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Forecasting Forage Yield from Precipitation in California's Annual Rangeland

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Highlight: *Total forage yield from 1936 to 1970 and yields of grasses, legumes, and forbs other than legumes for 24 years on the same area of annual rangeland on the San Joaquin Experimental Range in central California were correlated with total annual precipitation and precipitation during the most important month, the most important 2 months, and most important 3 months. Total peak forage yield and yield of components of the vegetation were only poorly correlated with any 1 month's, combination of months', or annual rainfall. Early-season precipitation appear to be of little value for predicting forage yield, yield of grasses, legumes, or forbs other than legumes under the conditions studied.*

Range managers would find it valuable for resource planning and management if they could predict several months in advance the peak yield of forage plants. Accurate forecasts would, for example, be useful in stocking rangelands. To develop a predictive model, investigators have correlated climatic variables with plant yield. Murphy (1970) found that precipitation in November provided a fair indicator of subsequent forage yield. His study was made at the University of California's Hopland Field Station in northern California.

To find out if precipitation affected forage yield at a more southerly location, we did a study at the U.S. Forest Service's San Joaquin Experimental Range, Madera County, in central California, about 357 km from the Hopland Station. Its purpose was to determine if it were possible to forecast forage yield from climatic variables early in the growing season of grasses, legumes, and forbs other than legumes.

Study Area

The 1900-ha San Joaquin Experimental Range lies on the lower central foothills of the Sierra Nevada. Elevations range from 214 m to 518 m. Soils (Ahwahnee and Visalia series) are of granitic origin, are relatively shallow, and have low capacity for storing water. Winters are mild and moist; summers are hot and dry. Winter temperatures seldom fall below -5°C and summer temperatures often reach 40°C. Precipitation averages about 48 cm, with extremes of 26 to 83 cm. Herbaceous vegetation consists almost entirely of annual native and introduced grasses and forbs, including genera found at the Hopland Field Station: *Bromus, Festuca, Hordeum, Erodium, Trifolium*, and *Lotus*.

The rainy season at the Experimental Range generally begins in October or November when enough precipitation (>1.25 cm) occurs to stimulate germination of annual plants (Table 1). Only twice in 34 years was precipitation adequate in September for plants to begin germinating, and at no time since records have been kept has germination occurred in June, July, or August.

Methods

Data on forage yield from 1936 to 1970 were available for a 20-ha area that had never been fertilized. Yield of individual components (grasses, legumes, and forbs other than legumes) of total forage yield was recorded in 24 of those years (Table 2). Forage yield data were taken from earlier studies by Bentley and Talbot (1951), Bentley et al. (1958), and Conrad et al. (1966), and from unpublished reports on file at the Experimental Range. The forage samples were collected at the time, usually in May, when the standing crop biomass was judged to be at its maximum. These samples were air-dried; weighed; sorted into the categories of grasses, legumes, and forbs other than legumes; and reweighed. Daily precipitation and temperature were recorded at a weather station less than a kilometer from the area where herbage data were collected.

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Table 1. Monthly precipitation (cm) at the San Joaquin Experimental Range, California, based on 34 years' data (1936–1970).

Month	Mean	SD	Coefficient of variation	Range
September	0.58	1.65	284.8	0.00 – 9.40
October	2.21	1.88	85.0	0.00 – 5.64
November	5.07	4.59	90.6	0.00 – 14.20
December	8.54	7.08	82.9	0.91 – 34.15
January	8.77	5.81	66.2	0.15 – 25.25
February	8.86	7.32	82.7	0.00 – 25.45
March	7.51	5.67	75.5	0.08 – 26.53
April	4.84	4.55	94.0	0.05 – 22.21
May	1.33	1.73	129.9	0.00 – 7.06
June	0.29	0.58	200.2	0.00 – 2.59
July	0.06	0.16	255.5	0.00 – 0.76
August	0.02	0.56	277.5	0.00 – 0.25
All months	47.95	15.94	33.2	25.70 – 82.50

Data on precipitation (monthly and annually) and forage yield (total and by composition) from 1936 through 1970 were analyzed by using two computer programs: STAT 38-R (Stepwise, Multiple Regression Routine, on file at the Colorado State University Statistical Laboratory, Fort Collins) and FSCREEN (screening all combinations of independent variables in a univariate multiple linear regression, described by Frayer et al., 1971).

Results and Discussion

Total forage yield was most closely correlated with total precipitation in April (Tables 3 and 4). But the correlation ($r = 0.41$) was only slightly higher than that with total annual precipitation ($r = 0.40$). The correlation coefficient can be substantially increased (0.53 and 0.62, respectively) by adding a second month, November, in multiple regression analysis and a third month, January (Table 4).

Table 2. Forage yield (kg/ha) at the peak of production for grasses, legumes, and forbs other than legumes, San Joaquin Experimental Range, California, 1936–1970.

Forage class	Mean	SD	Coefficient of variation	Range
Grasses[1]	1,397	624	44.7	159 – 2,652
Legumes[1]	225	192	85.1	13 – 750
Forbs other than legumes[1]	908	376	41.5	355 – 1,978
All classes[2]	2,442	657	27.9	879 – 4,215

[1] Data from 24 years.
[2] Data from all years, 1936–1970.

Table 3. Correlation of forage yield and precipitation, by month and forage class, San Joaquin Experimental Range, California.

Month	Total yield	Grasses	Legumes	Forbs other than legumes
September	-0.099	-0.410	-0.207	0.556
October	0.073	0.458	0.021	-0.156
November	0.284	0.404	0.317	-0.299
December	0.181	0.287	0.310	-0.215
January	0.289	0.309	0.105	0.112
February	-0.099	-0.159	-0.061	0.058
March	0.213	0.073	0.144	0.166
April	0.413	0.209	0.402	0.177
May	-0.253	-0.202	-0.289	-0.193
June	0.337	0.342	0.063	0.048
July	0.164	0.196	-0.010	-0.186
August	0.029	0.108	-0.011	-0.137
All months	0.403	0.390	0.376	0.015

Table 4. Peak forage yield (dependent variable) related to monthly precipitation (independent variables) by multiple regression analyses.

Forage class	Error degrees of freedom (df)	Month(s) with highest correlation	Regression coefficient	*P*-value[1]
Best month				
Grasses	22	October	0.46	0.021
Legumes	22	April	0.40	0.047
Forbs other than legumes	22	September	0.56	0.004
All classes	32	April	0.41	0.013
Best 2 months				
Grasses	21	October, December	0.58	0.010
Legumes	21	November, April	0.55	0.019
Forbs other than legumes	21	September, January	0.59	0.009
All classes	31	November, April	0.53	0.006
Best 3 months				
Grasses	20	October December, May	0.67	0.005
Legumes	20	November, April, May	0.59	0.025
Forbs other than legumes	20	September, January, July	0.67	0.005
All classes	30	November, January, April	0.62	0.002

[1] Probability of obtaining an *F*-value greater than the computed *F*-value as determined by analysis of variance.

These results agree with our observations that total forage yield at the Experimental Range depends on adequate distribution of precipitation throughout the season. Water must be adequate to stimulate germination and insure successful establishment of seedlings in fall, to allow overwintering without significant death due to desiccation in the winter, and to allow growth in spring when water demands are high because of rapid growth induced by higher temperatures.

After germination starts in fall, precipitation must be adequate to maintain seedling growth until cold temperatures of winter retard growth. Aboveground growth of forage plants does not occur in significant amounts when mean daily temperatures are below 10°C. These lower temperatures occur during December and January. In most years growth accelerates by late February. During the cold period the soil profile is generally recharged with enough water to prevent desiccation of seedlings. Plant growth in spring depends on water stored in the soil profile and on precipitation which falls in March, April, and May. Usually by late May, if not earlier, essentially all the soil water has been removed by evapotranspiration and most annual forage plants die.

Murphy (1970) showed that in northwestern California forage yield was correlated with November precipitation ($r = 0.70$). If we assume that spring rainfall is greater and more reliable in the north than in central or southern California, livestock ranchers in the north would have a tentative predictive tool to help them adjust stocking for the following spring. Our results suggest that it is not possible to use precipitation in central California for predicting yield. November precipitation explained only 8% of the variability in forage yield, the best month—April—explained only 17%; and the best three months—April, November, and January—explained only 38%.

The grass component of the total forage yield was most closely correlated ($r = 0.46$) with October precipitation (Table 4), suggesting an importance of early growth and root development before the winter cold period started. As with total forage yield, adding a second month, December (r = 0.58), and a third month, May (r = 0.67), to the regression analysis substantially increased the correlation coefficients (Table 4). These results support our hypothesis that water is equally important throughout all months of the growing season and that prediction of total grass yield is not possible by using any 1 month of precipitation. Our observations indicated grasses are relatively vulnerable to drought during any segment of the growth period—especially if early germination occurs and is followed by an extended dry period (Duncan and Reppert, 1960).

Legume yield was best but poorly correlated with April precipitation (r = 0.40). Legumes remain green later in the season than grasses and thus generally benefit more from late spring rains. The second month, November, added to the regression analysis yielded an r-value of 0.55 (Table 4), suggesting the importance of germination and successful establishment of seedlings in fall. The correlation coefficient was improved slightly by adding the third variable, May precipitation, (r = 0.59) to the regression (Table 4). This improvement further supports the suggestion that late spring precipitation helps legume development.

Forb (other than legume) yield appears to be fairly well correlated with September precipitation (Tables 3 and 4). However, this correlation was disproportionately influenced by one real, but extreme data point (September 1959) and a subsequent severe drought which lasted through December 1959 (Duncan and Reppert, 1960). During that year, abundant precipitation occurred in late September, promoting germination and water recharge of the soil profile. Adequate soil water and high temperatures of the early fall prevailed, and seedlings grew rapidly. In the next 3 months, no precipitation fell, causing most young grass plants to die. Probably because their tap roots extended rapidly during favorable conditions, the forbs were able to obtain water from lower strata of the soil profile and survive. When growth resumed in spring, they became more abundant than the grasses and, with the lack of competition, produced about 11 times more yield. The year 1959 established records for high forb yield (1978 kg/ha) and low grass yield (159 kg/ha). With the extreme data point thus explaining the September correlation, examination of Tables 3 and 4 reveals no correlation of forb yield with monthly precipitation or total precipitation.

Conclusions

In the annual grasslands of central California, total peak forage yield and yield of grasses, legumes, and forbs other than legumes were only poorly correlated with any particular month or annual precipitation. Correlations were improved by using the best 2 or 3 months' precipitation values in multiple regression analysis. Precipitation must be adequately distributed throughout the growing season to insure abundant forage yield. Thus, data on early-season precipitation are of little value to the range manager for predicting forage yield or yield of grasses, legumes, or forbs other than legumes.

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THESIS: COLORADO STATE UNIVERSITY

A Demographic Study of a Semidesert Grassland, by R. Gerald Wright. PhD, Range Science. 1972.

This paper reports on the use of long-term chart quadrats collected over the past 50 years on the Jornada Experimental Range in studies of perennial grass demography. Principal species in the study include: black grama, red and poverty three-awn, mesa dropseed, tobosa, and burrograss.

A method for automatic digital processing of the chart-quad maps using a photo-scanning system is developed. Demographic parameters calculated from the quantified data for the grasses included the mean lifespans, life tables, survival rates and patterns. The mean lifespans were low, generally less than 2 years, a consequence of the high juvenile mortality.

Age specific survival rates were developed for all species; and these were related on a yearly basis to the level of grazing, precipitation, competition, and other related aspects via several statistical tests.

The relationship with rainfall through a water-budget model gave the most significant results. The greatest single inhibitor of the survival of perennial grasses on the Jornada appeared to be the lack of rainfall in the period between the second and fourth years of a plant's life.

The results of all analyses were combined in a simulation model of plant demography, which attempted to mimic the changes in the stable grassland communities over a 50 year period. The model was based on the numbers of plants in each age class and the influence of environmental variables in altering the age specific survival rates. In the final phase, this model was used to investigate the disruption of a stable grassland community by the invasion of the mesquite shrub. A possible scenario whereby invading mesquite plants differentially alter the age specific survival rates of the different species is hypothesized.