Influence of Natural Mulch on Forage Production on Differing California Annual Range Sites

JAMES W. BARTOLOME, MICHAEL C. STROUD, AND HAROLD F. HEADY

Abstract

Manipulation of natural mulch on nine experimental plots in California annual grassland representing a range of mean annual precipitation from 160 to 16 cm provided information useful for grazing management. Peak standing crop correlated highly significantly with precipitation. Response of peak standing crop to five levels of natural mulch ranging from zero to 1,120 kg/ha differed with site. Three types of sites distinguished by mean annual precipitation and plant species composition were identified. On sites with significant numbers of perennial grasses and more than 150 cm of mean annual precipitation, maximum standing crop is reached when more than 1,120 kg/ha of mulch is present on the ground at the beginning of the fall growing season. Peak standing crop results from 840 kg/ha of mulch on sites containing the annuals *Bromus mollis* and *Erodium botrys* and with between 100 and 65 cm of mean annual precipitation. Mulch did not significantly influence standing crop in regions dominated by *Bromus rubens* and *Erodium cicutarium* and receiving less than 25 cm of mean annual precipitation. Annual grassland response to mulch and grazing is highly site specific, yet the resilience of annual rangelands also allows rapid recovery from overuse.

A distinctive combination of use by people and the influence of geography and climate fostered the formation of the present California annual grassland. The vegetation is dominated primarily by annual grasses of Mediterranean origin, which replaced the native bunchgrasses during the 19th century. Reflecting the diverse geography of the state, the California annual grassland varies in productivity, component species, and the degree of replacement of the native plants by aliens. The climate, although generally typically Mediterrean with cool wet winters and dry summers, varies for example, in average annual rainfall, from nearly 200 cm (80 inches) in the North Coast to less than 15 cm (6 inches) in the rainshadow of the South Coast ranges.

The growth of vegetation follows a characteristic pattern. In response to fall rains, plants establish from seed produced the previous spring. Slow vegetative growth and root development in the cool winter months are followed by rapid growth with warming temperatures in spring. Maximum annual standing crop generally occurs in late spring. In summer only the seeds are left as living agents to repeat this process again in the fall.

The authors are lecturer and associate specialist, Department of Forestry and Resource Management, University of California, Berkeley, 94720; conservationist (civilian), Department of the Navy, Western Div., Naval Facilities Engineering Command, San Bruno, California 94066; and assistant vice president, Division of Agricultural Sciences, University of California, Berkeley 94720.

Glen D. Savelle established and experimental plots and carried out the initial treatments and sampling. Michael D. Pitt contributed significantly to later sampling and plot manipulation. The cooperation of private and public landholders is gratefully acknowledged.

Manuscript received November 20, 1978.

Much of California's range livestock industry relies on the yearly rejuvenating capability of the annual range. Indeed, most of California's big game and upland wildlife populations rely on the annual forage crop for significant portions of their diet. The future of these valuable resources and capital investments need not be wholly entrusted to the whims of nature's erratically patterned and oftentimes meager rainfall. The purpose of this study was to show how prudent and knowledgeable seasonal management of the mulch layer in conjunction with an understanding of site differences over California's 6 million hectares of annual range can significantly influence the subsequent year's forage production.

The 6 million hectares of grassland in California (Barbour and Major 1977) extend nearly the entire length of the state. Stand composition and productivity vary considerably over the grassland. Munz and Keck (1949) divided the grassland into two plant communities, the Coastal Prairie and the Valley Grassland. Küchler's (1964) Fescue-Oatgrass and California Steppe vegetation types as updated into Coastal Prairie-Scrub Mosaic and Valley grassland (Küchler 1977) retain the basic divisions of Munz and Keck.

Detailed descriptions of species composition within the annual grassland remain scarce. Burcham (1975) reported abundance of annual grassland species from 38 plots in the Sierra foothills from Sacramento to Madera County and in the Coast ranges from Santa Clara to Monterey County. Species of *Bromus* and *Erodium* exhibited a high degree of constancy. Soft chess (*Bromus mollis*) formed a significant amount of the vegetative cover on 30 plots and was absent on only one plot. Ripgut brome (*Bromus rigidus*), although a significant percentage of the cover on only one plot, occurred on 21 plots. *Erodium* species were present on 31 plots, forming a significant portion of the cover on 28 plots.

Janes (1969) sampled species composition on the western side of the Central Valley and in the North Coast ranges along an average annual precipitation gradient ranging from 12.5 to 200 cm and also showed soft chess to be the most widely distributed annual grassland species. Janes encountered 124 species at his 20 sample locations, yet only seven species occurred at more than four locations. Soft chess occurred at 15 sites, ripgut brome at 11 sites, and broad-leaved filaree (*Erodium botrys*) at 7 sites. Janes' study in the spring of 1969 remains the only comprehensive survey of geographical variation in the annual grassland.

Understanding site variation in annual grassland is necessary for effective management. Composition and productivity of annual ranges vary remarkably between and within years.

Talbot et al. (1939) and Bentley and Talbot (1951) provided several years of data on yearly variations in composition and production of annual grassland at the U.S. Forest Service-operated San Joaquin Experimental Range (50 km north of Fresno), a site with continuous documentation since the early 1930's (Duncan and Woodmansee 1975). Composition and productivity at the University of California's Hopland Field Station has been monitored since the early 1950's with documentation of variations within the year (Heady 1958; Bartolome 1978; Savelle 1977) and yearly long-term production and composition (Murphy 1970; Pitt and Heady 1978) in relation to weather patterns. Consideration of sites apart from the San Joaquin Range and Hopland are few, including Evans et al. (1975) at the University of California's Sierra Foothill Range 100 km north of Sacramento, Batzli and Pitelka (1970), and Raliff and Heady (1962) near San Francisco Bay in Alameda County.

The impacts of grazing by livestock on annual grassland have not often been directly investigated. Elliot and Wehausen (1974) examined response of coastal prairie species to grazing on Point Reyes. A long-term grazing study at the San Joaquin Experimental Range enabled the development of management guidelines for annual range (Bentley and Talbot 1951). Hedrick (1948) also looked at the effects of grazing intensity on annual range. Most of the response of annual grassland species to grazing has been inferred from experiments simulating grazing through the removal of varying amounts of plant residue or mulch (Talbot et al. 1939; Heady 1956). Experiments at Hopland showed a response of the grassland to mulch manipulation similar to that which would be expected under livestock grazing (Heady 1961). These results were extended to a discussion of economic factors (Hooper and Heady 1970) involved in intensity of mulch removal on annual grassland. Mechanisms explaining the effects of mulch have not been demonstrated, but several factors probably are important. Soil organic matter and bulk density are both improved with increasing amounts of mulch, but only in the upper few inches of the soil (Heady 1966). Mulch protects the soil surface from erosion and provides a favorable environment for plant growth.

Fig. 1. *Map of California showing location of nine study plots.*

Several authors have ascribed the differences in botanical composition due to manipulation of mulch to the effect on plant establishment (Bartolome 1978; Evans and Young 1970; Tinnin and Muller 1971).

Methods

Figure 1 shows the locations of the nine plots in relation to major cities in California. A summary of specific site information on location, geography, rainfall, and soils is provided in Table 1. The plot sites were chosen to represent differing climatic types that support significant portions of the California annual range type.

The experimental treatments consisted of removal of mulch or plant residue to a fixed, predetermined level. Mulch manipulations were applied in late summer or early fall prior to the onset of the rainy season. Since the first rains of the season stimulating fall germination

Table 1. Location, geography, rainfall, and soils information for the study plots.

Plot number	Plot name (county)	Type of ownership	Cm of Average annual rainfall: Long term	Cm of Average annual rainfall: Study period	Elevation (M)	Latitude	Soil texture	Soil depth (M)
1	May Ranch (Humboldt)	Private	150	155	640	40° 25'N	Clay loam	1-1.2
2	Bear River Ridge (Humboldt)	Private	150	177	670	40° 30'N	Clay loam	1-1.2
3	Albee Ranch (Humboldt)	Private	160	144	550	40° 20'N	Loam	0.6-1
4	Hopland Field Station (Mendocino)	University of California	100	96	305	39° 00'N	Fine sandy loam	0.6-1
5	Jeffers Ranch (Tehama)	Private	65	62	365	39° 55'N	Light clay loam	0.3-0.6
6	Russell Reservation (Contra Costa)	University of California	65	65	215	37° 50'N	Clay	1.5-1.8
7	Panoche Hills (Fresno)	Bureau of Land Management	20	24	455	36° 40'N	Sandy loam	0.3-0.6
8	Kettleman Hills (Fresno)	Bureau of Land Management	16	17	215	36° 05'N	Fine sandy	0.6-1
9	Temblor Range (San Luis Obispo)	Bureau of Land Management	20	21	760	35° 00'N	Sandy loam	0.3-0.6

Fig. 2. *Study plot 3 (Albee Ranch) after manipulation in fall of 1970.*

usually come earlier at the northern most plots, these were manipulated first. Mulch treatments were applied to the other plots in essentially their numbered order. Mulch manipulation treatments were intended to be applied to each plot for five successive years. Treatments were initiated on plots 1, 2, 4, and 5 in the fall of 1967, on plots 3 and 6 in the fall of 1968, and on plots 7,8, and 9 in the fall of 1969. Treatments continued for only 3 years on plots 7, 8, and 9.

Treatment squares were 3 by 3 meters (10 × 10 ft) and arranged in a 5 × 5 latin square (five replications of five treatments). The square was mowed to a uniform stubble height of about 10 cm, then clipped by hand to establish the desired quantity of mulch. Treatment levels measured "zero," 280, 560, 840, and 1,120 oven-dry kg per hectare (0, 250, 500, 750, 1000 lb/acre) of mulch remaining (Fig. 2). Each square received the same treatment each year throughout the study period. After handclipping to approximately the desired level, two 30 × 30 cm (1-foot square) samples were clipped to ground level and weighed. Addition or subtraction of mulch resulted in the desired residue plus or minus an allowable error of 10%. Care was taken to avoid disturbing the soil surface, thus the treatment of "zero" pounds per acre represents a slightly greater amount. The "zero" mulch treatments constituted the base or standard for the other treatments. That is, the 280 kg treatment was applied on top of the small, comparable amount that remained in the "zero" plots. After all adjustments had been made, a 30 × 30 cm (sq. ft.) sample was taken and returned to the laboratory to determine the actual moisture-free amount of mulch applied. This amount was usually within a range of 25 kg per hectare on either side of the prescribed treatment.

Once a year at or near the time of maximum biomass (mid-April in the south to mid-June in the north), samples were clipped and oven dried to determine standing crop, the most convenient estimate of plant productivity. Recorded locations of all clipped samples prevented resampling the same square foot in subsequent years. The treatment squares were sampled for species composition and plant foliar cover, using the New Zealand-developed ten-point frame (Heady and Rader 1958). Species composition, indicated by the first hit, was measured in the middle of the treatment square where herbage samples were never taken. Species chosen for detailed discussion below comprise important plant groups both from the standpoint of forage production and as indicators of the overall variation in botanical composition throughout the annual grassland.

Site Classification

Location of the nine study plots reflected estimated average annual precipitation along a mean annual precipitation gradient from 160 to 16 cm. Therefore average rainfall forms the first measure of site variation between plots and constitutes the major variable explaining variation in peak standing crop and total vegetative cover as determined by regression analysis (Table 2). The linear correlation between average annual precipitation and standing crop ($r = 0.7572$) is somewhat better below 100 cm mean annual precipitation (Fig. 3). Although rainfall increased 60% between Hopland (Site 4) and Albee Ranch (Site 3) for example, standing crop increased only about 20%. This result suggests that effective rainfall, resulting in increased plant growth, drops off above approximately 100 cm. Cover shows a response similar to that of standing crop.

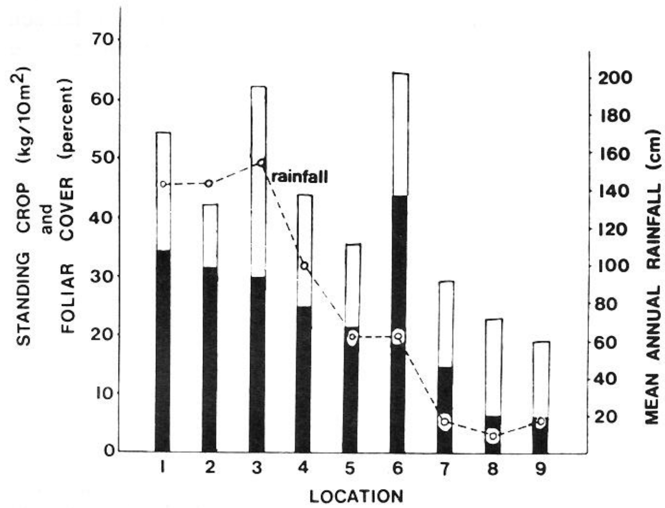

Fig. 3. *Relationship between spring peak standing crop, foliar cover, location, and mean annual precipitation. Results summarize 5 consecutive years for plots 1-6, 3 consecutive years for plots 7-9. The black portion of the bar represents standing crop.*

Species composition reflects the components of productivity on a site. Forage composition may be considered a further refinement of site characteristics as manifested in the vegetation. Although the flora of an individual study plot often included 50 or more species, five species groups will be discussed in this section. Figure 4 gives an example of variation in species composition at different locations. The most striking discontinuity in species distribution involves the replacement of soft chess and broad-leaved filaree with red brome (*Bromus rubens*) and red-stem filaree (*Erodium cicutarium*), respectively, on the three driest sites (plots 7-9), all with 25 cm or less of annual rainfall. Plots 4 and 5, receiving 100 and 65 cm mean annual precipitation, respectively, are both characterized by broad-leaved filaree, soft chess, and few or no perennial grasses. Site 6 contained no filaree species and was the only site with annual barley (*Hordeum*) species. The three wettest sites (plots 1-3) with greater than 150 cm

Table 2. Summary of multiple regression for the dependent variable "peak standing crop."

Independent variable	F to enter or remove	Significance	Multiple R	R^2	R^2 change	Simple r
Location	1271.385	p<.001	0.75722	0.57338	0.57338	0.75722
Mulch treatment	73.228	p<.001	0.77856	0.60615	0.03277	0.18074
Row	0.055	p<.814	0.77858	0.60618	0.00003	0.00360
Column	2.607	p<.107	0.77933	0.60735	0.00117	−0.03213
Year	16.237	p<.001	0.78398	0.61463	0.00728	−0.10550

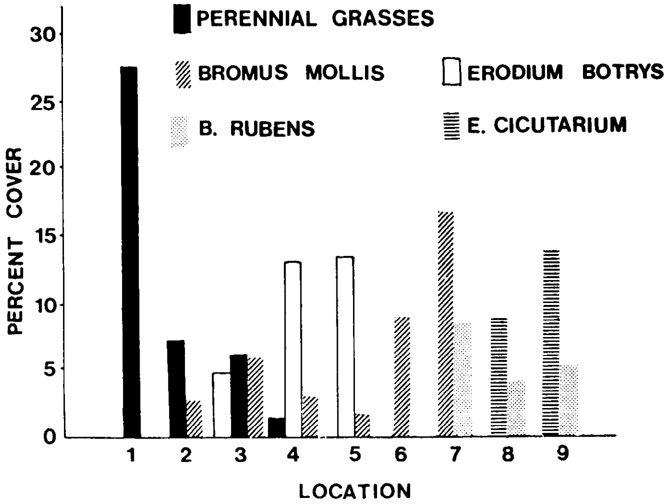

Fig. 4. *Percent cover contributed by selected plant groups at nine locations.*

precipitation, all contained broadleaved filaree or soft chess. Other annual grassland species also segregate out along the broad environmental gradient represented by the nine sites. For example, the perennial California oatgrass (*Danthonia californica*) and the annual crested dogtail (*Cynosurus echinatus*) were found only on the three wettest sites.

The discussion above illustrates a further division of site based on botanical composition, which reflects historical use of a given site and may be manipulated by grazing management. Yet each site has a limited set of potential species. Rangeland dominated by red brome and red-stem filaree could be a suitable management goal on a site with less than 25 cm average annual rainfall, yet reflect past abuses and poor quality rangeland on wetter sites. Perennial grasses may be a realistic management goal in the North Coastal region (plots 1-3) but not at other locations.

Effects of Mulch Manipulation on Productivity

The determination of site potential for both forage productivity and composition is necessary for evaluation of past, present, or proposed management. Within the annual grassland type little research has reported the effects of varying grazing intensities, especially on unimproved ranges. The following section describes the results of a series of mulch manipulations used to simulate the effects of varying grazing intensity on the nine study sites.

Although mulch significantly ($P<.05$; Table 2) affected standing crop, this treatment explains only 3% of the overall variation in herbage productivity. The effects of mulch reflect the response of individual plants to changes in the micro-environment near the soil surface. The overall productivity and composition of the vegetation result from the summed response to individual plant species.

Within the range of treatments applied, perennial grass sites (plots 1-3) responded to mulch in a manner suggesting that leaving 1,120 kg of plant residue per hectare is still too intensive a rate of defoliation (Fig. 5). Sites 2 and 3 showed large increases in productivity between 840 and 1,120 kg/ha. Thus no optimal relationship between mulch treatment and subsequent productivity can be determined. Response to treatment also reflects the perennial nature of the vegetation. Standing crop did not begin to show a consistent response to treatment until the second year of the experiment on sites 1-3. The perennial grass areas need more study to determine the effects of clipping on productivity.

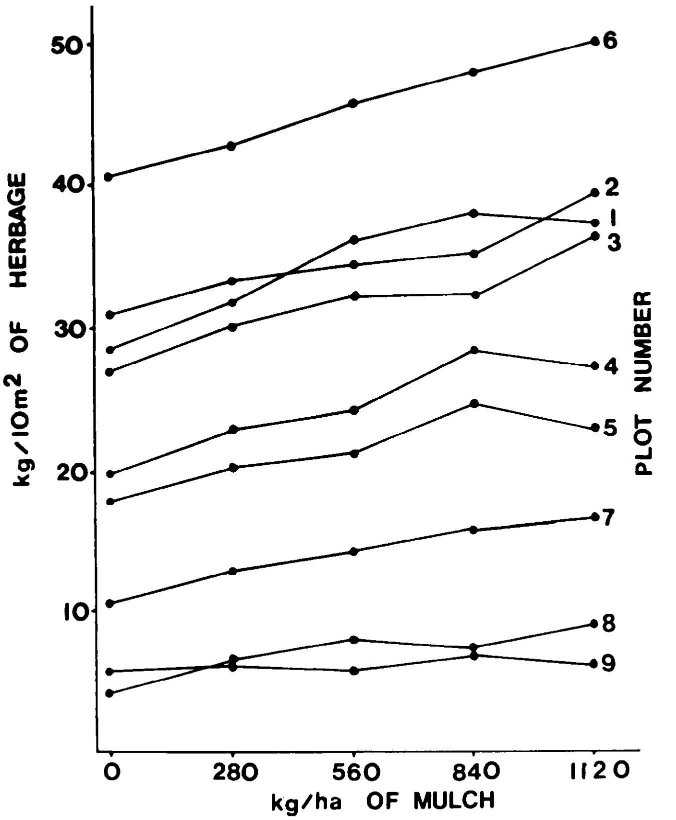

Fig. 5. *Effect of differing levels of natural mulch on peak standing crop at nine locations. Results average 5 years on plots 1-6, 3 years on plots 7-9. Least significant differences between means* ($P<.05$) *are 4.27 g/ft²* for plots 1-6, 5.51 g/ft² *for plots 7-9.*

The middle-rainfall sites 4 and 5, dominated by annual grasses, showed peaks of productivity of 840 kg/ha of mulch remaining in the fall. Plot 6, atypically, showed the smallest percentage change in productivity due to mulch, increasing only 23% between the lowest and highest mulch treatments. The response of other annual grass plots was immediate, with the establishment of the overall pattern in the first year following initiation of the treatment. The amount of increased forage approximated the added amount of mulch required for peak production of these mesic sites.

The dry sites (plots 7, 8, 9) varied in reponse to mulch, with the Kettleman Hills site (plot 8) showing a 106% increase with 1,120 kg/ha versus zero treatment (Fig. 5). However, for all three sites production in a given year may be well below 1,120 kg/ha. In no case did the extra mulch result in an equivalent increase in forage production.

Discussion

The results of our study clearly demonstrate the division of the California annual grassland into smaller units is both easily done using simple criteria and necessary for understanding of production and composition. The combination of average annual rainfall and botanical composition, as used in this study, gave excellent resolution of total productivity over the growing season. Rainfall and botanical composition separated reponse of different sites to mulch manipulation accurately enough for most management needs. Additional criteria of site definition, such as slope aspect, elevation, and soils will further enhance the accuracy of both measurement and prediction of total productivity. Differing sites will undoubtedly display markedly different seasonal production of herbage. This aspect of grassland production should be coupled with more precise measures of site variation.

Results from the manipulation of natural mulch on the study plots reflect both the characteristics of different sites and the definition of those sites. The three major site divisions each responded differently to mulch manipulation. The three most northerly perennial grassland sites illustrate the limitations of the methods used. Most perennial sites will require a seasonal defoliation study to clarify the proper intensity of grazing. Two of the three sites suggested that leaving 1,120 kg/ha (1,000 lb/acre) of mulch does not result in the optimal expression of productivity. For sites in the middle precipitation zones of 100 to 40 cm (40 to 15 inches) the optimal amount of mulch remaining is 840 kg/ha (750 lb/acre). At locations below 25 cm (10 inches) of annual precipitation, mulch cannot be an important decision-making criterion since the response of the vegetation is highly variable.

The results of this study provide valuable insight into grazing management. Yet differences between the mulch treatments and grazing are important. The manipulation of mulch was performed in late summer or early fall, while grazing usually is heaviest in the growing season. Grazing is selective, animals also trample the soil and redistribute nutrients, while clipping does not include these factors. We believe that grazing and clipping will give the same optimal rate of grazing intensity in the middle rainfall sites in annual grassland, 840 kg/ha (750 lb/acre). On perennial sites and the low rainfall (less than 25 cm) sites, effects of grazing versus clipping diverge.

Several important conclusions, which must be site specific, may be drawn concerning grazing management on annual grassland. Differing annual range sites require different management strategies. Perennial sites with annual precipitation greater than 100 cm probably should be managed as perennial grassland with attention paid to plant vigor, season of grazing use, and maintenance of at least 1,120 kg/ha (1,000 lb/acre) of mulch, preferably more, at the end of the grazing season. On the mid-rainfall annual ranges, mulch is the most important factor. Proper use of these ranges would leave 840 kg/ha (750 lb/acre) of mulch at the end of the season. Obviously, factors influencing mature plant vigor are not as important for annuals. On the drier sites, grazing management should be directed toward maintenance of sufficient plant cover to prevent soil loss; but within the constraint, animal performance can help to determine the degree of grazing intensity. Livestock often cannot graze intensively enough to reduce productivity on these dry sites without suffering performance losses as available forage drops below 560 kg/ha.

Annual ranges are remarkable in their year-to-year variability in both composition and production, and therefore respond rapidly to mulch treatment. In most cases the response was apparent in the first year following treatment. This rapid response implies a great flexibility in grazing management over the majority of annual ranges. The watershed and soil protection qualities of annual ranges benefit from this resilience as well.

Although the proper mulch prescription gives the optimum production within the limitations of a given year, an immediate response means that in an extreme situation the livestock manager may use forage, foregoing some production in the next year to obtain a benefit in the present year. An example would be a drought year where forage is short, livestock prices are low, feed prices are high. Instead of removing livestock when the optimal mulch level is reached the manager could instead "overgraze," knowing that in the subsequent year forage production would be reduced somewhat, but that if the next year were a high rainfall year much forage would be available, and the following year the system would return to "normal." When the forage is needed it may be used, because the range will recovery very rapidly. Composition and production of annual ranges is dictated both by the potential of the given site, each season's rainfall, and the appropriate management of natural mulch.

Literature Cited

Barbour, M.G., and J. Major. 1977. Introduction. *In:* Barbour, M.G. and J. Major (eds.) Terrestrial Vegetation of California: John Wiley and Sons, N.Y. p. 3-10.

Bartolome, J.W. 1979. Germination and establishment of plants in California annual grassland. J. Ecol. 67: (In Press)

Batzli, G.O., and F.A. Pitelka. 1970. Influence of meadow mouse populations on California grassland. Ecology 51: 1027-1039.

Bentley, J.R., and M.W. Talbot. 1951. Efficient use of annual plants on cattle ranges in the California foothills. U.S. Dep. Agr. Circ. 870. 52 p.

Burcham, L.T. 1975. Climate, structure, and history of California's annual grassland ecosystem. *In:* R.M. Love (ed.) The California Grassland Ecosystem. Inst. Ecol., Univ. California, Davis. p. 16-34.

Duncan, D.A., and R.G. Woodmansee. 1975. Forecasting forage yield from precipitation in California's annual rangeland. J. Range Manage. 28: 327-329.

Elliott, H.W., and J.D. Wehausen. 1974. Vegetational succession on coastal rangeland of Point Reyes Peninsula. Madrono 22: 231-238.

Evans, R.A., B.L. Kay, and J.A. Young. 1975. Microenvironment of a dynamic annual community in relation to range improvement. Hilgardia 43: 79-102.

Evans, R.A., and J.A. Young. 1970. Plant litter and establishment of alien annual weed species in rangeland communities. Weed Sci. 18: 697-703.

Heady, H.F. 1956. Changes in a California annual plant community induced by manipulation of natural mulch. Ecology 37: 798-812.

Heady, H.F. 1958. Vegetational changes in the California annual type. Ecology 39: 402-416.

Heady, H.F. 1961. Continuous vs. specialized grazing systems: A review and application to the California annual type. J. Range Manage. 14: 182-193.

Heady, H.F. 1966. The influence of mulch on herbage production in an annual grassland. Proc. 9th Int. Grassl. Congr. 1: 391-394.

Heady, H.F., and L. Rader. 1958. Modifications of the point frame. J. Manage. 11: 95-96.

Hedrick, D.W. 1948. The mulch layer of California annual ranges. J. Range Manage. 1: 22-25.

Hooper, J.F., and H.F. Heady. 1970. An economic analysis of optimum rates of grazing in the California annual-type rangeland. J. Range Manage. 23: 307-311.

Janes, E.B. 1969. Botanical composition and productivity in the California annual grassland in relation to rainfall. M.S. Thesis. Univ. California 47 p.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. Amer. Geog. Soc. Spec. Pub. 36.

Küchler, A.W. 1977. The map of the natural vegetation of California: *In:* Barbour, M.G. and J. Major (eds.) The Terestrial Vegetation of California. John Wiley and Sons, N.Y. pp. 909-938.

Munz, P.A., and D.D. Keck. 1949. California plant communities. El Aliso 2: 87-105.

Murphy, A.H. 1970. Predicted forage yield based on fall precipitation in California annual grasslands. J. Range Manage. 23: 363-365.

Pitt, M.D., and H.F. Heady. 1978. Responses of annual vegetation to temperature and rainfall patterns in northern California. Ecology 59: 336-350.

Talbot, M.W., H.H. Biswell, and A.L. Hormay. 1939. Fluctuations in the annual vegetation of California. Ecology 20: 394-402.

Tinnin, R.O., and C.H. Muller. 1971. The allelopathic potential of *Avena fatua:* influence on herb distribution. Bull. Torr. Bot. Club. 98: 243-250.