Division of Agricultural Sciences
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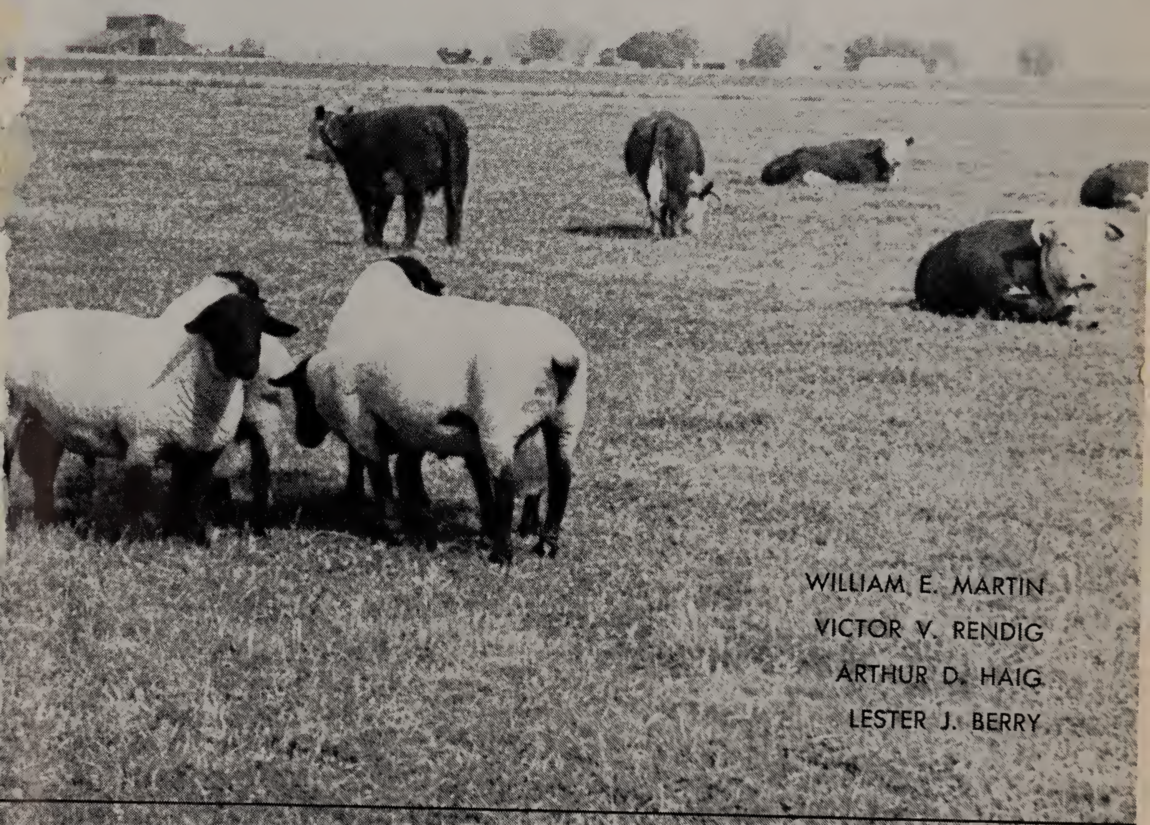
FERTILIZATION of IRRIGATED PASTURE and FORAGE CROPS in California



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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

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FERTILIZATION OF FORAGE CROPS . . .

on irrigated pastures in California is influenced by the state's varied climatic conditions and soil types. Nitrogen, phosphorus, and sulfur are the principal nutrients involved.

Over the past 10 years, numerous field tests with fertilizers have been conducted on cattle ranches throughout California. Results of the tests have been released in the various areas either as progress reports or as county publications.

This bulletin brings together and summarizes the more important findings for the three major forage areas: northeastern California; the coastal and north central valleys; and the San Joaquin Valley.

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FERTILIZATION of IRRIGATED PASTURE and FORAGE CROPS in California

William E. Martin • Victor V. Rendig • Arthur D. Haig • Lester J. Berry

THE PROBLEM

Irrigated pasture and forage crops for hay or grazing are grown under a wide variety of climatic conditions in California. Whether the crops are harvested by machine, for hay, or by grazing animals, depends upon the rancher's forage needs.

In northeastern California, forage crops are commonly grown in high valleys, referred to as mountain meadows. These meadows are usually at elevations of 3,000 to 4,000 feet, and are irrigated by spring and winter runoff from melting snows. A hay crop is commonly harvested in late spring or early summer, and the regrowth grazed throughout the summer and fall. The forage may be either from unimproved meadows composed of native species of grass, sedges, and clovers, or from improved meadows seeded with trefoil, alfalfa, or clover, and grasses such as tall fescue, orchardgrass, and others. Cereal rye or oats are occasionally seeded into a legume stand to provide extra forage for hay or grazing.

The irrigated pastures in the central valley and the coastal areas are usually made up of a mixed community of plants, including legumes such as Ladino clover, trefoil, or alfalfa, and grasses such as ryegrass, orchardgrass, or tall fescue. Although pastures in these areas are grown primarily for grazing, hay crops are sometimes taken at the time of the spring flush of growth when a surplus of forage may occur. Ladino clover stands are often grazed before a seed crop is taken.

In the southern San Joaquin Valley, irrigated pastures are dominated by warm-season species such as dallisgrass or the bermudagrasses. In these areas irrigated pastures are usually grown on the poorly drained soils in the trough of the valley, which are commonly saline or alkaline or both. Narrowleaf trefoil is often planted with the grasses, but makes little forage under saline or alkaline conditions. Salina strawberry clover is now being tested for use under such conditions.

Fertilization problems of irrigated forage crops usually involve nitrogen, phosphorus, and sulfur. Many of the soils on which irrigated pastures are grown are old red terrace soils deficient in phosphorus. In the northern areas of the state, deficiencies of both phosphorus and sulfur are common. Ideally, an irrigated pasture that is a mixture of grasses and legumes will need relatively little nitrogen since the legume component, if vigorous and healthy, fixes nitrogen from the air through the action of the symbiotic bacteria in nodules on the roots. Subsequently, the roots slough off and decompose, releasing nitrogen to the grass portion of the pasture association. Legumes such as Ladino clover, trefoil, or alfalfa are used both to provide a high protein component in the forage and to supply nitrogen to the grasses. In areas where legumes grow poorly or where few are present, nitrogen fertilizers may be used profitably to keep the grass species productive. One of the recurrent problems in the central valley has been a reduction in growth of clover pastures during the hot summer months, particularly on the phosphorus-deficient hardpan soils. In some areas, pastures on thin soils must be irrigated at almost weekly intervals. This creates problems in maintaining fertility, particularly where nitrogen applications have been made.

NORTHEASTERN CALIFORNIA—NATIVE AND IMPROVED FORAGE CROPS

In Modoc, Lassen, Siskiyou, and Plumas counties, and in parts of Shasta County, both native meadow forage and improved pasture species are used for hay and grazing. Much of this area of mountain valleys at 3,000 to 4,000 feet is acutely deficient in sulfur (Martin, 1958).[1] Parts are also deficient in phosphorus and boron. Native and planted grasses have responded spectacularly to added commercial nitrogenous fertilizers both where legumes are sparse and where more productivity is desired than the grass-legume mixture provides.

Fertilization of Native Mountain Meadow Forage for Hay or Grazing

Fertilizer tests and demonstrations were carried out in the area to determine what forms of nitrogen are most effective on native grass-sedge meadows and how much nitrogen can be most economically used (Bedell, 1962).

Does the area need nitrogen and sulfur?

The first group of tests, from Modoc and Lassen counties, shows the importance of using a sulfur-containing, nitrogenous fertilizer.

In these demonstrations straight nitrogen carriers such as urea or ammonium nitrate were compared with nearly equal nitrogen from ammonium sulfate (table 1). The nitrogen and sulfur treatment gave higher yields than the nitrogen in six of the seven paired comparisons. It is believed that nitrogen was the first factor limiting growth, and that additions of sulfate were required for greater growth. Since ammonium sulfate usually costs no more per pound than other forms of nitrogen, it is recommended for this area instead of straight nitrogen materials.

[1] See "Literature Cited" for citations referred to in the text by author and date.

Table 1. Effects of Nitrogen and of Nitrogen plus Sulfur on Yield of Mountain Meadow Forage
(Modoc and Lassen Counties)

County and farm	Year	Average yield of forage from:		
		No fertilization	65 lb. N/acre	69 lb. N/acre 103 lb. S/acre
		tons/acre	tons/acre	tons/acre
Modoc County:				
Cockrell	1953	1.51	2.14	2.85
Grove	1953	2.78	4.55	5.30
Bishop	1953	2.26	5.52	5.05
Caldwell	1953	1.70	4.10	4.25
"J&D"	1954	0.90	1.91	2.30
Lassen County:				
Nash	1953	1.53	3.19	3.64
Albaugh	1962	2.06	3.26	3.49
Average	....	1.82	3.52	3.84

Does it pay to add phosphorus?

Further comparisons were made to determine whether the addition of phosphorus in ammonium phosphate sulfate (16–20) gave better yields than did ammonium sulfate. In these tests, 12 of the 16 comparisons gave numerically higher yields from such addition of phosphorus (table 2).

The economic effectiveness of phosphorus additions was evaluated by comparing profits from use of ammonium sulfate with those from (16–20), assuming a hay value for the increased hay at $15 per ton. Only five of the tests gave enough extra hay to show appreciable profit from use of phosphorus. Had a value of $10 per ton of hay been used, only two of the 16 phosphorus treatments would have paid the cost of adding phosphorus.

The inclusion of phosphorus in commercial fertilizers supplying nitrogen and sulfur is recommended only for locations where its need has been established by field test or by soil analysis. Added phosphorus will no doubt be required after meadows have been cropped longer and more intensively.

Trials in the Sierra and Indian valleys of Plumas County have shown more frequent benefit from additions of phosphorus to nitrogen-bearing fertilizers.

How much are yields raised by higher nitrogen rates?

Sixteen tests to determine the most economical nitrogen rate were carried out, with at least one test in each major area where native mountain meadows are fertilized. The results are shown in figure 1. Results from seven tests with ammonium sulfate in Modoc County, 1953, indicated somewhat higher efficiency than has been obtained in subsequent years. Data from later groups of well-replicated rate tests indicate that we might expect approximately one-half ton of dry material from 20 pounds of nitrogen, three-quarters ton from 40 pounds of nitrogen, and about 1.5 tons where 80 pounds were used.

Two nitrogen rate tests to determine practical upper limits of fertilization were carried out in 1961 in Modoc County. Nitrogen rates were increased stepwise from 21 to 336 pounds of nitrogen per acre (as 100 to 1,600 pounds of ammonium sulfate). Average yields from the two plots form a smooth curve that levels off at the higher nitrogen rates. Results from other county tests were generally similar at the lower rates of nitrogen.

Where phosphorus is needed, how much should be used?

Data obtained in 1961–1962 from three tests with ammonium phosphate sulfate, in Plumas County, indicate that the nitrogen responses with this carrier are about the same as those obtained with ammonium sulfate on soils with adequate phosphorus.

Few data are available on the amounts of phosphorus that should be added to nitrogen and sulfur when phosphorus is needed. Seventeen pounds of phosphorus (40 P_2O_5) per acre, in two comparisons in 1962 and 1963, respectively, did as well as 44 pounds (100 P_2O_5).

How do fertilization and time of cutting affect protein content of the hay?

Both fertilization and time of cutting may affect crude protein content of meadow hay. On three ranches in Modoc County, hay was cut three to four weeks earlier than usual in experimental plots, and samples were analyzed for crude protein ($N \times 6.25$). These values were compared with hay samples taken from plots cut at the usual July harvest date. Results of this study, given in table 3, show that time of cutting was of far more importance than fertilization in changing the protein content. Hay cut in June at a relatively immature stage gave average values of about 12 per cent crude protein, while late-cut samples showed values of only 8.5 to 9 per cent, or two-thirds as much protein. At each date, high nitrogen treatments tended to increase protein slightly. These results are similar to results reported in mountain meadow fertilization studies carried out in Colorado (Willhite, Rouse, and Miller, 1955).

Table 2. Effect of Nitrogen plus Phosphorus and of Nitrogen-Sulfur-Phosphorus on Yield of Mountain Meadow Forage (Modoc, Lassen, and Shasta Counties)

County and ranch	Year	Average yield of forage from:					Profit or loss per acre from:*		Profit or loss from use of P
		No fertilizer	$N_{42}+S_{48}$†	$N_{48}+S_{45}+P_{26}$‡	$N_{84}+S_{96}$§	$N_{30}+S_{60}+P_{44}$‖	NS	NPS	
		tons/acre	tons/acre	tons/acre	tons/acre	tons/acre			
Modoc County:									
Cockrell	1953	1.51	2.28	2.62	....	....	$ 5.25	$ 2.85	$ −2.40
Grove	1953	2.78	4.66	5.03	....	....	21.90	19.95	−1.95
Cantrall	1953	1.77	2.26	3.70	....	....	1.05	15.15	14.10
Bishop	1953	2.26	4.67	5.22	....	....	29.85	30.60	0.75
Caldwell	1953	1.70	3.80	4.50	....	....	25.20	28.20	3.00
Lassen County:									
Nash	1953	1.53	3.24	3.74	....	....	19.35	19.35	.....
Modoc County:									
Fluornoy	1954	1.40	1.70	2.50	....	....	−1.80	5.70	7.50
Rice	1960	2.11	....	....	3.66	3.50	10.65	−2.15	−12.80
Kresge	1961	2.19	....	....	3.72	3.14	10.35	−8.75	−19.10
Fee	1961	2.27	....	....	3.84	3.64	10.95	−2.45	−13.40
Shasta County:									
McArthur	1961	2.18	....	....	2.59	2.94	−6.45	−11.60	−5.15
Lassen County:									
Albaugh	1962	2.06	....	....	3.49	3.46	8.85	−2.00	−10.85
Modoc County:									
Bickle	1962	1.54	....	....	1.88	3.14	−7.50	1.00	8.50
Swickert	1962	1.33	....	....	3.02	3.19	12.75	4.90	−7.85
Rowland	1963	1.95	....	....	2.67	3.00	−1.80	−7.25	−5.45

P_{26} = 60 P_2O_5; P = 100 P_2O_5. (See p. 18.)
* Hay valued at $15 per ton.
† Fertilizer cost per acre, $13.80. (Ammonium phosphate sulfate, 16–20–0, at $89 per ton.)
‡ Fertilizer cost per acre, $13.80. (Ammonium phosphate sulfate, 16–20–0 at $89 per ton.)
§ Fertilizer cost per acre, $12.60.
‖ Fertilizer cost per acre, $23.

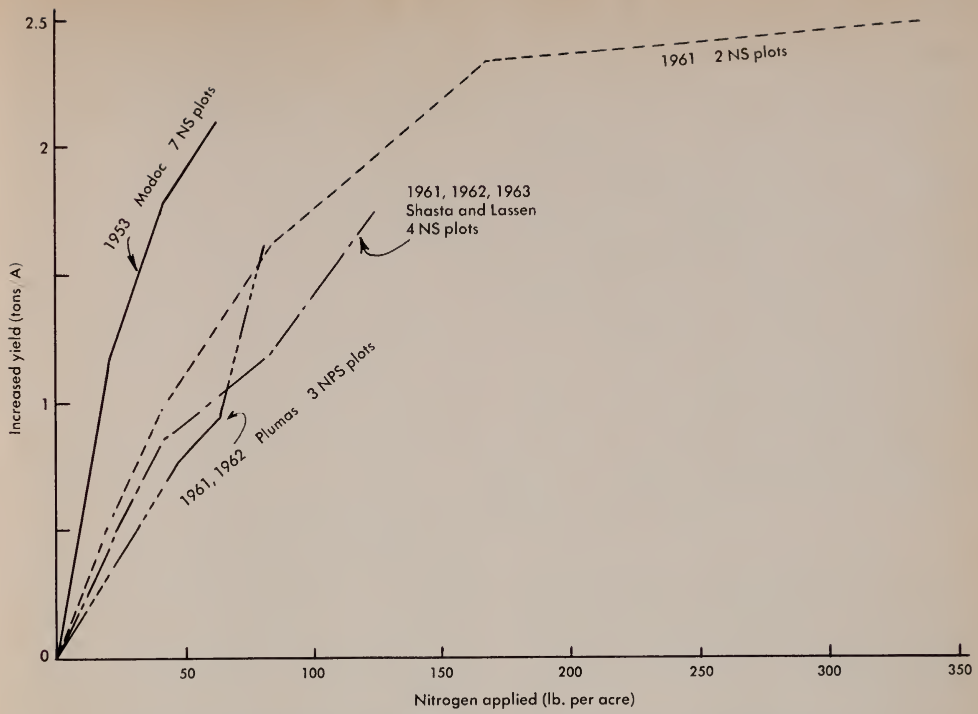


Fig. 1 Graph shows how much yields are raised by higher nitrogen rates.

How efficiently does meadow forage use fertilizer nitrogen?

Tests in both Lassen and Modoc counties show that successively higher yields with increasing nitrogen up to 168 pounds per acre were obtained with no significant effect on protein values. Calculation of nitrogen recovered in forage shows that at low rates the extra nitrogen harvested in the hay amounted to 60 to 80 per cent of the amount added in the fertilizer (tables 4 and 5). As the rates of nitrogen were increased, the apparent recovery decreased to only 26 to 28 per cent at very high nitrogen rates (table 5).

Table 3. Effect of Time of Cutting and Applied Nitrogen* on Crude Protein in Forage (Modoc County, 1962)

Ranch	Amount of crude protein from:			
	Early cutting (June)		Late cutting (July)	
	High N (160 lb.)	Low N (0–80 lb.)	High N (160 lb.)	Low N (0–80 lb.)
	per cent	per cent	per cent	per cent
Weber	14.7	12.7	9.8	8.9
Fee	11.9	11.1	7.4	8.0
Fluornoy	11.6	11.1	9.7	8.7
Average	12.7	11.6	9.0	8.5

* As ammonium sulfate.

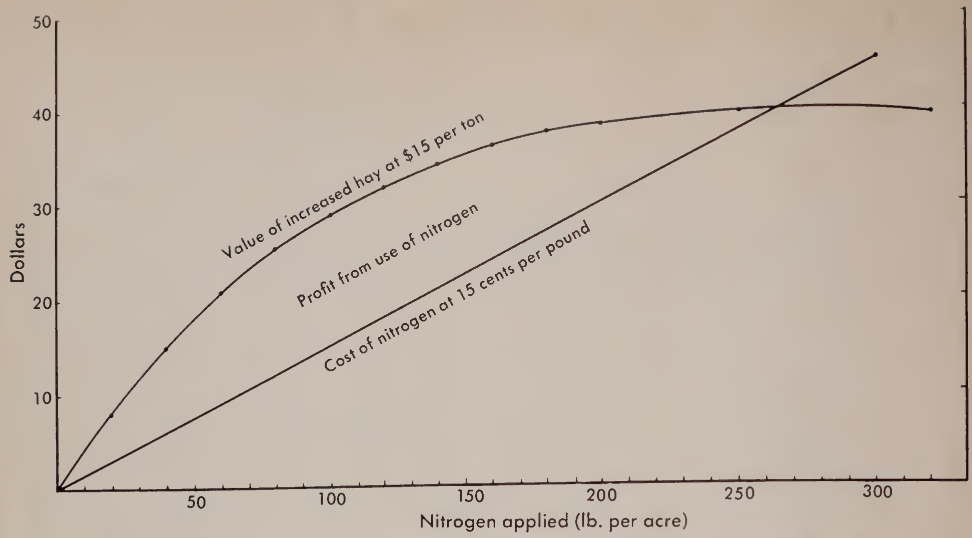


Fig. 2. How to measure maximum profit from fertilization of mountain meadow.

Hay at both locations was cut in late July, and crude protein was increased significantly only with the very highest nitrogen treatment.

Fertilization with nitrogen may reduce clovers

In the Modoc test, clovers and grasses were separated. The percentage of clovers in the hay decreased with increasing nitrogen treatments. This decrease was not offset by the addition of phosphorus at the 80-pound nitrogen rate.

How to determine the most profitable rate of nitrogen

In the most profitable fertilizer program, a maximum profit over cost of fertilizer is achieved. To make such an evaluation, a value must be placed upon the extra forage resulting from fertilization, and the cost of the fertilizer required to bring about the observed result subtracted from that value. Such a calculation is shown in figure 2, with actual data from two Modoc County tests where rates of nitrogen were increased up to 360 pounds per acre. In this chart the value of the increased hay resulting from fertilization is plotted as dollars of value at a price of $15 a ton. A maximum of nearly $40 increased value was achieved. A second line indicates the costs of the nitrogen used. The calculated cost is charged at 15 cents per pound of nitrogen applied. The cost of the nitrogen applied continues

Table 4. Amount of Crude Protein and Apparent Nitrogen Recovery in Forage (Lassen County, 1962, Swickert Ranch)

Fertilizer applications (lb. per acre)	N applied	Hay yield	Crude protein*	N harvested in hay	Extra N due to treatment	Apparent N recovery
	lb./acre	lb./acre	per cent	lb./acre	lb./acre	per cent
None	..	2,695	7.7	33.3	....	..
Ammonium sulfate:						
200	42	4,475	8.1	62.1	28.8	69
400	84	6,033	8.3	80.3	47.0	56
600	126	6,958	7.5	83.5	50.2	40
16–20:						
500	80	6,377	7.9	80.9	47.6	59

* Changes not significant at 5 per cent level.

to increase in a straight line while the value of the increased hay levels off. At 260 pounds of nitrogen per acre the cost of the nitrogen exactly equaled the value of the increased hay. At the lower rates of nitrogen, the value of the increased hay was increasing faster than was cost of materials. At the higher rates, the cost of the nitrogen was increasing faster than the value of the hay. The maximum profit, represented by the difference between the two lines, was greatest at about 110 pounds of nitrogen per acre, but did not change rapidly because the value line was almost parallel with the cost line between 90 and 120 pounds of nitrogen per acre.

Price of fertilizer nitrogen and value of forage must both be considered in deciding how much nitrogen should be used. Data for the Modoc County high nitrogen-rate tests show striking differences in "fertilizer profits" after increase in forage is evaluated and cost of nitrogen deducted. The curve in figure 2 shows a single price-value relationship. The curves in figure 3 illustrate how the "most profitable rate" and "profit over cost" change with different nitrogen prices and changing values for forage.

It will be noted that the "profit per acre" curves have broad peaks, and that for any value of forage, profit varies but little over a fairly wide range in rate of application. Several rates of nitrogen, differing by 10 to 20 pounds per acre and $1.50 to $3 in cost, may give profit values of within 10 to 15 cents of each other. In other words, the point of maximum profit should more properly be referred to as "zone of maximum profit" in which value of extra yield is about equal to cost of fertilizer required to produce each added increment. In this zone we are essentially trading dollars.

It is clear, however, that as forage increases in value and nitrogen decreases in price, much greater profits from fertilization are possible and high rates of nitrogen application are feasible. At lower forage values and higher priced nitrogen, the reverse is true.

Fertilization of Improved Grass-Legume Mixtures

Pasture species such as clover, trefoil, and alfalfa have frequently been planted with grass for either hay or grazing in many areas of northeastern California. Deficiencies of phosphorus, sulfur, and boron have been common, particularly on the alfalfa component of the forage mixture. Application of these nutrients alone or in combination has often stimulated the legumes sufficiently to keep the grass reasonably well supplied with nitrogen.

Table 5. Amount of Crude Protein and Apparent Nitrogen Recovery in Forage (Modoc County, 1961, Fee Ranch)

Fertilizer applications (lb. per acre)	N applied	Hay yield	Legume in hay	Crude protein	N harvested in hay	Extra N due to treatment	Apparent N recovery
	lb./acre	lb./acre	per cent	per cent	lb./acre	lb./acre	per cent
None	..	4,540	21.6	8.4	61.3	....	..
Ammonium sulfate:							
100	21	6,080	17.5	8.1	79.0	17.7	84
200	42	6,980	5.7	7.8	87.3	26.0	62
400	84	7,700	7.4	8.4	104.0	42.7	51
800	168	9,220	3.5	7.4	108.0	46.7	28
1,600	336	9,080	not determined	10.2	148.0	86.7	26
16–20:							
500	80	7,280	6.3	7.4	85.9	24.6	31

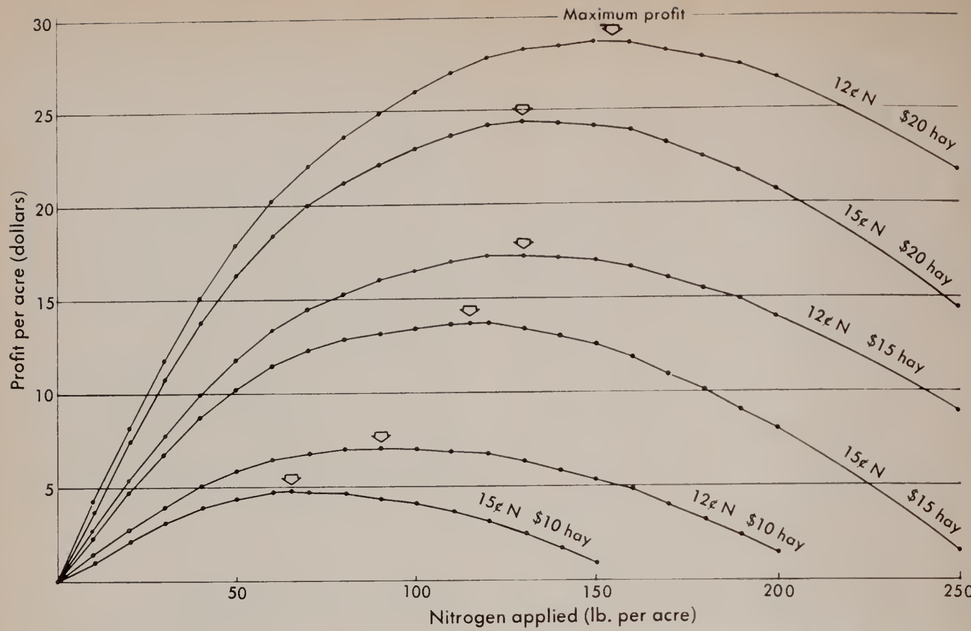


Fig.3. Effect of forage value, nitrogen rate, and price on profit from meadow fertilization.

Responses to sulfur are often spectacular

Sulfur is usually the first deficiency to be encountered, and responses of the legume, in a grass-legume mixture, to added sulfur are the most common. The yield figures in table 6 show the response obtained from applications of gypsum to irrigated alfalfa, grass, and clover-grass mixtures in Lake, Modoc, and Shasta

Table 6. Effect of Sulfur on Yield of Improved Legume-Grass Irrigated Pasture Mixtures

County, year, and crop	Fertilizer	Yield (dry wt)	Gain from sulfur	Cost of sulfur	Cost per ton of extra forage
		lb./acre	lb./acre		
Lake, 1955:					
Orchardgrass, trefoil, and alfalfa	None	1,634	.....	....	....
	500 lb. gypsum (90 lb. S/acre)	5,939	4,305	$5.00	$2.33
Shasta, 1961:					
Orchardgrass, ryegrass, alfalfa, and trefoil	None	1,790	.....	....	....
	200 lb. gypsum (36 lb. S/acre)	4,100	2,310	2.00	1.73
Modoc, 1956:					
Alfalfa, cereal rye, oats and	None	3,312	.....	....	....
	400 lb. gypsum (72 lb. S/acre)	4,511	1,199	4.00	6.60

Table 7. Effect of Boron and Phosphorus on Yield of Irrigated Alfalfa-Grass Forage (Siskiyou County, 1958)

Fertilizer applications (lb. per acre)	Dry material (first cutting)		
	Alfalfa	Grass	Total
	lb./acre	lb./acre	lb./acre
None	1,413	1,090	2,503
600 single superphosphate	2,336	1,110	3,446
100 borax	2,268	971	3,239
600 single superphosphate plus 100 borax	3,308	897	4,205

counties. Note that the additional forage was produced at a fertilizer cost of $2 to $6 per extra ton of hay. Similar results have been observed in many areas on non-irrigated, legume-grass forage plantings.

Boron and phosphorus deficiencies are important in some areas

Boron deficiency occurs at a number of locations in Shasta and Scott valleys in Siskiyou County, often along with a deficiency of phosphorus or sulfur or both. Boron-deficient alfalfa, either alone or with grass and pasture mixes, shows characteristic bright yellow terminal leaves, fails to set seed, and shows die-back of terminal growing points in severe cases. Results of boron and superphosphate applications to alfalfa grass mixtures used for hay and grazing are shown in table 7. Both single superphosphate (to supply phosphorus and sulfur) and boron were required to correct the three nutrient deficiencies at this location. Applied phosphorus and boron tend to remain effective for several years, whereas gypsum or other sources of sulfur must be applied annually or at least every two years.

COASTAL AND NORTH CENTRAL VALLEYS— LEGUME-DOMINANT PASTURES

Legume-dominant pastures are common throughout the Sacramento Valley, the northern San Joaquin Valley, and in the cooler valleys adjacent to the Pacific coast. Here Ladino clover and trefoil are the principal legumes, with ryegrass, orchardgrass or tall fescue the most common grass species. Many of the locations devoted to irrigated pasture in the northern part of the central valley are on reddish, hardpan soils or old claypan soils commonly deficient in available phosphorus and sulfur. It has been an accepted practice in many of these areas to fertilize the pastures with single superphosphate (which contains both phosphorus and sulfur) in an effort to stimulate the clovers. If the clover responds vigorously, it may be expected to provide additional nitrogen for the grass component of the pasture association. Considerable grass should be present to reduce the bloat hazard associated with a high percentage of clover in the forage.

A series of fertilizer tests were set up on irrigated pastures to find out: (1) what responses to fertilizers could be anticipated; (2) how much phosphorus could most profitably be used; and (3) whether additional nitrogen could be economically used to increase growth.

This study sought reliable information about the effect of fertilizers on production of seasonal forage and on the shifts in individual plant species present. The test areas were harvested at intervals through-

Table 8. Yield of Forage with Various
(Shasta County, 1950)

Ranch and soil type	Fresh weight of forage with:				
	No fertilizer (control)	N	S	N and S	P and S
	lb./acre	lb./acre	lb./acre	lb./acre	lb./acre
Carpenter; Red Bluff loam......	3,585	5,080	13,960	16,865	7,760
Hopson; Columbia loam...........	6,410	8,830	11,840	10,360	9,530

* N = 50 N per acre from 150 lb. ammonium nitrate.
S = 76 S per acre from 400 lb. gypsum.
P = 73 P (168 P_2O_5) from 400 lb. treble superphosphate.
K = 100 K (120 K_2O) from 200 lb. muriate of potash.

out the growing season by mowing strips through each treated plot with a mobile forage harvester or power mower. Replicated randomized block experiments were used. The experimental areas were fenced and protected from grazing. In later tests the entire area was grazed by cattle as soon as the test samples had been removed. In this way plots were harvested at the normal intervals throughout the grazing season and were also subjected to the impact of rotation grazing.

Yields of the experimental forage plots were measured by weighing the fresh material clipped from a measured strip cut across each treated area. After the fresh material was weighed, samples were taken and placed in plastic bags for hand separation into component plant species. In this way it was possible to measure how fertilizers affected individual yields of the legume and grass species in the mixture.

Chemical analyses of forage samples were made to measure the recovery of added fertilizer by pasture plants and to determine the influence of fertilization upon plant composition and forage quality. Soil samples were taken to establish phosphorus status prior to fertilization (Olsen *et al.*, 1954).

Table 9. Effect of Nitrogen and Phosphorus on Forage Yields

County, soil series, and year	Bicarbonate-soluble soil P (HCO_3–P)	Nutrients applied			Total annual yield, dry wt. (untreated)
		N	(P_2O_5)	P	
	p.p.m.	lb./acre	lb./acre		lb./acre
Napa, Coombs, 1954..............	4.0	100	(60)	26	3,538
Yolo, Capay, 1956................	30.5	52	(66)	29	9,471
Solano, Solano, 1956.............	8.1	150	(100)	44	3,563
Placer, Rocklin, 1956............	4.4	150	(80)	35	3,155
Sacramento, San Joaquin:					
1956..........................	2.2	200	(80)	35	5,804
1957..........................	....	180	(160)	70	5,903
1958..........................	....	100	(320)	140	6,345
Glenn, Tehama, 1957.............	4.9	210	(80)	35	8,074
Napa, Dublin, 1961...............	11.7	80	(80)	35	3,126

* Significant benefit from nitrogen at 5 per cent.
† Addition of phosphorus gave significant increase in yield over untreated or nitrogen only.

Nutrient Combinations*

N, P, and S	P, K, and S	N, P, K, and S
lb./acre	lb./acre	lb./acre
9,665	16,840	16,455
11,250	12,480	15,260

What Fertilizer Nutrients are Needed?

Tests have indicated that nitrogen, phosphorus, sulfur, and potassium are the fertilizer nutrients most likely to improve growth of pasture forage. Results from replicated exploratory tests in the Anderson-Cottonwood area of Shasta County are shown in table 8. In both tests nitrogen alone increased yield, but nitrogen plus sulfur gave higher yields. The addition of phosphorus greatly improved yield in the Carpenter test but only slightly in the Hopson test. Application of

in Legume-dominant Irrigated Pastures

Yield increase from:		
P only	N + P	N only
lb./acre	lb./acre	lb./acre
2,530†	4,736*	1,570*
261	1,746*	.....
286	1,627*	1,563*
1,154†	2,537*†	.....
2,008†	3,804*†	1,965*
2,775†	4,424*†	1,180*
3,035†	3,648*†	1,105*
871	2,246*†	1,284*
47	636*†	465*

potassium did not result in any consistent benefit. Potassium responses have only rarely been observed in the major irrigated pasture regions although local areas in Siskiyou, Butte, and Stanislaus counties are known to benefit from this nutrient (McCollam, 1948; Ulrich, 1940).

Tests with nitrogen and phosphorus

Nine tests were carried out on legume-dominated pastures, with five to seven cuttings, over entire seasons. Nitrogen (ammonium sulfate), phosphorus (single superphosphate), and a combination of both were used. Results are shown in table 9. Total seasonal yields without treatment varied from about 3,500 pounds dry matter to somewhat over 9,000 pounds. Every test showed significant increases in yields as a result of fertilization. Three of the tests, in Yolo, Napa, and Solano counties, were on soils sufficiently supplied with phosphorus, so that no significant increases in yield resulted from added phosphorus. In the remaining six tests, soils were deficient in phosphorus, and yields were increased by fertilization with that nutrient. Nitrogen plus phosphorus increased yields on the phosphorus-deficient soils more than did nitrogen alone. Similarly, yields were greater with nitrogen plus phosphorus than with phosphorus only. Analysis of soil samples from the tests in this study indicates need of phosphorus fertilization only on soils with less than 4.9 ppm of phosphorus (using the Olsen bicarbonate extractant). Recent sampling of the pasture plots in the north coast and mountain areas suggests that in those regions a considerably higher threshold value will have to be used.

Irrigated pastures throughout much of northern and central California are grown on relatively shallow, red hardpan soils or on soils with a claypan layer. These soils are commonly phosphorus-deficient. At any location, the magnitude of the response to phosphorus will depend on the phosphorus level in the soil. This in turn will be affected by duration of cropping, previous fertilizer history, and phosphorus fixation characteristics of the soil.

Table 10. Effect of Superphosphate on Yield of Legume-dominant Irrigated Pasture Mixture on Phosphorus-deficient Soils

County, soil series, and year	Soil phosphorus (HCO_3–P)	Total annual yield, dry weight (untreated)	Increase in dry weight of mixed forage from:	
			35 P (80 P_2O_5)	70 P (160 P_2O_5)
	p.p.m.	lb./acre	lb./acre	lb./acre
Placer, Rocklin, 1956	4.4	3,155	1,154	1,235
Sacramento, San Joaquin, 1956	2.2	5,804	2,008	2,858
Glenn, Tehama, 1957	4.9	8,074	871	1,232
Solano:				
Capay, 1956	3.0	5,475	509	694
Lindsey, 1958	3.2	9,009	1,742	2,523
Average	...	6,303	1,257	1,708

Such variation in response was shown in tests conducted in the Sacramento Valley (table 10). In these tests, 400 pounds of single superphosphate (35 P) applied in early spring gave increases in yield of from 500 to about 2,000 pounds for the entire season. Doubling the phosphorus further increased the yield by only about 50 per cent. The data show the magnitude and range of response to be expected on phosphorus-deficient soils *provided a responsive legume is present,* capable of making improved growth under the prevailing climatic and soil conditions.

EFFECT OF FERTILIZERS ON GRASSES AND LEGUMES

Inorganic ammoniacal or nitrate nitrogen fertilizers, alone or with phosphorus where needed, nearly always cause an increase in growth of the grass in mixed legume-grass stands. Normally, grass in a pasture association is provided with nitrogen by the decomposition of soil organic matter and of legume roots and nodules. The amount of nitrogen so provided, however, is rarely as much as the grass could use. Consequently, grass growth often increases with nitrogen application. Nitrogen rarely stimulates legumes directly, and single applications seldom have any permanent effect upon the stand of legumes in a pasture mixture.

How long do effects of nitrogen last?

Single applications of commercial inorganic nitrogen usually remain effective only a few weeks, or until the forage stimulated by that nitrogen is removed. Tests with nitrogen at various rates up to 100 pounds per acre show little, if any, response after the first cutting or grazing. This is illustrated by the 1956 yield curves from Sacramento County (fig. 4) which show the increases in grass yields due to nitrogen either alone or with phosphorus. Ammonium nitrogen fertilizers applied in March were effective at the time of the first cutting in April. By the time of the next cutting, in May, yields had been reduced to the level of the untreated plots. The same material applied after the second cutting increased yields for only about a month. In 1957, more frequent, smaller applications of ammonium sulfate gave more regular response.

Results similar to those for 1957 in figure 4 were obtained from spring applications of nitrogen in tests in Yolo and Solano counties. These findings indicate

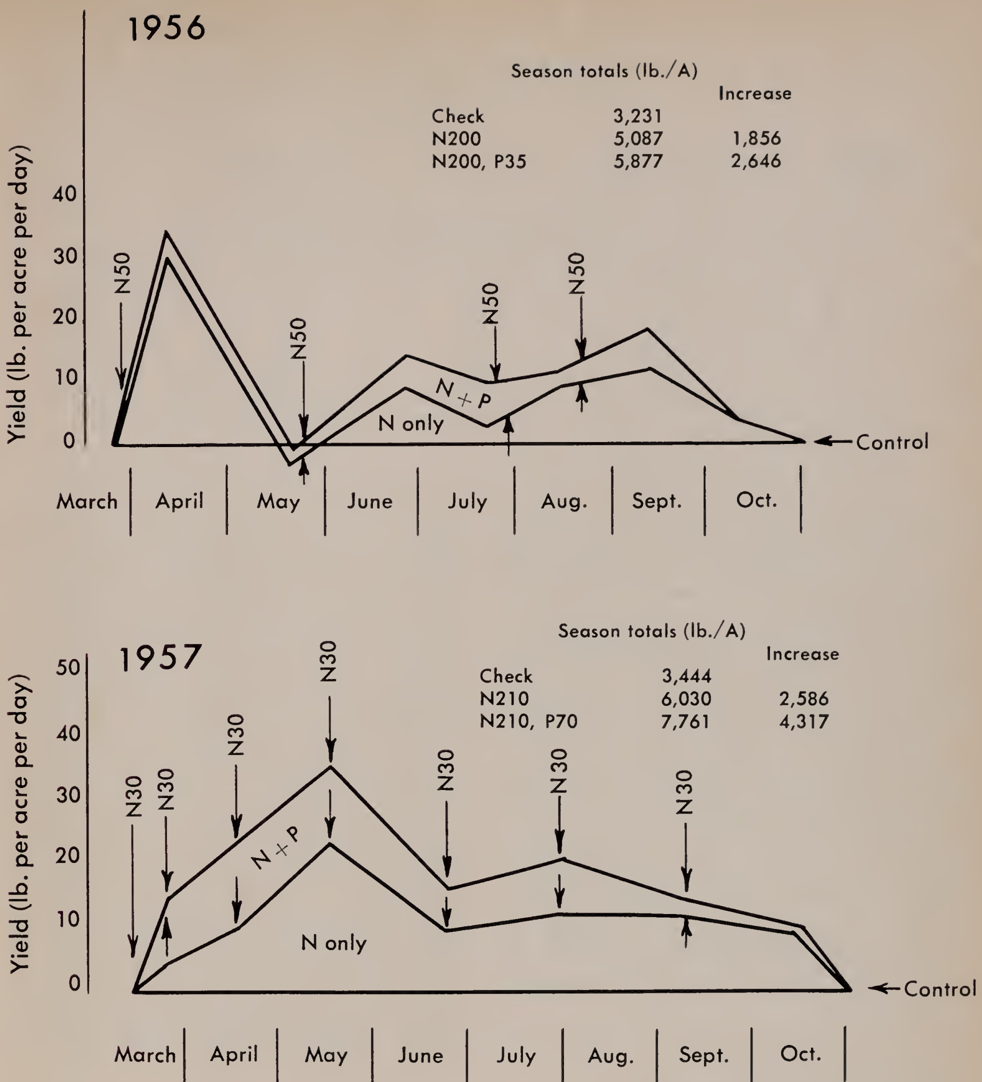


Fig. 4. Increase in yield of grass as result of applied nitrogen. Test conducted on Lewis ranch, Sacramento County, shows how long a nitrogen application lasts.

that a single application of nitrogen, even as much as 100 pounds per acre, will last only about a month in a pasture that is being grazed and watered regularly.

Nitrogen often crowds out clover

Continuing nitrogen application may have an important effect on the relative growth of grasses and legumes. In an experiment at Davis in 1957, various rates of ammonium sulfate were applied to a newly established, mixed pasture of Ladino clover and orchardgrass (Peterson and Bendixen, 1961).

Results of the first season's test showed a definite increase in total yield of forage in response to nitrogen (table 11). The nitrogen treatments were continued for a second year with no increase in total yield. Orchardgrass had replaced the Ladino clover in areas where continuing applications of nitrogen had been made during the summer months. In unfertilized sec-

Table 11. Yield of Ladino-Grass Forage as Influenced by Nitrogen Applied on a Soil with Adequate Phosphorus

Nitrogen application (lb. per acre)	Yield of forage			
	First season total*	Second season		
		Grass	Ladino	Total
	tons/acre	tons/acre	tons/acre	tons/acre
0	2.84	1.57	2.11	3.68
80	3.70	2.09	1.52	3.61
120	3.94	2.58	1.27	3.85
160	4.79	2.49	1.06	3.55

* No species separation made during first season.

tions, yields of the grass-legume mixture were slightly under 4 tons per acre, and the clover percentage remained high throughout the entire season (fig. 5). Nitrogen definitely increased growth of grass, but the increase was almost exactly offset by a reduction in the growth of clover, and the total yield was no greater than that of the check (table 11).

This test on a productive, high-phosphorus soil shows that nitrogen-stimulated grass can crowd out clover. Nitrogen influences the balance of grasses and legumes because low nitrogen limits grass but not clover, while at high nitrogen levels grass competes with clover for water, space, and light and remains dominant so long as the high nitrogen supply is maintained.

Phosphorus benefits both grasses and legumes

On soils that are moderately deficient in phosphorus, applications of this nutrient usually stimulate the legumes present, while applications of nitrogen generally improve the growth of grass.

A treatment with both nitrogen and phosphorus usually gives a better yield of grass than does nitrogen alone. When separate tests were made on grasses and legumes with nitrogen and phosphorus (table 12), applications of phosphorus to phosphorus-deficient soils in three counties increased the growth of clover in every instance. Applications of nitrogen did not benefit the clover, but did increase the growth of grass. Yields of grass from nitrogen plus phosphorus were greater than from nitrogen alone. Even with phosphorus alone, some slight increase in grass growth occurs (probably because clovers are stimulated and, during the summer, make available to the grasses some of the nitrogen fixed through extra root growth and nodule activity).

Trefoil is often the dominant legume on phosphorus-deficient soils. If Ladino clover is present, it is usually a minor constituent. Applications of phosphorus to some soils often cause the Ladino to "get going" and crowd out the trefoil. If no Ladino is present, phosphorus applications can and do greatly stimulate trefoil growth. Frequent watering also favors Ladino clover, while longer intervals between irrigations give trefoil an advantage.

Effects of continuing nitrogen and phosphorus treatments where phosphorus is needed

When phosphorus is deficient, both nitrogen and phosphorus fertilizers may affect the botanical composition of the pasture mixture.

The Sacramento County test was carried out for three successive years to find out whether maintaining a very high phosphorus level in the presence of nitrogen would reduce the crowding of legumes by nitrogen-fertilized grasses. Each season six or seven cuttings were made, and plant separations were made

Table 12. First-year Effects of Nitrogen and Phosphorus on Species Response in Irrigated Pastures

County, soil type, and year	Nutrients applied			Annual yield of forage (dry weight)				
	N*	(P_2O_5)	P	Ladino	Trefoil	Ladino and trefoil†	Grass	Total
	lb./acre	lb./acre		lb./acre	lb./acre	lb./acre	lb./acre	lb./acre
Napa, Coombs clay loam, 1954	...	..	..	.....	.....	1,670	1,868	3,538
	...	(80)	35	.....	.....	3,606‡	2,462	6,068‡
	100	(80)	35	.....	.....	2,693‡	5,581‡	8,274‡
	100	..	..	.....	.....	1,047	4,061‡	5,108‡
Placer, Rocklin loam, 1956	...	..	..	574	511	.....	2,070	3,155
	...	(80)	35	916‡	633	.....	2,460	4,009
	150	(80)	35	879‡	713	.....	4,100‡	5,692
Sacramento, San Joaquin loam, 1956	...	..	..	1,386	1,187	.....	3,231	5,804
	...	(80)	35	2,577‡	1,052	.....	4,183	7,812
	200	(80)	35	2,261‡	1,470	.....	5,877‡	9,608
	200	..	..	1,398	1,284	.....	5,077‡	7,759

* From ammonium sulfate.
† No separations of ladino and trefoil were made for Napa County.
‡ Significantly better than untreated.

for each cutting to find out how each kind of plant had been affected by fertilization. Results from the second year of treatment (1957 season) are shown in figure 6. Yields were calculated as pounds per acre per day, to show changes during the season and help visualize the results in terms of animal use. A cow or steer needs 20 to 25 pounds of dry matter each day. On this basis, the untreated pasture (fig. 6) would carry only about an animal per acre, with a surplus of feed in May and June. The heavily phosphated pasture would have carried nearly two animals per acre for most of the season.

Figure 6 also shows that nitrogen treatments alone caused a big increase in grass growth, especially in May, that continued for most of the summer. Ladino clover and trefoil were greatly reduced by straight nitrogen treatments.

Phosphorus treatments seem to have increased grass growth somewhat in the spring, but nearly doubled Ladino clover production.

When both nitrogen and phosphorus were used, grasses really took over. Ladino was better than in the control plot, but much less than where straight phosphorus treatment had been made. Trefoil was almost completely eliminated.

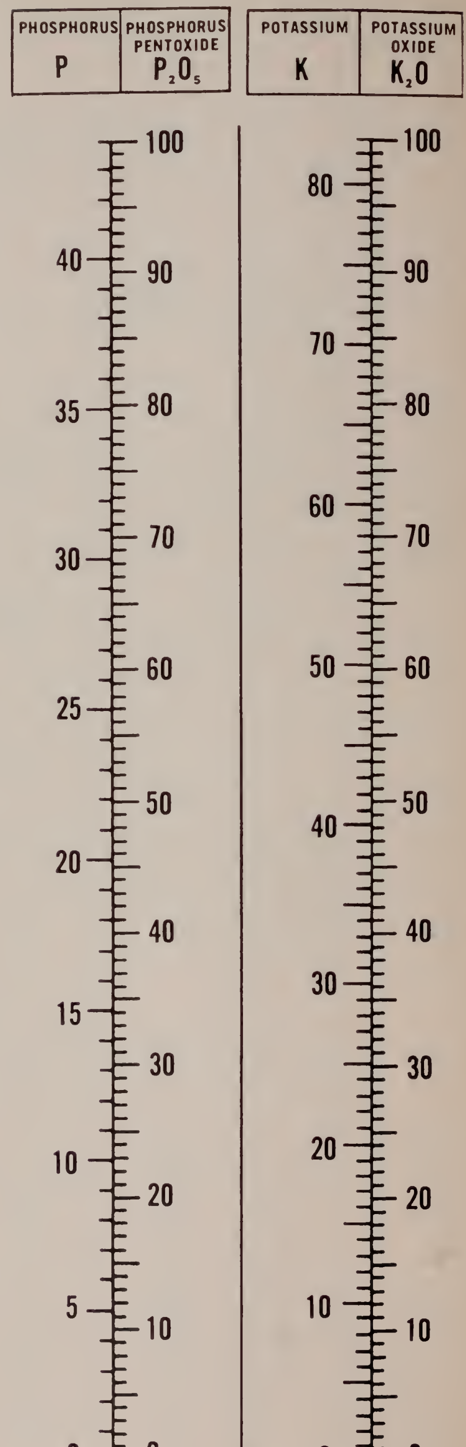
Over a three-year period (fig. 7), nitrogen, even with adequate phosphorus, caused a decrease in the proportion of legumes in the mixture. Furthermore, while nitrogen alone may favor grass, nitrogen plus phosphorus apparently makes grass grow even better. Increasing amounts of phosphorus were applied to find out whether a high level of phos-

> In this publication, the nutrients nitrogen, phosphorus, and potassium are expressed as actual amounts of the element applied. Since phosphorus and potassium have usually been expressed as P_2O_5 (phosphorus pentoxide) and K_2O (potassium oxide), respectively, the alternative values are also given. The conversion scale at the right should prove helpful in determining actual amounts of the element from the amount of fertilizer applied.

FERTILIZER CONVERSION SCALES

Element to Oxide

(Pounds or Per Cent)



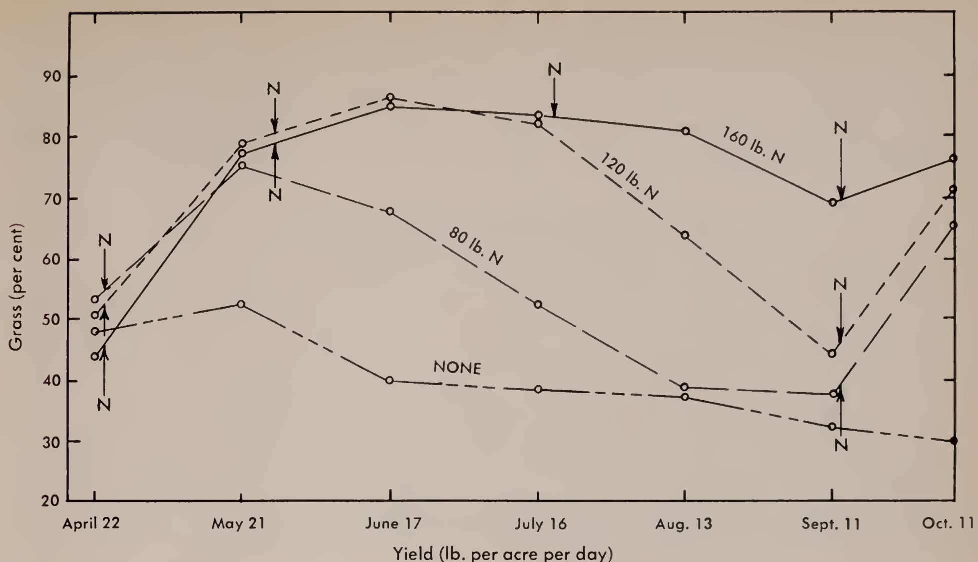


Fig. 5. Second-year effect of nitrogen on percentage of grass in Ladino-orchardgrass pastures at Davis. Arrows indicate time at which 40 pounds of nitrogen increments were added.

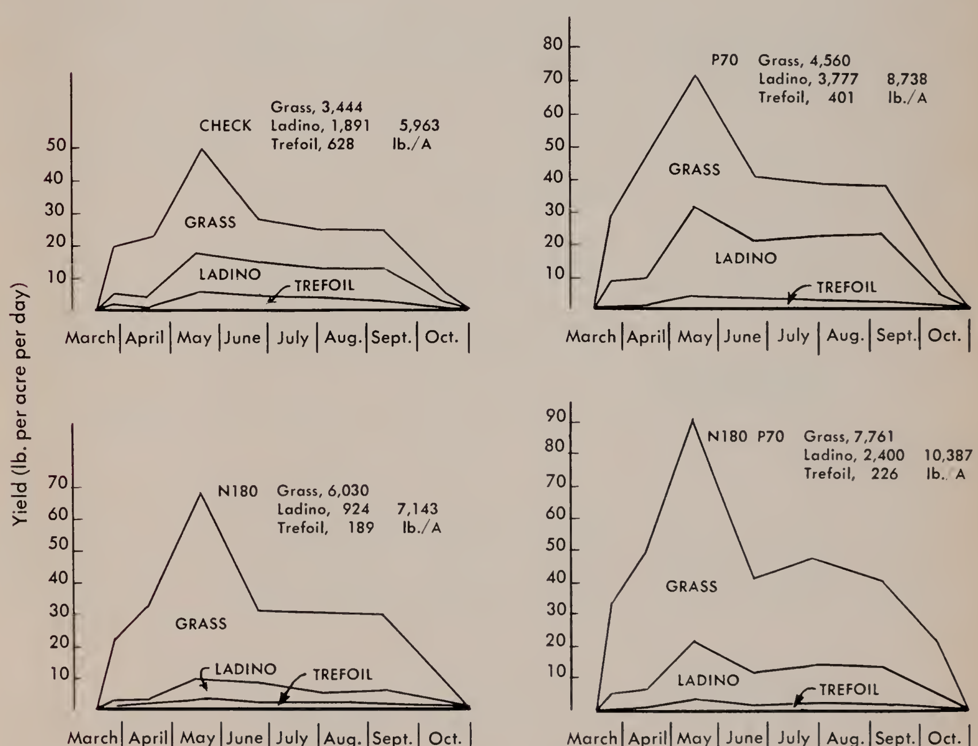


Fig. 6. Effect of nitrogen and phosphorus on yield of separate pasture species.

phorus would prevent crowding out of legumes by nitrogen-fertilized grasses. Even at 140 pounds of phosphorus (320 P_2O_5), legume yields continued to decrease. In 1958, yields from the high-phosphorus treatment were about the same as those from nitrogen and phosphorus in combination. Where both nitrogen and phosphorus were applied, the proportion of legumes in the mixture was much less, and nitrogen-fixing capacity was reduced correspondingly.

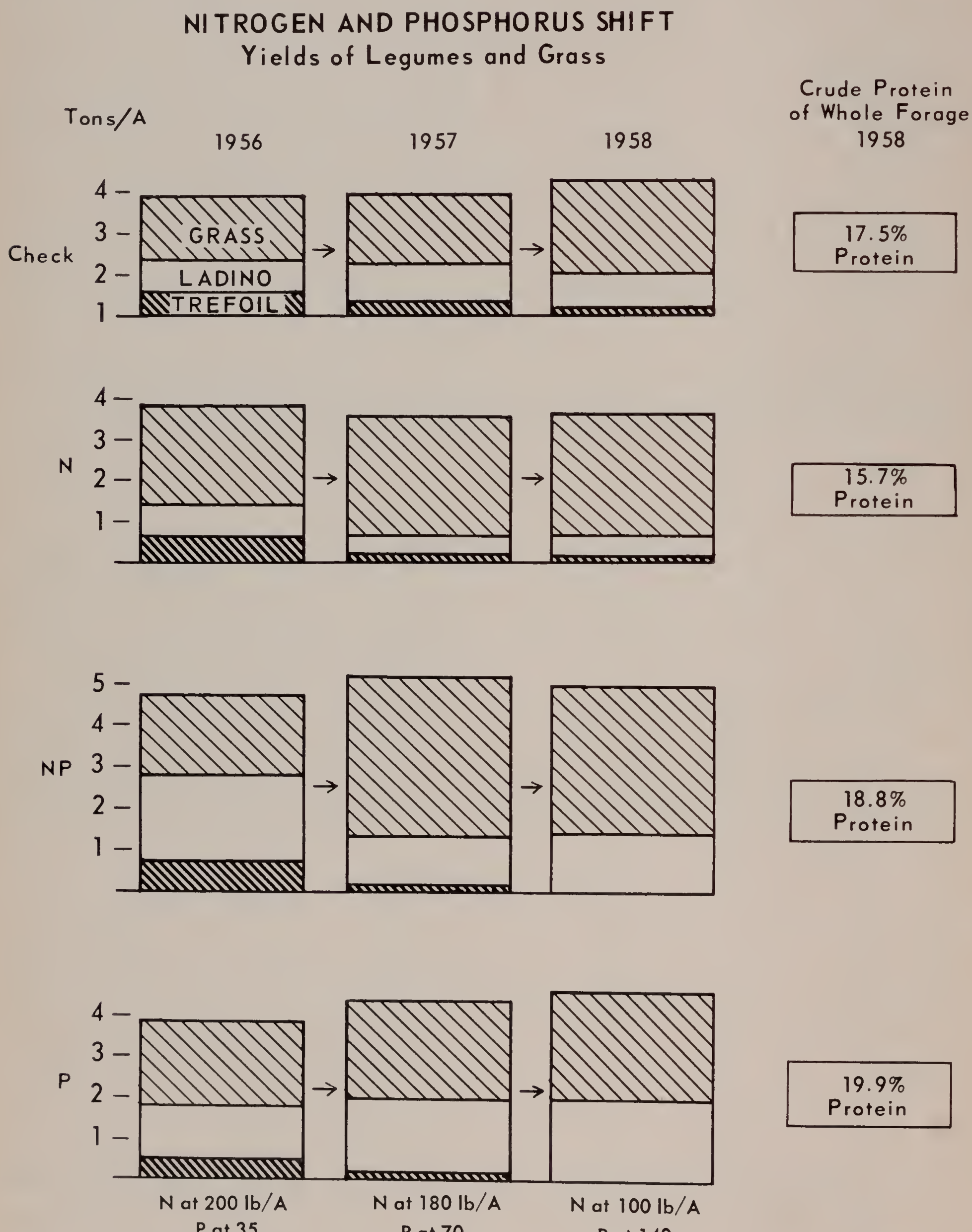


Fig. 7. Influence of continuing nitrogen and phosphorus treatments on yields of grass and legume and on crude protein content of whole forage.

EFFECT OF FERTILIZATION ON PROTEIN AND PHOSPHORUS CONTENT OF FORAGE

The protein content of legumes such as trefoil and Ladino clover is much higher than that of grasses. Factors that cause an increase in the amount of clover in forage tend to increase the protein content of the entire pasture mixture.

Earlier studies (Rendig, Martin, and Smith, 1950) of pasture fertilization in the Anderson-Cottonwood district of Shasta County showed that phosphorus fertilization increases total growth, alters relative amounts of grass and legumes present, and materially changes the chemical composition of the forage. The crude protein of whole forage was increased from 16.3 to 19.3 per cent by phosphate application, principally because of a larger proportion of high-protein Ladino in the mixture. However, there was also a slight increase in protein content of the grass. The phosphorus content of both Ladino and grass was increased by fertilization, with the grass showing somewhat higher phosphorus values than the legumes.

In the Sacramento County test, yields were materially changed by fertilization with either nitrogen or phosphorus (fig. 7). The phosphorus fertilization increased the amount of high-protein clover in the mixture, thus increasing somewhat the crude protein content of the whole forage. Nitrogen alone increased the protein content of the grass very slightly, but tended to decrease the proportion of high-protein clover in the mixture. As a result, the protein content of the entire pasture mixture was reduced by nitrogen.

The effects of continuing nitrogen and phosphorus treatments on the composition of forage and yield of individual species (Napa County) are shown in table 13. First- and second-year responses were compared. Both seasons' data show that the protein content of whole forage was increased by use of phosphorus because more high-protein clover was present. In both years, nitrogen reduced the protein content appreciably because it reduced the amount of clover. Where nitrogen

Table 13. Effect of Continuing Fertilizer Treatments on Yield and on Amount of Crude Protein in Forage (Napa County, Marshall Ranch)

Annual fertilizer treatment (lb./acre)	Yield (lb. per acre) of forage (dry weight)					
	1954			1955		
	Grass	Legume	Both	Grass	Legume	Both
None	1,600	1,670	3,270	1,592	904	2,496
26P (60 P_2O_5)	2,333	3,606	5,939	3,361	3,482	6,843
100N	3,598	1,047	4,645	2,839	184	3,023
100N, 26P	4,839	2,693	7,532	4,380	2,087	6,467
	Per cent of crude protein in forage					
None	14.8	22.8	18.3	13.8	22.7	16.9
26P (60 P_2O_5)	15.9	22.1	19.7	14.9	23.9	19.4
100N	14.8	22.7	16.5	13.6	22.2	14.1
100N, 26P	15.3	23.8	18.3	14.5	24.1	17.6

alone had been used for two seasons, clover was almost eliminated, and protein content of the whole forage was appreciably reduced.

Both grasses and legumes showed increased phosphorus following its application at all phosphorus-deficient locations. The increase was probably of little significance to grazing animals, however, because the total percentage of phosphorus in the unfertilized forage was generally well above critical levels for animal requirements established by the National Research Council (Burroughs, 1958).

Except where phosphorus was acutely deficient, unfertilized grass tended to have a higher percentage of phosphorus than did associated legumes.

In the Sacramento test (table 14), nitrogen alone or with phosphorus had little effect on the phosphorus content of either grasses or legumes. Phosphorus treatments increased the phosphorus content —more so in the grass than in the legume fraction.

Table 14. Effect of Nitrogen and Phosphorus Fertilizer on Phosphorus in Pasture Forage
(Sacramento County, Lewis Ranch)

Year and treatment (lb. / acre)	Phosphorus in pasture forage	
	Grass	Legume
	per cent	per cent
1957:		
None........	0.23	0.23
200N........	0.24	0.23
200N, 35P....	0.30	0.27
35P.........	0.31	0.28
1958:		
None........	0.24	0.23
180N........	0.23	0.21
180N, 70P....	0.35	0.30
70P.........	0.37	0.30
1959:		
None........	0.27	0.26
100N........	0.23	0.23
100N, 140P...	0.44	0.36
140P........	0.45	0.37

FERTILIZATION MAY CHANGE NUTRIENT UPTAKE BY PASTURE PLANTS

The amounts of nitrogen and phosphorus taken up by pasture plants are related to the supply of those nutrients in the soil and to fertilization practices. Calculations of actual amounts of nitrogen and phosphorus in the harvested pasture forage show how fertilization may change the nitrogen and phosphorus uptake of the pasture community.

How nitrogen fertilization alters nitrogen recovery on high-phosphorus soils

Nitrogen rate studies at Davis, on a soil considered to have adequate phosphorus, showed the effect of nitrogen on nitrogen recovery by Ladino, orchardgrass, and a mixture of the two species (Peterson and Bendixen, 1961). Table 15 shows nitrogen uptake by grass and clover in the second year of identical ammonium sulfate treatments.

Yields of a pure stand of orchardgrass were about quadrupled by 160 pounds of nitrogen applied at intervals throughout the season. Nitrogen supplied by the soil to the unfertilized plants amounted to 27.1 pounds per acre. Extra nitrogen recovered in the harvest of fertilized grass was 92.4 pounds from 160 pounds of fertilizer nitrogen, or 58 per cent of the amount applied.

Ladino clover in pure stand yielded 318 pounds of nitrogen in the harvested crop for the entire season. This amounts to 290 pounds of nitrogen fixed per acre if allowance is made for the nitrogen-supplying power of the soil as measured

Table 15. Second-year Effects of Ammonium Sulfate Nitrogen Fertilization on Uptake of Nitrogen by Pure Stands and by Mixed Grass and Legume
(Davis, California, 1958)

Crop	Amt. N applied	Yield (dry wt.)	Concentration of N in forage	Amt. of N uptake by:			Gain or loss in N from fertilization	Apparent N recovery
				Grass	Legume	Total		
	lb./acre	lb./acre	per cent	lb./acre	lb./acre	lb./acre	lb./acre	per cent
Orchardgrass	0	1,092	2.48	27.1	.....	27.1	....	..
	80	2,392	2.45	58.6	.....	58.6	31.5	79
	120	3,671	2.69	98.7	.....	98.7	71.6	60
	160	4,314	2.77	119.5	.....	119.5	92.4	58
Ladino clover	0	8,060	3.94	.....	317.6	317.6	....	..
	80	8,175	3.90	.....	318.8	318.8	1.2	3
	120	8,352	4.08	.....	340.8	340.8	23.2	11
	160	8,390	4.10	.....	344.0	344.8	26.4	17
Orchardgrass and Ladino	0	7,361	3.43	80.1	172.0	252.1	....	..
	80	7,217	3.23	111.4	121.4	232.8	−19.3	None
	120	7,705	3.27	149.9	102.2	252.0	−0.1	None
	160	7,111	3.24	146.2	84.2	230.4	−21.7	None

Source of data: Peterson and Bendixen (1961).

by nitrogen uptake of unfertilized grass. Additions of nitrogen to Ladino clover grown alone caused only very slight increases in the percentage of nitrogen or in nitrogen uptake per acre. Nitrogen applied at 160 pounds per acre increased the amount of nitrogen in the harvested forage by 26 pounds—an apparent recovery of 17 per cent. Either the applied nitrogen was not used by the clover, and was therefore lost, or the clover did not fix as much nitrogen as it did when unfertilized.

Nitrogen on the mixed legume-grass stand at Davis in the second year of the same experiment had encouraged the grass growth. This change in plant population reduced the ability of the pasture community to fix nitrogen, since clovers had been greatly reduced. Nitrogen uptake data from this test show a substantial reduction in the amount of clover nitrogen found in the harvest of the mixed planting. The percentage of nitrogen in these clover plants remained the same, but the yield was less. The amount of nitrogen harvested in the grass increased since the yield of grass was up. The total amount of nitrogen harvested in the grass-legume mixture fertilized with 80, 120, or 160 pounds of nitrogen per acre was no greater than that produced in the unfertilized plots. It seems clear that any gains in uptake of nitrogen by grass was offset by a reduction in the amount of clover nitrogen.

How nitrogen and phosphorus alter nitrogen recovery on phosphorus-deficient soils

When soil phosphorus is deficient, fertilization with this nutrient over a period of time may greatly alter the nitrogen recovery of the pasture community if responsive legumes are present. As already shown, nitrogen treatments remain important because they may alter the proportion of plant species present in the pasture mixture.

Napa County Tests. Nitrogen uptake by the individual species and by the whole forage, for the two-year test period, is shown in table 16. In the first year, the nitrogen harvested in phosphorus-treated whole forage was double that in forage from the unfertilized area. Most of this extra nitrogen was found in the legume fraction, but an appreciable amount was also harvested in the associated grasses.

Straight nitrogen treatments reduced the amount of legume nitrogen harvested, but did increase the amount of grass nitrogen for an over-all apparent recovery of 24 per cent of the fertilizer nitrogen applied.

By the second season, straight nitrogen treatments had nearly eliminated legumes and thereby reduced nitrogen fixation to such an extent that the amount of nitrogen recovered was no more than that in the check plot.

Phosphorus treatments, on the other hand, increased nitrogen uptake at harvest in both the legume and grass portions of the forage in both seasons.

Nitrogen uptake from the nitrogen-phosphorus treatments in the second year was somewhat less than in the area where only phosphorus had been applied.

Sacramento Test. Effects of fertilization upon nitrogen fixation and recovery are summarized, for a three-year period, in table 16. The effect of the first year's nitrogen application was a definite gain in total nitrogen harvested, since grasses were stimulated and clovers little affected. The over-all recovery of fertilizer nitrogen was about 33 per cent. When 35 pounds of phosphorus (80 P_2O_5) were applied alone or in combination with nitrogen there was an increase in nitrogen uptake amounting to approximately 64 pounds, mostly in the legume fraction.

Results of the second year of this test showed that applications of nitrogen very greatly reduced the total amount fixed by the smaller legume population while increasing the nitrogen uptake of the grasses. For the community as a whole, the apparent nitrogen recovery was reduced to 7 to 8 per cent of that applied. At the same time, applications of phosphorus resulted in an increase in nitrogen uptake amounting to about 100 pounds of nitrogen per acre for the entire season.

Table 16. Effect of Continuing Nitrogen and Phosphorus Treatments on Nitrogen Uptake of Grass and Legume Forage on Phosphorus-deficient Soils

County, soil type, and year	Nutrients applied			Nitrogen uptake in:			Increased N	Caused by:
	N*	(P_2O_5)	P	Grass	Legume	Both		
	lb./acre	lb./acre		lb./acre	lb./acre	lb./acre	lb./acre	
Napa, Coombs clay loam, 1954..........	...	..	..	37.8	60.9	98.7	.....	...
	...	(60)	26	59.3	113.8	173.1	74.4	P
	100	..	..	84.9	38.0	122.9	24.2	N
	100	(60)	26	118.1	102.6	220.7	122.0	NP
Napa, Coombs clay loam, 1955..........	...	..	..	35.0	32.8	67.8	.....	...
	...	(60)	26	80.3	133.0	213.3	145.5	P
	100	..	..	61.9	6.5	68.4	000.6	N
	100	(60)	26	101.6	80.5	182.1	114.3	NP
Sacramento, San Joaquin loam, 1956.....	...	..	..	67.3	87.4	154.7	.....	...
	...	(80)	35	88.8	130.5	219.3	64.3	P
	200	..	..	128.1	93.4	221.5	66.8	N
	200	(80)	35	151.0	134.1	285.1	130.4	NP
Sacramento, San Joaquin loam, 1957.....	...	...	..	76.5	89.1	165.6	.....	...
	...	(160)	70	115.0	152.7	267.7	102.1	P
	180	...	..	139.8	38.6	178.4	12.8	N
	180	(160)	70	188.2	94.2	282.4	116.8	NP
Sacramento, San Joaquin loam, 1958.....	...	...	...	99.4	78.1	177.5	.....	...
	...	(320)	140	136.5	162.7	299.2	121.7	P
	100	(320)	...	141.4	43.1	184.5	7.0	N
	100	(320)	140	194.9	106.0	300.9	123.4	NP

* As ammonium sulfate.

Table 17. Phosphorus Uptake by Grass-Legumes in Forage as Influenced by Nitrogen and Phosphorus Fertilization of Legume-dominant Pasture

County, soil type, and year	Nutrients applied			Phosphorus uptake in:			Increased P	Caused by:
	N*	(P_2O_5)	P	Grass	Legume	Both		
	lb./acre	lb./acre		lb./acre	lb./acre	lb./acre	lb./acre	
Sacramento, San Joaquin loam, 1956.....	...	..	..	7.49	5.78	13.27	.....	...
	...	(80)	35	13.09	9.98	23.07	9.80	P
	200	..	..	11.97	6.29	18.26	4.99	N
	200	(80)	35	17.91	10.22	28.13	14.86	NP
Sacramento, San Joaquin loam, 1957.....	...	...	..	8.24	5.68	13.92	.....	...
	...	(160)	70	16.77	12.74	29.51	15.59	P
	180	...	..	13.67	2.36	16.03	2.11	N
	180	(160)	70	27.04	7.83	34.87	20.95	NP
Sacramento, San Joaquin loam, 1958.....	...	...	...	11.17	5.26	16.43	.....	...
	...	(320)	140	23.82	15.37	39.19	22.76	P
	100	...	...	13.94	2.86	16.80	00.37	N
	100	(320)	140	32.22	9.62	41.84	25.41	NP

* As ammonium sulfate.

In the third and final season of the Sacramento test, recovery of fertilizer nitrogen in the grass and legume fractions remained low. An increasing amount of nitrogen was fixed where phosphorus fertilization had been continued. The increase in harvested nitrogen attributable to phosphorus was distributed both in the greater legume growth and in the associated grasses which benefited indirectly from nitrogen released by the extra clover growth stimulated by phosphorus fertilization.

Results from three separate locations show quite clearly that the continuing use of nitrogen either alone or with phosphorus, on legume-grass pastures, stimulates the grass, drives out the clovers, and thus reduces permanently that portion of the pasture which can and does fix nitrogen for plant use. The continued use of nitrogen fertilizers where a good stand of clovers is present may so change the pasture population as to reduce or eliminate the nitrogen-fixing ability of the pasture and make necessary continued fertilization with nitrogen to keep the remaining grass in a productive state. Phosphorus applied without nitrogen will stimulate clover to fix more nitrogen for the plant community if the soil is deficient in phosphorus. The same high rates of phosphorus, however, will not offset the harmful effects of continued application of nitrogen in reducing the clover population.

Phosphorus recovery is changed by fertilization

The changes in phosphorus uptake by the grass and legume components of the pasture mixture in the three years of the Sacramento test are summarized in table 17. The soil at this location supplied approximately 13 to 16 pounds of phosphorus annually.

In the unfertilized plots, more phosphorus was taken up by the grasses than by the legumes.

Fertilization with nitrogen increased grass growth, with the result that greater amounts of phosphorus were picked up from the soil even though none had been applied. In subsequent seasons progressively less extra phosphorus was "mined" from the soil.

Analyses of samples showed a substantial increase in phosphorus removal each year in plots where phosphate fertilizer had been applied. This removal was about the same whether nitrogen was applied with the phosphorus or not, and amounted to about 28 per cent of the added phosphorus the first year, 22 to 27 per cent the second year, and 16 per cent the third year when considerably higher rates of phosphorus were used.

Measurements on plots heavily fertilized only once in 1956 indicate that from an initial application of 70 pounds of phosphorus (160 P_2O_5), 34 per cent of the added phosphorus was recovered over a period of three years (table 18).

Table 18. Recovery of Residual Phosphorus in Pasture Forage (Sacramento County)

Year	Uptake of phosphorus by forage from:		Increase from fertilization	Recovery
	No P	70 P*		
	lb./acre	lb./acre	lb./acre	per cent
1956	13.26	29.57	16.31	23.3
1957	13.97	19.34	5.37	7.6
1958	16.43	18.55	2.12	3.0
	.....	.....	.....	33.9

* 70 P = 160 lb. P_2O_5. This was applied only once, in 1956.

COST OF FORAGE FROM PASTURE FERTILIZATION

The effectiveness of fertilization was evaluated by calculating the costs per ton of the extra forage resulting from fertilization. The amounts of nitrogen used were charged at 12 cents per pound plus $1 per acre for each application made. The phosphorus used was charged at 11 cents per pound with $1 per acre per application where separate applications were made. It is recognized that additional forage may be valuable in providing extra feed when badly needed, or as a convenience in the ranching operation. It is also recognized that actual nitrogen costs may be somewhat less than those used in this system of evaluation. Results from one location to another should be comparable, however, and the costs of forage produced under the various fertilizer treatments should provide a fair evaluation of the materials employed.

Soils with adequate phosphorus need little help

Results of fertilizer tests on three soils with adequate phosphorus are shown in table 19. Good stands of clover and grass were present and no significant yield responses to added phosphorus were observed.

In each of these tests nitrogen alone was effective in stimulating grass growth, but the extra forage cost from $12 to $45 per ton. In every instance these were first-year results, and stimulation of grass on a short-term basis had not appreciably affected the stand of legumes.

Applying phosphorus to soils already adequately supplied serves no useful purpose, and merely adds to the cost of the pasture operation. Data from two tests in which phosphorus was applied needlessly show that nitrogen and phosphorus combined added greatly to the cost of the total forage with no resulting benefit.

Additional tests not shown here indicated that summer applications of nitrogen may be effective in increasing feed supply from grasses in areas where clover growth may have been slowed during the summer months.

The use of nitrogen fertilizers on legume-dominant pasture appears uneconomical because the extra forage produced is usually quite expensive. In certain situations, however, additional grass may be needed to reduce bloat hazard. Under such circumstances, nitrogen fertilization on a short-term basis may be highly desirable.

Fertilization pays on phosphorus-deficient soils

Fertilizers may greatly increase the yield of forage on phosphorus-deficient soils—sometimes quite economically. Table 20 shows yield increases, cost of fertilization, and unit cost of the extra forage produced for the first year of several fertilizer tests conducted between 1954 and 1957. In most of the tests, both nitrogen and phosphorus were applied alone and in combination. In several tests, two rates of phosphorus alone were compared.

The extra forage provided by the application of straight nitrogen materials to these phosphorus-deficient soils was in every case more expensive than forage produced by the use of both nitrogen and phosphorus. Costs of the extra forage from nitrogen alone varied from $17 to $50 per ton.

The greatest increases in yield were obtained where both nitrogen and phosphorus were employed. The extra forage, 1 to 2 tons per acre, was obtained at a fertilizer cost of $8 to $36 per ton. In three of the four tests with nitrogen-phosphorus treatments the extra forage cost less than $20 per ton. The use of nitrogen and phosphorus treatments on a legume-dominant pasture may offer a practical means of increasing feed supplies on a short-term basis, particularly where extra grass growth is needed.

In these tests, treatments with phosphorus alone produced the lowest cost

Table 19. Cost of Forage from Fertilization with Nitrogen and Phosphorus on Legume-dominant Pastures on Soils with Adequate Phosphorus

County, soil series, and year	Nutrients applied			Yield (dry wt.) of forage (unfertilized)	Increase from fertilization	Fertilizer cost* per acre	Cost per ton of extra forage
	N	(P_2O_5)	P				
	lb./acre	lb./acre		lb./acre	lb./acre		
Yolo, Yolo, 1957	...	...	..	5,680	.....	.....	.....
	80	...	..	.....	1,720	$10.60	$12.32
	120	...	..	.....	2,200	17.40	15.82
	160	...	..	.....	3,900	23.20	11.90
Solano, Solano, 1956	...	...	..	3,563	.....	.....	.....
	...	(100)	44	.....	286	12.00	.....
	150	...	..	.....	1,563	20.00	25.60
	150	(100)	44	.....	1,627	31.00	38.11
Napa, Dublin, 1961	...	...	..	3,126	.....	.....	.....
	...	(80)	35	.....	47	9.80	.....
	80	...	..	.....	465	10.60	45.59
	80	(80)	35	.....	636	19.40	61.00

* N at 12 cents per pound; P_2O_5 at 11 cents per pound ($1 per acre per application).

Table 20. Cost of Forage from Fertilization with Nitrogen and Phosphorus on Legume-dominant Pastures on Phosphorus-deficient Soils (Sacramento and Coastal Valleys)

County, soil series, and year	Nutrients applied			Yield (dry wt.) of forage (unfertilized)	Increase from fertilization	Fertilizer cost* per acre	Cost per ton of extra forage
	N	(P_2O_5)	P				
	lb./acre	lb./acre		lb./acre	lb./acre		
Napa, Coombs, 1954	...	...	..	3,538	.....	.....	.....
	100	(60)	26	.....	4,736	$19.60	$ 8.28
	100	...	..	.....	1,570	13.00	16.77
	...	(60)	26	.....	2,530	7.60	6.00
Placer, Rocklin, 1956	...	...	..	3,155	.....	.....	.....
	150	(80)	35	.....	2,537	21.80	17.19
	...	(80)	35	.....	1,154	9.80	16.98
	...	(160)	70	.....	1,235	18.60	30.12
Sacramento, San Joaquin, 1956	...	...	..	5,804	.....	.....	.....
	200	(80)	35	.....	3,804	37.50	19.71
	200	...	..	.....	1,965	29.00	29.52
	...	(80)	35	.....	2,008	9.80	9.76
	...	(160)	70	.....	2,859	18.60	13.01
Glenn, Tehama, 1957	...	...	..	8,074	.....	.....	.....
	210	(80)	35	.....	2,246	41.00	36.51
	210	...	..	.....	1,284	32.20	50.15
	...	(80)	35	.....	871	9.80	22.53
	...	(160)	70	.....	1,232	18.60	29.43
Solano, Lindsey, 1957	...	...	..	9,009	.....	.....	.....
	...	(80)	35	.....	1,742	9.80	11.25
	...	(160)	70	.....	2,523	18.60	14.74
Solano, Capay, 1956	...	...	..	5,475	.....	.....	.....
	...	(80)	35	.....	509	9.80	38.51
	...	(80)	35	.....	694	18.60	53.60

* N at 12 cents per pound; P_2O_5 at 11 cents per pound ($1 per acre per application).

feed. The unit cost of forage ranged from $6 to $22 per ton where 60 to 80 pounds of phosphorus had been applied. Most of the stimulation was in the legume fraction of the pasture, with the grasses increased to some degree. Fertilization with phosphorus at locations where phosphorus is needed appears to be a very effective way of increasing forage production at a reasonable cost. It may have the disadvantage, however, of increasing bloat hazard on pastures that already have more clover than desirable.

Doubling the rate of phosphorus usually produced somewhat more forage the first season. In every instance, however, the cost of the additional forage produced in the first season was quite expensive, and would not be justifiable unless considerable residual effects were obtained.

Carry-over effects of superphosphate may be important

The residual, or carry-over, effects of a 70-pound (160 P_2O_5) application of phosphorus were measured at one location in Sacramento County (table 21). Results showed an increase of over 2,800 pounds of dry material per acre for the first year, with additional increases of 2,400 pounds over the next two seasons. Fertilizer cost of the extra forage produced the first year was $13 per ton but this was reduced to $7 per ton when increases over the next two seasons were included. These findings indicate that heavier single applications which remain effective for several years are economical.

Table 21. Carry-over Effect of Superphosphate on Forage from Irrigated Pasture (Sacramento County)

Year	Fertilizer	Yield (dry wt.) (unfertilized)	Increase from fertilization		Cost per extra ton of forage
			Annual	Cumulative	
	lb./acre	lb./acre	lb./acre	lb./acre	
1956.....	70 P* (160 P_2O_5)	5,804	2,859	.....	$13.00
1957.....	None	5,963	1,431	4,290	8.67
1958.....	None	6,345	997	5,287	7.00

* Derived from 800 lb. of superphosphate (20 per cent P_2O_5) at a cost of $18 per acre.

THE SAN JOAQUIN VALLEY— GRASS-DOMINANT PASTURES

In these hot valley locations, trefoil or Ladino clover is sometimes planted, but often contribute relatively little to the pasture production. Poor water relations and other adverse conditions usually prevail. Warm-season grasses offer opportunities to use such lands for summer grazing provided enough nitrogen is available for vigorous growth. Fertilizer tests have been carried out at a number of locations where dallisgrass or bermudagrass has been planted for use by grazing animals. These grasses seem well adapted to the high summer temperatures in the San Joaquin Valley. They produce fairly well on alkali or saline soils which are still in the process of reclamation. Similarly, warm-season grasses grow on thin hardpan soils along the edge of the valley where water penetration may be too erratic for sensitive grasses or legumes to produce efficiently.

Under these conditions, vigorous-growing grasses assume dominance. As yet no really well-adapted legumes have been used in fertilizer tests in the area. Nitrogen or nitrogen plus phosphorus treatments have shown most promise for increasing grass growth during the summer months.

Fertilization of Dallisgrass Pastures

In Madera County, an area of irrigated dallisgrass-clover pasture on San Joaquin hardpan soil was selected for clipping tests and grazing trials (table 22). The effect of nitrogen and phosphorus fertilizers on production of both forage and beef was studied. Results illustrate the response often obtained when a legume-grass mixture of this type is fertilized with nitrogen and phosphorus materials. Phosphorus treatments at this location had practically no effect upon the Ladino clover and trefoil harvested throughout the season, although a response might have been expected in view of the low soil analysis value. Nitrogen treatments were quite effective, however, in increasing the amounts of dallisgrass produced. Nitrogen treatments were applied as frequent light applications at the beginning of the season and after every cutting. In this way grass growth was maintained. Nitrogen recovery from this sod was 30 to 40 per cent of that applied.

The nitrogen-supplying power of the untreated soil was about 81 pounds of nitrogen per acre. Most of the nitrogen was in the grass since legumes were only a very minor part of the pasture community, at least as measured by clipping. Nitrogen uptake and forage production were more than doubled by use of nitrogen.

Protein content of the whole forage tended to be low throughout the season because of a preponderance of low-protein grass (table 23). Levels of protein, however, were probably high enough for cattle needs. The protein content was not altered appreciably by phosphorus treatment nor by nitrogen at the rates employed.

A grazing test was also carried out in 1956 on six irrigated pasture fields on the same ranch in Madera County. Weight gains of yearling steers were used to measure results from fertilization. Three fields of 23 acres each were left unfertilized and three fields of 16 acres each were fertilized, in May, with nitrogenous fertilizers sufficient to provide 50 pounds

Table 22. Effect of Nitrogen and Phosphorus on Yield of Dallisgrass-Ladino Pasture*

County, soil type, and year	Nutrients† applied			Yields (dry wt.)			Gain from fertilizer	Fertilizer cost per acre	Fertilizer cost per extra ton of forage
	N	(P_2O_5)	P	Ladino and trefoil	Dallisgrass	Total			
	lb./acre	lb./acre	lb./acre	lb./acre	lb./acre	lb./acre	lb./acre		
Madera, San Joaquin loam, 1957	0	. . .	. .	360	3,995	4,355	. . . . .	. . . . .	. . . . .
	150	. . .	. .	300	7,813‡	8,113‡	3,758‡	$19.00	$10.02
	210	. . .	. .	251	8,766‡	9,017‡	4,662‡	31.20	13.38
	0	(80)	35	429	5,284	5,713	1,358	9.80	14.48
	150	(80)	35	443	6,770‡	7,213‡	2,858‡	28.80	20.15
	210	(80)	35	359	9,388‡	9,747‡	5,392‡	40.20	14.90

* Soil phosphorus = 4.0 p.p.m. HCO_3–P.
† N at 12 cents per pound; P_2O_5 at 11 cents per pound ($1 per acre per application).
‡ Significantly better than control at 5 per cent.

Table 23. Effect of Nitrogen and Phosphorus on Crude Protein in Forage and on Uptake of Nitrogen in Grass-dominant Pasture

County, soil type, and year	Nutrients applied			Crude protein in:			Nitrogen in:			Increase in whole forage from N
	N	(P_2O_5)	P	Ladino and trefoil	Dallis-grass	Whole forage	Ladino and trefoil	Dallis-grass	Whole forage	
	lb./acre	lb./acre		per cent	per cent	per cent	lb./acre	lb./acre	lb./acre	lb./acre
Madera, San	0	...	...	20.6	10.9	11.7	11.9	69.5	81.4	....
Joaquin loam,	150	...	...	21.1	11.4	11.8	10.1	142.1	152.1	70.7
1957	210	...	...	21.4	11.8	12.1	8.6	165.6	174.3	92.9
	0	(80)	35	21.4	11.3	12.0	14.7	95.2	109.9	28.5
	150	(80)	35	21.3	11.4	12.0	15.1	123.3	138.4	57.3
	210	(80)	35	21.3	11.3	11.7	12.2	170.1	182.4	101.0

of nitrogen plus 17 pounds (40 P_2O_5) of phosphorus. Eighty additional pounds of nitrogen in 40-pound increments were applied in July and September. The pastures were primarily of dallisgrass with some Ladino clover and trefoil present. The clipping tests referred to in table 21 were carried out in a fenced exclosure in one of the untreated fields of the grazing trial.

The experimental fields were stocked with yearling steers at rates of 2.7 animals per acre on the unfertilized fields and 4.08 per acre on the fertilized. The fields were grazed on a rotation basis, with animals on each field 7 days, followed by 14 days allowed for recovery.

The fertilized fields gave a beef production of 602 pounds per acre as compared with 324 pounds on the nonfertilized field (table 24). Animals in the fertilized fields gained at a slightly higher rate per day. The beef gains—evaluated at 18 cents per pound—gave a grazing income of $108 per acre on the fertilized fields, as compared with only $58 per acre on the control fields. The profit per acre from fertilization, after deducting cost of material applied, amounted to $23.11.

It will be noted in the clipping test (table 22) that 150 pounds of nitrogen per acre almost doubled grass yields—from 3,995 pounds per acre to 7,813 pounds. Similarly, beef gains were almost doubled—from 324 to 600 pounds. The additional 288 pounds of beef attributable to 145 pounds of nitrogen are equivalent to 1.98 pounds of beef per pound of nitrogen applied.

Grazing and clipping tests in Merced County were also carried out in 1956 on dallisgrass pasture on a heavy clay soil with some alkali spots present to find out whether fertilization with nitrogen and phosphorus might be feasible. Both trefoil and Ladino were present, but grew poorly. Most of the forage production in the summer months was from dallisgrass in the better areas and from bermudagrass around the alkali spots.

The following results show that dry-weight forage yields were much higher with nitrogen plus phosphorus than with nitrogen alone.

FERTILIZER	YIELD OF FORAGE
lb./acre	*lb./acre*
None	1,438
170 N	2,125
170 N + 15 P (35 P_2O_5)	3,412

Two fields (one of which was fertilized with nitrogen and phosphorus) with access to water were selected for the grazing test. Each was divided by cross fences into three smaller fields which were grazed on a rotation basis. The first year's results showed beef production almost doubled on the fertilized fields. With beef evaluated at 18 cents per pound, and nitrogen costing 15 cents per pound, the operation scarcely broke even (table 25).

In the second season, anhydrous ammonia, a lower priced source of nitrogen, was applied at low concentration in the irrigation water during the summer, following a spring treatment with (16–20–0). The lower-cost nitrogen, plus higher-priced beef, returned a profit of $27.63. With low-cost nitrogen, fertilization of dallisgrass pastures appears economically feasible at this location.

Some hay or barley supplement was required to maintain daily gains of cattle at desired levels on pasture of this type.

Fertilized Coastal Bermudagrass Showed High Nitrogen Recovery

Results from a demonstration on fertilized coastal bermudagrass in Kings County show a large increase in growth as a result of frequent but low nitrogen applications (table 26). In this test, 150 pounds of nitrogen per acre, applied in five 30-pound increments, gave a yield increase of approximately 3⅓ tons for a fertilizer cost of only $8 per extra ton if the nitrogen was figured at 12 cents per pound. The additional nitrogen harvested from the forage amounted to 134 per cent of the amount applied. This apparent recovery implies that fertilized grasses have the ability to forage more deeply and to "mine" nitrogen and exploit more soil than do unfertilized grasses. The economics of fertilizing a pasture of this type is quite encouraging because the extra forage is probably worth considerably more than the nitrogen required to produce it. With forage at $15 per ton, the point of maxi-

Table 24. Results of Irrigated Pasture Fertilization* on the Basis of Cattle Gains (Madera County, May 8 to September 26, 1956)

Factor	Unfertilized pasture	Fertilized pasture
Number of acres	70	50
Average number of yearling steers per acre	2.70	4.08
Average weight of steers at start of test	494 lb.	480 lb.
Average weight of steers at end of test	617 lb.	640 lb.
Days pastured	103 to 141	103 to 141
Average total gain per head	123 lb.	160 lb.
Average daily gain per head	0.93 lb.	1.18 lb.
Average production of beef per acre	324 lb.	602 lb.
Value of beef produced per acre at 18 cents/lb.	$ 58.34	$108.36
Value of additional beef produced per acre		$ 50.02
Cost of fertilizer applied per acre		$ 26.20
Interest per acre on fertilizer investment at 6 per cent		$ 00.71
Profit per acre from fertilization		$ 23.11

* Fertilizer applied:
May 2, 1956:
200 lb. 20–20–0 per acre.
100 lb. ammonium sulfate per acre.
July 6, 1956:
200 lb. ammonium sulfate per acre.

mum profit would be about 200 pounds of nitrogen per acre.

It should also be noted that the protein content of the forage was increased with each added increment of nitrogen. However, probably no real advantage in forage quality would result from the higher rates of nitrogen.

Table 25. Results of Irrigated Pasture Fertilization* on the Basis of Cattle Gains (Merced County, 1956 and 1957)

Factor	1956 129 days (5/28–10/4)		1957 162 days (4/9–9/18)	
	Untreated pasture	Fertilized pasture	Untreated pasture	Fertilized pasture
Stocking rate (average animals per acre)	1.45	2.30	1.45	2.30
Average daily gain (lb.)	1.02	1.08	1.11	1.20
Production of beef per acre (lb.)	194	322	261	446
Increase due to fertilizer (lb.)	......	128	......	185
Value of beef per pound	$00.18	$00.18	$00.20.5	$ 00.20.5
Value of beef per acre	$35.00	$58.00	$53.50	$ 91.43
Cost of hay fed	$00.50	$ 1.50	$ 1.00	$ 1.50
Value of extra pasture per acre	......	$ 6.00	$ 3.80	$ 18.00
Total grazing income per acre	$35.00	$64.00	$57.30	$109.43
Cost of fertilizer	......	$29.50	......	$ 24.50
Profit or loss from fertilization	......	−$00.50	......	$ 27.14

* Fertilizer applied (1956)

May	N_{70} + P_{15} from (20–10–0)
July	N_{40} urea
August	N_{60} urea
Total	N_{170} + 15P (35 P_2O_5)

Fertilizer applied (1957)

March	N_{40} + P_{22} from (16–20–0)
Summer	N_{115} from NH_3 in 10 irrigations
Total	N_{155} + 22 P(50 P_2O_5)

Table 26. Effect of Fertilization on Yield, Quality, and Cost of Coastal Bermudagrass Pasture Forage (Kings County, 1962, six cuttings)

Fertilizer applications (lb. per acre)	Yield (dry wt.)	Fertilizer cost	Fertilizer cost per extra ton forage	Crude protein	Nitrogen recovery	
					In forage	As per cent of N applied
	tons/acre			per cent	lb./acre	
None	4.25	.....	.....	11.9	163	...
30 × 5 = 150 N	7.58	$26.50	$ 7.96	15.5	361	134
60 × 5 = 300 N	7.98	46.75	12.53	16.6	420	87
120 × 5 = 600 N	9.25	87.25	17.45	18.6	549	65

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