in this grazing system paid large dividends, increasing production as much as 73 percent and nearly doubling gross profits.

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