Correlation of degree-days with annual herbage yields and livestock gains

MELVIN R. GEORGE, CHARLES A. RAGUSE, W. JAMES CLAWSON, CHARLES B. WILSON, ROBERT L. WILLOUGHBY, NEIL K. MCDOUGALD, DON A. DUNCAN, AND ALFRED H. MURPHY

Abstract

On California's winter annual rangelands precipitation controls the beginning and end of the growing season while temperature largely controls seasonal growth rates within the growing season. Post-germination accumulated degree-days (ADD) account for the length of the growing season and variation of daily temperature. Simple correlations of ADD and herbage yield or resultant livestock gains were determined at 5 locations in annual type range in northern California. Degree day values were determined by summing daily degree-days from the beginning of the growing season after germinating rainfall until the clipping or weigh dates. Accumulated degree-days accounted for 74 to 91% of the variation in seasonal herbage yield while accumulated days (AD) accounted for 64 to 86% of the variation. Together, ADD and AD accounted for 94 and 86%, respectively, of the variation in stocker cattle weights. Regression coefficients relating ADD to herbage yield appear to predict maximum site productivity. A procedure for estimating a seasonal herbage yield profile based on key growth curve inflection points and using simple field observations with 3 clipping dates and ADD is proposed.

Key Words: heat units, weather, sampling methods, modeling, seasonal production

Year-to-year variation in range herbage yield has frequently been attributed to variations in precipitation (Sneva and Hyder 1962). However, Duncan and Woodmansee (1978) were unable to show a relationship between herbage yield and precipitation on California annual rangeland. Pitt and Heady (1978) identified 5 annual range weather variables that explained 73% of the variation in March standing crop. Three of these variables were temperature related. Another set of 5 variables explained 90% of the variation in June standing crop. Two of these were temperature variables.

The annual range growing season can be partitioned into fall, winter, and spring periods. Fall precipitation and cooling winter temperatures determine the length of the fall growing season. The duration of slow winter growth is variable depending on the beginning and ending dates of the cold season. The length of the rapid spring growth period is also variable depending on the date that warm spring temperatures begin and the date spring soil moisture becomes depleted. Thus, precipitation controls the beginning and end of the whole growing season while temperature controls the end of the fall and beginning of the spring growing season.

The winter annual growth habit of California's annual rangeland appears to be an ideal system for explaining forage productivity based on accumulated degree-days (ADD), which integrates season length and temperature. Equations derived from degree-days to estimate or predict phenological stage or growth rate have been criticized (Wang 1960) but Bauer et al. (1984) concluded that the precision of ADD is equal to alternative methods and practical because air temperature is readily available from weather stations. This paper presents the simple correlations of seasonal herbage and resultant livestock yield with ADD at 5 annual range locations in California.

Materials and Methods

A 3-year field study of seasonal range herbage yield on 2 sites in Yuba and Butte Counties (Fig. 1) suggested a strong relationship between seasonal yield and ADD. To further verify this relationship, existing published and unpublished weather data and seasonal herbage yield data from the San Joaquin Experimental Range and University of California Hopland Field Station (Murphy et al. 1986) and seasonal cattle gain data from the University of California, Sierra Foothill Range Field Station (Raguse et al. 1986), were analyzed (Table 2). Weather data were acquired from the research stations and from the University of California Integrated Pest Management Data Base for Durham, California. The Durham data are more representative of the valley and adjacent terrace weather at the Butte County site than nearer weather stations at higher elevations in the foothills.

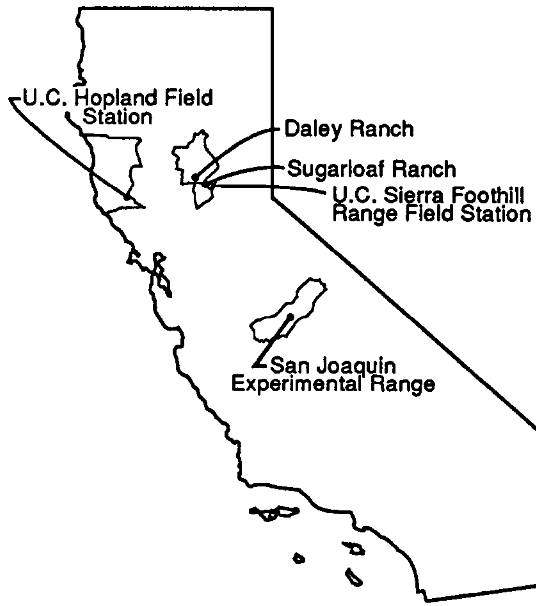


Fig. 1. *Location of 5 annual rangeland sampling sites in 4 California counties.*

Cages were used in the phytomass estimation procedures on the grazed sample sites Y1, B1, and H1-4 (Table 2). The grazed areas (SJ1 and SJ3) were split into 2 pastures that were alternately grazed and ungrazed during successive growing seasons. Seasonal yield was estimated in the ungrazed pasture each year. The ungrazed pasture was grazed following the growing season. Ungrazed standing crop was estimated in permanent livestock exclosures (SJ2 and SJ4).

Senior, second, and third authors are extension specialist, professor, and extension specialist, Agronomy and Range Sci. Dep., Univ. of California, Davis 95616. Fourth, fifth, and sixth authors are farm advisors, Yuba, Butte, and Madera Counties, Univ. of Calif. Coop. Ext., Berkeley 94720. Seventh author is director, San Joaquin Exp. Range, California State Univ. Fresno 93710. Eighth author is superintendent (retired), Univ. of California Hopland Field Sta., Hopland 95449.

The authors wish to thank Drs. W. Williams and J. Menke, professors, Agronomy and Range Sci. Dep., Univ. of California, Davis, for reviewing this manuscript and providing thoughtful suggestions. Acknowledgement also goes to the many research assistants and other employees who dependably collected data at various locations for many years.

Manuscript accepted 15 December 1987.

Table 1. Site descriptions and sampling conditions for 11 sample areas.

Site Description			Sample Description				
Soil series and family	Location (elevation)	Weather station (distance)	Area	Conditions	Size and unit	Dates	Years
Auburn loamy, mixed thermic Ruptic-Lithic Xerocrept	Sugarloaf Ranch, Yuba County (290 m)	Sierra Foothill Range Field Station (13 km)	Y1	grazed, caged exclosures	mean of 16 0.09 m² plots	4 dates each year October–May	1982–85
Corning fine, mixed thermic Typic Palexeralf	Daley Ranch, Butte County (40 m)	Durham, Butte County (33 km)	B1	grazed, caged exclosures	mean of 16 0.09 m² plots	4 dates each year October–May	1982–85
Ahwahnee Series coarse-loamy, mixed thermic Mollic Haploxeralf	San Joaquin Experimental Range (360 m)	Station (1.5 km)	SJ1	grazed at end of growing season	mean of five 0.09 m² plots	4 to 6 dates October–July depending on length of growing season	1980–85
Ahwahnee Series coarse-loamy, mixed thermic Mollic Haploxeralf			SJ2	ungrazed permanent exclosures	mean of five 0.09 m² plots	4 to 6 dates October–July depending on length of growing season	1980–85
Visalia Series coarse-loamy, mixed thermic Pachic Haploxeralf			SJ3	grazed at end of growing season	mean of five 0.09 m² plots	4 to 6 dates October–July depending on length of growing season	1980–85
Visalia Series coarse-loamy, mixed thermic Pachic Haploxeralf			SJ4	ungrazed permanent exclosures	mean of five 0.09 m² plots	4 to 6 dates October–July depending on length of growing season	1980–85
Mixture of Laughlin and Sutherlin Series Laughlin fine-loamy, mixed, mesic Typic Xeroxchrept Sutherlin fine, mixed mesic Aquic Haploxeralf	Hopland Field Station (350 m)	Station (1 km)	H1	grazed, caged exclosures	mean of 20 0.09 m² plots	Early February and late April to early May	1962–82
			H2	grazed, caged exclosures	mean of 20 0.09 m² plots	Early February and late April to early May	1962–82
			H3	grazed, caged exclosures	mean of 20 0.09 m² plots	Early February and late April to early May	1962–67
			H4	grazed, caged exclosures	mean of 20 0.09 m² plots	Early February and late April to early May	1962–72
Sobrante-Las Posas fine-loamy or fine mixed thermic Mollic Haploxeralfs	Sierra Foothill Range Field Station (330 m)	Station (1 km)	SF1	8–12 calves (200–400 kg) per pasture	mean of 4 pastures (14 ha each)	Weighed every three or four weeks from December to June	1982–85

The weight gain data were gathered from stocker cattle (200 to 230 kg) at the Sierra Foothill Range Field Station (SF1) which began grazing in November or early December. Initial stocking rates were 3.3, 2.2, and 1.7 ha per animal, respectively, each year. Stocking rates increased as herbage levels increased, attaining 1.1, 0.86, and 0.54 ha per animal for the corresponding years. Each year grazing was terminated in May or June when average daily gain began to decline, based on an every 21-day weigh schedule.

Accumulated degree-day values were determined using the sine function method described by Logan and Boyland (1983). Negative values were equated to zero. Negative values are infrequent because the mean daily temperature is seldom less than 5° C in the mild winters of California's Mediterranean climate. The base temperature used in this study was 5° C. Temperatures at or near 5° C have been used as the base temperatures or minimum temperatures for growth for many cool-season plants (Chang 1968, Bootsma 1983, Fitzpatrick and Nix 1970, and Bentley and Talbot 1951). Several annual range plants have minimum germination temperatures near a daily average temperature of 5° C (Young et al. 1973, 1975a, 1975b).

Degree-day accumulations were initiated on the estimated date that fall germination began, using Bentley and Talbot's (1951) criterion that annual plants start to germinate after the first rains of 12 to 25 mm. For this study the start of germination was defined as the day after 25 mm of precipitation occurred in 1 week. Days and degree-days were accumulated to each sampling or animal weigh date.

Linear correlation was used to determine the degree of association between accumulated days (AD) or ADD and herbage yield or livestock gains (Y). Accumulated degree-days integrates the 2 variables AD and temperature. The "extra sums of squares principle" (Draper and Smith 1981) was used to determine if the linear model using ADD as the independent variable was an improvement over a linear model using AD as the independent variable.

Table 2. Regression equations for accumulated degree-days (ADD) and forage yield or stocker cattle gains, R^2 or ADD accumulated days (AD) and their differences.

Sample Area	ADD a	b	SEŷ	R^2	AD R^2	Differ. R^2
			Forage Yield			
Y1	-120	5.2	424	0.95	.86	.09
B1	14	4.4	396	0.91	.83	.09
SJ1	- 90	3.8	632	0.85	.77	.18
SJ2	-141	3.1	570	0.82	.64	.18
SJ3	- 54	3.9	1052	0.77	.74	.04
SJ4	-280	4.9	925	0.88	.75	.13
H1	77	2.2	469	0.74	.83	-.09
H2	138	2.8	580	0.76	.83	-.07
H3	96	4.1	439	0.91	.84	.07
H4	82	2.7	591	0.74	.77	-.03
			Cattle Gain			
SF1	2.9	0.1	8.81	0.94	.86	.08

Table 3. Regression coefficients and maximum productivity under favorable weather conditions for six range soils.

Soil Series	Regression Coefficient	Maximum Yield
	(b)	(kg/ha)
Laughlin	2.7	2500[1]
Ahwahnee	3.1	3200[2]
Sutherlin	4.1	3500[1]
Corning	4.4	3600[3]
Visalia	4.9	5000[1]
Auburn	5.2	5700[3]

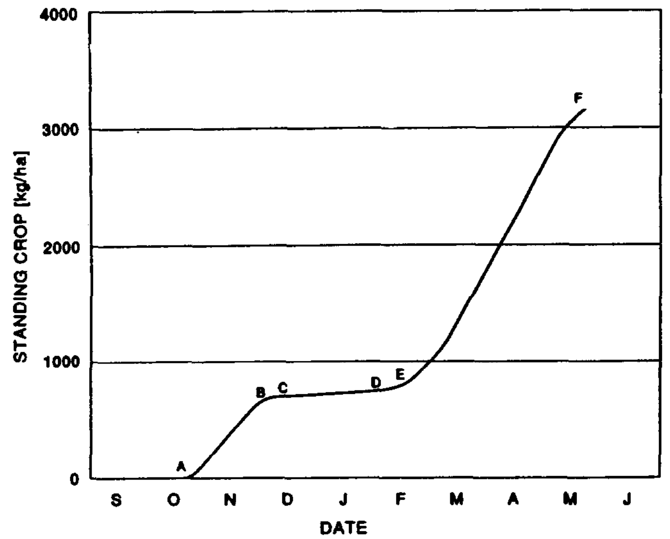
[1]George, M.R. and E.A. Jacobsen 1987.
[2]Clawson, W.J. 1986. unpublished.
[3]George, M.R. et al. 1987

Results and Discussion

The regression of herbage yield on ADD for the Yuba (Y1) and Butte (B1) sites indicated a strong relationship between these 2 variables (R^2>0.9) (Table 2). Analysis of larger data sets from other locations indicated that ADD accounted for 74 to 91% of the variation in seasonal herbage yield. It also accounted for 94% of the variation in seasonal weight gains of stocker cattle. Significant regression coefficients were obtained for ADD on seasonal yield regressions for all sites in the study.

Regression (slope) coefficients for the regression of herbage yield on ADD at areas SJ1-4 were 3.8 and 3.1, respectively, for the grazed and ungrazed Ahwahnee soil series and 3.9 and 4.9, respectively, for the more productive Visalia series (Table 3). Accumulated degree-days accounted for a greater proportion of variation (R^2=0.77 to 0.88) in seasonal herbage yield than AD (R^2=0.64 to 0.77) at SJER. The SEŷ was greatest on the Visalia series where yields are potentially quite high under favorable growing conditions and can be quite low under poor conditions. The associated Ahwahnee series has a lower potential under favorable weather conditions.

Regression coefficients for areas H1-4 were 2.2, 2.8, 4.1, and 2.7. The data set for H3 covered fewer years than areas H1, H2, and H4. For the 1962-67 period H3 had a higher herbage yield than the other 3 areas (Murphy et al. 1986). Accumulated days accounted for a greater proportion of the variation in seasonal herbage yield than did ADD in 3 of 4 pastures (Table 1). Unlike the data from the other sites, the Hopland data do not include an early winter yield estimate (C in Fig. 2). Without an early winter yield estimate, the relationship between AD and yield may be stronger than the relationship between ADD and yield. Addition of an early winter



A. emergence of new seedlings
B. beginning of winter
C. early winter herbage yield estimate
D. late winter herbage yield estimate
E. end of winter
F. end of growing season (peak standing crop) herbage yield estimate

Fig. 2. *Seasonal herbage production profile for annual rangelands.*

yield estimate tends to make the relationship between ADD and yield stronger than the relationship between AD and yield.

The results of this study using widely separated locations support the notion that ADD is a useful index to growing conditions on annual rangeland, where season length and temperatures are highly variable. Strong relationships between ADD and standing crop or yield have been shown for several forages including alfalfa (Selirio and Brown 1978) and barley (Chakravarty et al. 1984). This study applies degree-day concepts to a community of mixed vegetation dominated by cool-season annual species that have similar minimum temperature requirements for germination (Young et al. 1973, 1975a, 1975b), grow slowly during the winter, and grow rapidly during spring (Pendleton et al. 1983). Degree-day concepts assume every degree of temperature is physiologically equivalent. Since this assumption is only an approximation, we are dealing with a concept of indexing rather than a precise cause-effect relationship. However, the information developed in this study provides the basic relations from which we can approximate annual range herbage yield during the growing season on like soils and under like climatic variation to that of the study sites.

Regression (slope) coefficients appear to be related to site productivity as indicated in Table 3. If further study confirms this relationship over a wider array of sites, we would have the basis for an index to site productivity based on past climatic records.

The relationship between ADD and herbage yield can only be strong if soil moisture is not limiting. Droughts causing high plant mortality are normally rare in the middle of the growing season because the soil moisture recharge is adequate to keep plants alive during the winter when potential evapotranspiration is very low. Droughts within the growing season may be more important at more southerly locations than those in this study. If this is the case the regression coefficients may not be correlated with site productivity.

Applications and Conclusions

Accumulated degree-days can be used to normalize seasonal yield data to produce seasonal production curves described by George et al. (1985) (Fig. 2). They describe 3 phases of herbage production simulated by ELMAGE (Pendleton et al. 1983). These growth phases are:

1. Break of season in fall (A) beginning after the first fall rains which exceed 25 mm of rainfall. This fall growth period (A–B) is usually 2 to 3 weeks in length but can be longer with early rains or late onset of cold temperatures. Fall growth may not occur if germinating rains occur after the onset of cold temperatures.
2. Winter growth period (B–E) occurs at the end of the fall growing season and is the result of cooling temperatures, shorter days, and low solar radiation levels.
3. Rapid spring growth (E–F) begins with the onset of warming spring temperatures, longer days, and high solar radiation. Peak standing crop and soil moisture depletion occur at the end of this period marking the beginning of the dry season.

The following procedure estimates points A, C, D, and F using field observations and 3 clipping dates. Degree-day accumulations are used to estimate the inflection points at the beginning (B) and end (E) of winter.

1. Record the growing season starting date (A). This can be the date of the first observed seedling emergence or it can be estimated from daily precipitation records following 25 mm precipitation in 1 week.
2. Determine the beginning of the winter growth period (B). This is defined as the first cold day (degree-days $<$2.78) in a 7-day period that averages less than 2.78 degree-days per day (2.78 degree-days is derived from a minimum temperature of 5° C, a maximum temperature of 10.5° C, and a base temperature of 5° C).
3. Estimate herbage standing crop at the beginning of the winter growth period (C) to establish forage yield between the beginning of the growing season and the start of the cold winter season. Forage should be estimated as soon as possible after the onset of cold weather (B).
4. Late in the cold winter season (usually before mid-February), a second standing crop estimate will define herbage production during the winter growth period (D).
5. Determine the first day of the spring growing season (E) which is defined as the first warm day (degree-days $>$2.78) in the first 14 day period that averages more than 2.78 degree-days per day.
6. Finally, a herbage standing crop estimate at the end of the growing season (F) will define spring production as well as total growing season production. Proper timing of the peak standing crop estimate is not specified in the literature, but common practice is to sample when the annual grasses such as soft chess *(Bromus mollis)* are between the soft and hard dough stage of maturity. Waiting too long will result in loss of delicate herbage, especially some forbs which shatter quickly on drying.

A difference of several days between the beginning of winter (B) and the actual sampling date (C) or the end of winter (E) and sampling date (D) is inherent in this procedure. However, the rate of growth during the winter period is less than 5 kg/ha/day (Jones 1967, Pendleton et al. 1983, George et al. 1987) and this difference is unlikely to be of statistical significance. George et al. (1987) report that the differences between early and late-winter standing crop estimates, a period of 60 to 90 days, were not significantly different at the Yuba and Butte locations used in this study.

In practice, most studies only report treatment effects on peak standing crop (F), missing important information about treatment response in fall and winter. Fall and winter forage yield is important because that is the period when forage need exceeds forage supply in foothill livestock operations. A few researchers have reported 2 or 3 seasonal measures of standing crop, but their timing has not followed that proposed here. For example, Pitt and Heady (1978) used March standing crop to estimate fall and winter production. In years where spring starts in early-to-mid February, 2 or more weeks of rapid spring growth may be included in the fall and winter estimate, giving an inflated estimate of fall-winter production.

Growth analysis techniques (Russelle et al. 1984) that compare productivity on a yield per degree-day basis rather than yield per day could be used to remove differences in observed experimental or site productivities due to season length and temperature. Differences in results from experiments conducted on similar sites but in different years have resulted in wide variation in yield response to seeding and fertilization. Although data from control treatments can be used to show yield differences due to treatment, they do not account for yield differences due to weather variation between locations or years which are often more influential than the treatments themselves.

Because of the strong relationship between ADD and herbage yield at several locations and under a variety of sampling regimes, ADD shows promise as an estimator of herbage yield in California's winter annual ranges. In future monitoring efforts, collection of weather data on-site and sampling as proposed in this paper should allow testing and improvement in the strength of this relationship.

Literature Cited

Bauer, Armand, A.B., Frank, and A.L. Black. 1984. Estimation of spring wheat leaf growth rates and anthesis from air temperature. Agron. J. 76:829-835.

Bentley, J.R., and M.W. Talbot. 1951. Efficient use of annual plants on cattle ranges in the California foothills. USDA Circ. 870, Washington, D.C.

Bootsma, A. 1984. Forage crop maturity zonation in the Atlantic Region using growing degree-days. Can. J. Plant Sci. 64:329-338.

Chakravarty, N.V.K., B.N. Murty, and P.S.N. Sastry. 1984. Degree-days and biomass accumulation in different genotypes of barley. Ind. J. Plant Physiol. 3:295-299.

Chang, Jen-Hu. 1968. Climate and agriculture, an ecological survey. Aldine Publ. Co., Chicago, Ill.

Draper, Norman, and Harry Smith. 1981. Applied regression analysis, second edition. John Wiley & Sons, New York.

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

Fitzpatrick, E.A., and H.A. Nix. 1970. The climatic factor in Australian grassland ecology. P. 8-11. *In:* Moore, M.R. (ed.) Australian Grasslands. Australian Nat. Univ. Press, Canberra.

George, M.R., W.J. Clawson, J.W. Menke, and J. Bartolome. 1985. Annual grassland forage productivity. Rangelands 7:17-19.

George, M.R., and E.A. Jacobsen. 1987. Range productivity data base. Range Sci. Rep. 15, Agron. and Range Sci. Dep., Univ. of Calif., Davis.

George, M.R., C.B. Wilson, R.L. Willoughby, P. Sands, and R. Kouriri. 1987. Seasonal productivity of seeded and unseeded annual range. Range Sci. Rep. 13, Agron. and Range Sci. Dep., Univ. of Calif., Davis.

Jones, Milton B. 1967. Forage and nitrogen production by subclovergrass and nitrogen fertilized California grassland. Agron. J. 59:209-214.

Logan, S.H., and P.B. Boyland. 1983. Calculating heat units via a sine function. J. Amer. Soc. Hort. Sci. 108:977-980.

Murphy, A.H., M.B. Jones, and R.M. Love. 1986. Comparison of animal yields on annual grasslands-stocking rates and improvement practices. Range Sci. Rep. No. 6, Agron. and Range Sci. Dep., Univ. of Calif., Davis.

Pendleton, D.F., J.W. Menke, W.A. Williams, and R.G. Woodmansee. 1983. Annual grassland ecosystem model. Hilgardia 51:1-44.

Pitt, M.D., and H.F. Heady. 1978. Responses of annual vegetation to temperature and rainfall patterns in northern California. Ecology 58:336-350.

Raguse, C.A., J.L. Hull, M.B. Jones, J.G. Morris, M.R. George, K.D. Olson, K.L. Taggard, and R.E. Delmas. 1986. Plant, livestock, and economic responses to selective fertilization of annual rangeland with nitrogen, phosphorus, and sulfur. Range Sci. Rep. 8, Agron. and Range Sci. Dep., Univ. of Calif., Davis.

Russelle, M.P., W.W. Wilhelm, R.A. Olson, and J.F. Power. 1984. Growth analysis based on degree-days. Crop Sci. 24:28-32.

Selirio, I.S., and D.M. Brown. 1979. Soil moisture-based simulation of forage yield. Agr. Meteorol. 20:99-114.

Sneva, F.A., and D.N. Hyder. 1962. Estimating herbage production on semiarid ranges in the Intermountain region. J. Range Manage. 15:88-93.

Wang, J.Y. 1960. A critique of the heat unit approach to plant response studies. Ecology 41:785-790.

Young, J.A., R.A. Evans, and B.L. Kay. 1973. Temperature requirements for seed germination in an annual-type rangeland community. Agron. J. 65-656-659.

Young, J.A., R.A. Evans, and B.L. Kay. 1975a. Dispersal and germination dynamics of broadleaf filaree, Erodium botrys (Cav.) Bertol. Agron. J. 67:54-57.

Young, J.A., R.A. Evans, and B.L. Kay. 1975b. Germination of Italian ryegrass seeds. Agron. J. 67:386-389.