

# Long-term Effects of Fertilization and Subclover Seeding on Northern California Annual Range

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## Abstract

The long-term effects of P and S fertilizers and subclover seeding on northern California annual range production and composition were measured during a 20-year study. Following an initial calibration period, two pastures were seeded and fertilized; pasture A prior to the 1968 growing season and pasture B prior to the 1973 growing season. After treatment pasture A produced significantly more forage annually. It also produced significantly more winter forage, and winter and annual forage N than either of two adjacent untreated control pastures during the period from 1973 to 1979. This was due primarily to an increase in native legumes because subclover averaged only 7% of cover. Treatment on pasture B gave similar responses, but the relative increases in forage production were larger (annual production increased about 2,000 kg/ha compared to 1,200 kg/ha on pasture A), and winter forage N concentrations were significantly higher than on pasture A. This was due to the greater subclover component (36%) on pasture B. The significant increases in forage production and protein indicate that subclover seeding and appropriate fertilization are practical ways of improving utilization of northern California annual range.

Rangeland, most of it dominated by annual herbaceous species, occupies an estimated 14.5 million hectares in California and supplies about 60% of the total feed required for meat animals produced on the state's farms and ranches (Reed 1974). Despite the obvious importance of annual rangeland to the livestock industry, much of it is characterized by low forage productivity, particularly during winter, and low summer forage quality (Murphy et al. 1973). With increasing demands being made on the available land-based resources, it would appear that increasing, or even sustaining, present livestock production levels will certainly require more intensive management programs.

Much of the possibility for intensifying the utilization of available range is in the potentially more productive annual grasslands and annual grass-woodlands. Early experiments indicated that P and S fertilizers increased forage production and improved the

quality of resident annual pastures deficient in these nutrients (Conrad 1950, Williams et al. 1956, Bentley et al. 1958). A major part of this response was due to stimulation of growth by annual legumes, and significant residual effects have been observed for several years following P and S applications (Jones 1974). Nursery trials throughout California (Jones and Love 1945) indicated that the introduced annual, subterranean clover (*Trifolium subterraneum* L., commonly referred to as subclover) was widely adapted. Early attempts at establishing good persistent stands of subclover were difficult because of management and inoculation problems. Many of these problems have subsequently been resolved (Jones et al. 1978). The nutritional advantages of subclover-annual grass pastures compared to resident annual pastures are well documented (Torrell et al. 1972, Jones 1974). In reviewing early studies, Love (1967) estimated that the 12 million hectares of California annual grassland, or potential annual grassland, could be made three to four times more productive by fertilizing and seeding with improved plant species.

While these important nursery and fertility trials established that considerable potential did not exist for improving the productivity of annual grassland, they were largely feasibility investigations conducted mostly on small plots for relatively short periods. Large fluctuations in production and botanical composition were also observed to result from changes in annual weather patterns (Talbot et al. 1939) and such site variables as soil capability, slope, and exposure (Bentley and Talbot 1951, Biswell 1956). This made it important that investigations be extended to long-term studies on annual pastures of agriculturally practical size. A study on the long-term effects of seeding and fertilizing on California annual grassland productivity and composition was conducted on the research facilities at the University of California Hopland Field Station.

## Methods

This 20-year study was conducted in north-coastal California, 160 km north of San Francisco on the University of California Hopland Field Station. The climate has been described as Mediterranean or subhumid to humid mesothermal (Gowans 1958). Rainfall averages 90 cm annually, mostly received between October and

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The authors would like to thank Dr. M. B. Jones and Dr. R. M. Love for manuscript review, Dr. D. M. Center for help with statistics, and Mr. B. San Diego for assistance with sampling.

May. The herbaceous vegetation is dominated by annuals.

The 115-ha experimental area was divided into four pastures (designated pastures A, B, C, and D), which shared a common corner. These pastures had been grazed regularly by sheep since 1952. The soils were described as upland, predominantly medium-textured, overlying sandstones and shales of the Franciscan Formation (Gowans 1958). Elevations ranged from 240 to 460 m. All pastures had southwest exposures with mostly moderate slopes (0–30%).

The study was divided into three treatment periods. The 8 years from 1960 to 1967 comprised the calibration period. Botanical composition and both winter and annual production on the unimproved pastures were calibrated during this first period. The second period began in the fall of 1967 when pasture A was drill-seeded with inoculated, lime-pelleted (Jones et al. 1978) subclover seed (cultivar 'Mt. Barker') at the rate of 13.5 kg/ha. The pasture was also fertilized at planting and again in the fall of 1968 and 1969. Phosphorus and S were applied because soils in the area are commonly deficient in these nutrients. Fertilization dates, sources, and rates are shown in Table 1. The effects of this first improvement program were measured over the next five growing seasons (1968–1972). The third treatment period began in the fall of 1972. Pasture B was fertilized and seeded with a mixture of subclover cultivars 'Mt. Barker', 'Geraldton', 'Dinninup', and 'Wooenellup' at the rate of 20 kg/ha. Both pastures A and B also received follow-up fertilizer treatments (Table 1). In addition, pasture A was reseeded in the fall of 1976 to improve the subclover stand. The seeding was a mixture of cultivars 'Geraldton', 'Dinninup', and 'Wooenellup' at the rate of 20 kg/ha. During the final seven growing seasons (1973–1979), the relative effects of these treatments on pasture production, composition, and herbage N content were determined.

**Table 1.** Fertilizer application dates, sources, and rates used on the improved pastures A and B.

Date applied	Fertilizer source	Application rates (kg/ha)			
		Pasture A		Pasture B	
		P	S	P	S
10/67	SSP <sup>1</sup>	31	42	—	—
9/68	SSP	38	50	—	—
10/69	Soil S	—	90	—	—
9/72	SSP	—	—	28	38
10/72	GTP <sup>2</sup> +NaP <sup>3</sup> +Soil S	17	54	—	—
9/74	SSP	—	—	18	24
9/76	SSP	9	12	20	26
10/78	TSP <sup>4</sup> +Soil S	18	90	19	97

<sup>1</sup>Single superphosphate

<sup>2</sup>"Golden treble" (sulfur-fortified treble superphosphate)

<sup>3</sup>Trisodium phosphate

<sup>4</sup>Treble superphosphate

Twenty 1-m diameter wire mesh enclosures were distributed in the grazed areas of each pasture. Forage production was measured in the winter (February) and at the end of each growing season (May) by clipping a 0.1-m<sup>2</sup> quadrat of herbage at ground surface from within each enclosure and from a similar adjacent grazed area. Clipped herbage was oven-dried at 60° C and weighed. The enclosures were moved after each clipping within small, botanically similar sampling areas to avoid repeatedly sampling the same location (Pitt and Heady 1979). Botanical composition was determined at the May sampling date by a modification of the step-point method of Evans and Love (1957). Fifteen points were taken in each sampling area and 300 points in each pasture. Nitrogen was determined on the 1973–1979 herbage by micro-Kjeldahl analysis. Because the enclosures could not truly be considered as replications, mean comparisons were done by Student's "t"-test. Botanical composition percentages were first subjected to arcsin√% transformation.

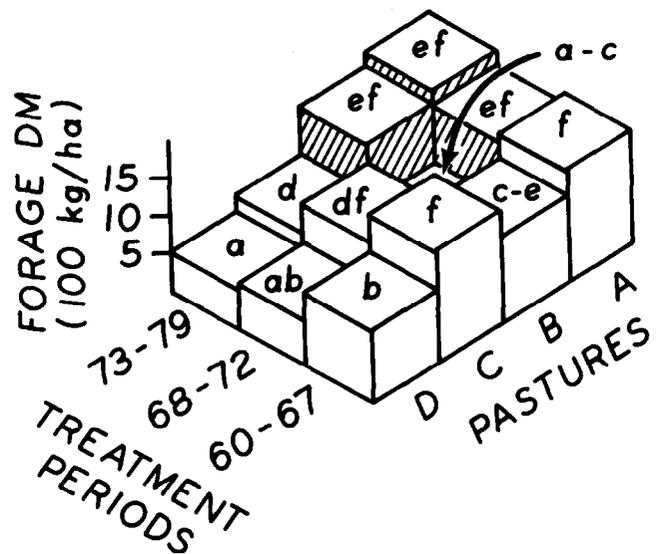
Beginning in 1959, the pastures were continuously grazed by

sheep. Stocking rates were kept moderate to minimize stress to the animals, averaging about 310 sheep/ha/year on a whole-pasture basis. This varied from year-to-year, both within and between pastures, and was adjusted to utilize available feed. Pitt and Heady (1979) observed that only very heavy sheep grazing rates, where the animals were under stress, produced any significant residual impacts on annual forage production and botanical composition. They concluded, however, that these impacts were short-term and managerially insignificant. Such heavy intensity was not a factor in this study, and it was assumed that the effects of grazing rate differences were insignificant in comparison to the impacts of pasture improvement and weather.

## Results and Discussion

### Winter Forage Production

The effects of seeding and fertilization on winter forage production are illustrated in Figure 1. Winter production on the unimproved control pastures C and D declined after the 1960–1967 calibration period and was significantly lower on both pastures by the 1973–1979 treatment period (Fig. 1). A decrease was also observed on pasture B during the 1968–1972 period, before this pasture received any improvements. Previous observations from 1955 to 1958 on these same pastures indicated that average winter forage production was about 700 kg/ha (Jones et al. 1957, Murphy et al. 1961). This suggests that the higher winter production (1940–1,460 kg/ha) observed during the calibration period of this study was likely due to more favorable winter weather conditions in the 7 years from 1960 to 1967. There was no similar decline in winter productivity on pasture A, however, which was seeded and fertilized prior to the 1968 growing season, and there was a significant increase in production on pasture B after treatment (Fig. 1). During the final period of the study (1973–1979) winter forage yields were significantly higher on both these treated pastures than either of the unimproved pastures.



**Fig. 1.** Mean winter forage dry matter (DM) production on four California annual pastures. Shaded columns indicate production after P and S fertilization and seeding subclover. Means within treatment periods and pastures (reading horizontally and vertically) followed by the same letter are not significantly different ( $P < 0.05$ ) according to Student's "t" test.

These results indicate that fertilized subclover-grass pastures increased in forage production during the critical winter lambing season, and also minimized the between-year production variation so common on annual pastures in California's Mediterranean-type climate (Heady and Pitt 1979). Love and Williams (1956) suggested this as a benefit of pasture improvement, but after only 4 years' observations.

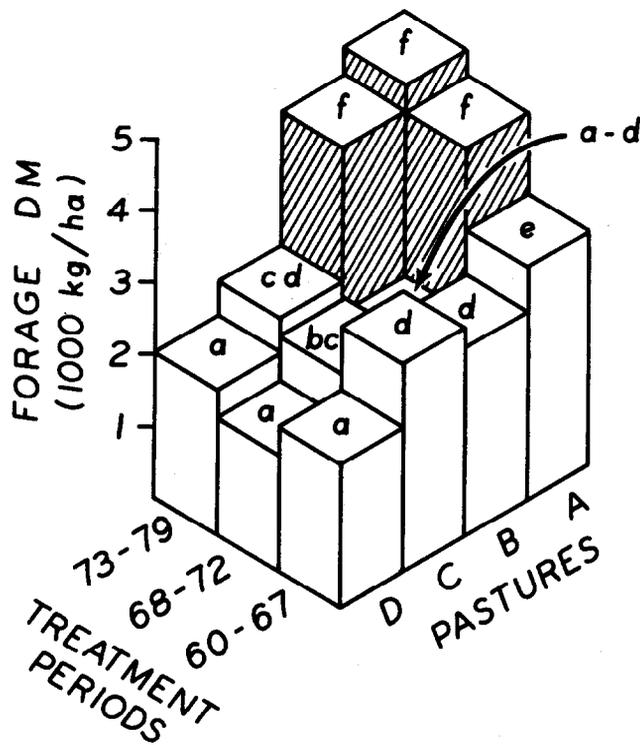


Fig. 2. Mean annual forage dry matter (DM) production on four California annual pastures. Shaded columns indicate production after P and S fertilization and seeding subclover. Means within treatment periods and pastures (reading horizontally and vertically) followed by the same letter are not significantly different ( $P < 0.05$ ) according to Student's "t" test.

### Annual Forage Production

Figure 2 shows the effects of pasture improvements on total annual forage production. Unlike winter production, total annual production on the unimproved pastures did not decline. This supports the conclusion that the winter forage production declines were due to more favorable early-season growing conditions during the calibration period of the study. Seeding and fertilization increased annual production more than winter production. Both pastures A and B were significantly more productive after improvement, and they were also significantly more productive than the unimproved pastures C and D (Fig. 2). Annual production increases averaged about 1,200 kg/ha on pastures A, compared to about 2,000 kg/ha on pasture (Fig. 2). This may have been due partly to the fact that pasture A was the most productive pasture during the calibration period ( $P < 0.05$ ), and was therefore less response to fertilization and seeding. Pasture B had lower inherent productivity and more dramatic response to improvement.

### Nitrogen Content

Herbage N uptake and concentration were measured during 1973-1979 (Table 2). It appeared that the benefits of the pasture improvements were better reflected in forage quality than production. While seeding and fertilizing about doubled winter forage production during the period from 1973 to 1979 (Fig. 1), the average N uptake of this forage was at least tripled in comparison to the untreated pastures C and D (Table 2). This was due to the significantly higher herbage N concentrations on the improved pastures. The effects on annual forage quality were similar, again because of significantly higher herbage N concentrations on the improved pastures. Similar responses to P and S fertilizers have been observed in previous studies (Jones 1974) and it was suggested that the effects were due largely to the stimulation of growth by legumes, both seeded and native. These late-season increases in N content (representing about 11% crude protein) are extremely

Table 2. Winter and annual mean herbage N uptake and concentration on four California annual pastures during the period 1973-1979.

Pasture <sup>1</sup>	Winter		Annual	
	N uptake (kg/ha)	N concentration (%)	N uptake (kg/ha)	N concentration (%)
A	40.0c <sup>2</sup>	2.80b	92.7c	1.70b
B	43.1c	3.31c	96.3c	1.84b
C	16.9b	2.15a	40.8b	1.43a
D	11.1a	2.17a	29.3a	1.42a

<sup>1</sup>Pastures A and B were previously by fertilized with P and S and seeded with subclover.

<sup>2</sup>Means within columns followed by the same letter are not significantly different ( $P < 0.05$ ) according to Student's "t" test.

important on California annual range where summer forage protein is often below livestock maintenance levels. It has been demonstrated that summer protein content on well-managed subclover-annual grass pastures can be adequate for animal needs (Jones 1974).

### Botanical Composition

The effect of pasture improvement on percentage botanical composition is summarized in Table 3. Individual species were not considered of managerial importance, and have therefore been included in larger vegetative groups on the basis of forage value and botanical similarity (Love 1954). The desirable annual grasses included soft chess (*Bromus mollis*) and slender oat (*Avena barbata*). Undesirable annual grasses (less palatable and of lower forage value) on these pastures were dominated by silver hairgrass (*Aira caryophylla*), annual fescues (*Festuca* spp.), and medusa-head (*Taeniatherum asperum*). The miscellaneous forbs included primarily filaree (*Erodium* spp.) and the native legumes, mainly true clovers (*Trifolium* spp.).

Table 3. Botanical composition (%) of two California annual pastures before and after subclover seeding and P and S fertilization treatments.

	Desirable annual grasses	Undesirable annual grasses	Misc. forbs	Native legumes	Subclover
Pasture A					
Pre-treatment (1960-1967)	32	13	39	16	0
Post-treatment (1968-1979)	21	26	22	23	7
t (df=18)	2.839* <sup>1</sup>	6.438** <sup>2</sup>	5.454**	1.911 <sup>NS</sup> <sub>3</sub>	
Pasture B					
Pre-treatment (1960-1972)	20	16	53	11	0
Post-treatment (1973-1979)	16	15	21	12	36
t (df=18)	0.996 <sup>NS</sup>	0.690 <sup>NS</sup>	8.893**	0.579 <sup>NS</sup>	

<sup>1</sup>\* $P < 0.05$

<sup>2</sup>\*\* $P < 0.01$

<sup>3</sup><sup>NS</sup>Not significant

Pitt and Heady (1978) observed that weather patterns have significant influence on botanical composition on annual range. Annual changes due to temperature and rainfall fluctuations might partially mask the effects of pasture improvement. However, by comparing the improved pastures A and B to the unimproved control pastures C and D during similar time periods, trends in botanical composition due to seeding and fertilizing should be apparent.

Despite large between-year variation, there were only two significant ( $P < 0.05$ ) trends in botanical composition change observed on pastures C and D. Undesirable annual grasses increased on both

pastures from 1960–1967 calibration period to the 1968–1979 period from (18 to 26% and 17 to 22% on pastures C and D respectively) and native legumes decreased from 18 to 11% on pasture C during the same period. It would appear that these trends were primarily due to different weather patterns during the study periods. For this reason, the increase in undesirable annual grasses observed on pasture A (Table 3) was probably as much a result of weather patterns as seeding and fertilizing.

It was obvious from the botanical composition data that a much better subclover stand developed on pasture B where vegetative cover averaged 36% subclover after seeding and fertilizing. The relatively poor subclover growth on pasture A (7% of vegetative cover) was probably a result of several factors: poor commercially available rhizobia on the first seeding (Jones et al. 1978); competition from ineffective native rhizobia associated with the large native legume population (Table 3); and an historically unprecedented two-year drought (City of Ukiah Fire Department-unpublished records) which coincided with the second seeding on pasture A in 1976. The larger component of subcover on pasture B quite likely contributed to the significantly higher winter herbage N concentrations observed from 1973 to 1979 (Table 2), and also helps to explain the more dramatic winter and annual production increases on this pasture following treatment (Fig. 1 and 2). A previous study (Vaughn and Jones 1976) also indicated that fertilization resulted in greater forage production and N uptake by subclover compared to five locally common species of native clovers. It would also appear that the successful seeding program had the beneficial effect of at least partially suppressing the increases in percentage composition of undesirable annual grasses which was observed on the other three pastures.

The subclover stand on pasture A was not good, but fertilization resulted in a large increase in native legumes (significant at  $P < 0.06$ ), so that total legum cover averaged 30% after treatment (Table 3). This was an important contribution to the significantly higher herbage N values observed on pasture A compared to the unimproved pastures C and D (Table 2).

It is likely that the significant post-treatment declines in miscellaneous forbs (primarily filaree) observed on both pastures A and B were a result of lusher, taller growth being stimulated by fertilization. Bentley et al. (1958) observed a similar significant decline in forbs, dominated by broad-leaved filaree (*Erodium botrys*), following the application of S fertilizers, and Pitt and Heady (1979) reported that filaree declined when taller annual plants were favored.

The decrease in desirable annual grasses on pasture A may have resulted from P and S fertilization. Williams et al. (1956) reported that superphosphate fertilizers increased legume growth at the expense of the resident annual species, which consisted mainly of broad-leaved filaree, and the desirable annual grasses wild oat (*Avena fatua*) and soft chess. While these shifts in botanical composition on the improved pastures were the result of complex annual environmental variables (Pitt and Heady 1978), it appears that they were primarily a function of the relative ability of each species to compete for the added nutrients.

### Summary and Conclusions

This long-term study indicated that seeding subclover and fertilizing with P and S were both of benefit on annual grassland pastures. Taking into account the poor subclover stand on pasture A, it would appear that fertilization accounted for essentially all of the post-treatment increase in annual forage production (Fig. 2) and winter and spring forage N content (Table 2) observed on this pasture. This was apparently due to the stimulation of native legume growth (Table 3). The results on improved pasture B were similar, but the relative increase in forage production were larger and winter forage N concentrations were significantly higher (Table 2). This was probably due to the much larger percentage of sub-

clover on pasture B (Table 3). The benefits of subclover growth were even more striking in view of the fact that pasture B had significantly lower productivity than did pasture A during the 1960–1967 calibration period (Figs. 1 and 2).

These increases in winter forage production and spring forage quality are particularly important for sheep management on California annual pastures. Lambing generally occurs during late fall and early winter, normally a season of low forage production on unimproved range. And while summer forage dry matter may be adequate, it is usually below maintenance protein levels. The results of this study suggest that planting the self-reseeding subclover, accompanied by appropriate fertilization and good inoculation, is a practical way of improving productivity and utilization of annual upland pastures in north-coastal California.

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