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Prediction of Pasture Growth Rates from Climatic Variables

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Research Question

Pasture feed budgeting, as practiced in New Zealand, requires an estimate of expected daily growth rate (DGR) of pasture for each month. This study estimated monthly DGR and the influence of solar irradiance, air temperature, soil temperature, and the amount of herbage per unit area of pasture (herbage mass) on DGR for an irrigated pasture in California's Sacramento Valley.

Literature Summary

Regional estimates of DGR are readily available to pasture managers in New Zealand but not in California. Daily growth rates will vary as solar irradiance and air temperature change. Herbage mass also influences DGR. Daily growth rates are often greatest within a herbage mass range of 1000 to 2500 lb DM/acre. Below that range leaf area is inadequate to capture solar irradiance efficiently and above that range shading and aging leaf tissue reduces photosynthetic capacity.

Study Description

Herbage mass was estimated during the rest periods on a rotationally grazed, irrigated pasture. Herbage mass was estimated weekly from May to September, biweekly from mid-February to April and October to mid-November, and monthly from mid-November to mid-February. Daily growth rate was determined from the change in herbage mass divided by the number of days. Solar irradiance, air temperature, and soil temperature were obtained from a weather station located on the irrigated pasture.

Location:	Sacramento Valley, California
Pasture Mix:	Tall fescue and strawberry clover
Soil:	Capay silty clay
Pasture size:	120 acre divided into 16 equal paddocks
Irrigation:	Biweekly, April to October
Fertilization:	300 lb/acre of ammonium phosphate-sulfate (16-20-0-15) in November and March

Applied Questions

What are the monthly average pasture growth rates for a typical Sacramento Valley irrigated pasture?

Using data from this study, DGR for January through October can be estimated. Relying on data collected in other studies and the experience of the authors, November and December DGRs are estimated to be less than 10 lb/acre/d.

J	F	M	A	M	J	J	A	S	O	N	D
4	20	21	27	42	50	50	47	36	10	<10	<10

How do daily growth rates respond to seasonal changes in solar irradiance, temperature, and herbage mass?

Daily growth rate increased with increasing solar irradiance until air temperatures exceeded optimum temperatures for growth of cool season pasture species. Herbage mass, solar irradiance, air temperature, and

Full scientific article from which this summary was written begins on page 86 of this issue.

soil temperature were not strong predictors of DGR. Without a reliable predictive tool, DGR must be estimated at each location where feed budgeting is to be implemented. Several years of DGR estimation will provide an estimate of yearly variation in DGR. The authors have embarked on an irrigated pasture monitoring program that will estimate yearly variation in monthly DGR on six rotationally grazed irrigated pastures in northern California.

Feed budgeting has the potential to increase harvest efficiency of irrigated pasture, resulting in improved water, fertilizer, and energy use efficiency.

Prediction of Pasture Growth Rates from Climatic Variables

David F. Lile and Melvin R. George*

Feed planning enables ranchers to use feed resources efficiently and increase profits. Feed budgeting requires estimates of expected daily growth rate (DGR) of pasture. The purpose of this study was to estimate DGR and determine if weather variables and herbage mass could be used to predict DGR for an irrigated pasture dominated by tall fescue (*Festuca arundinacea* Schreb.) and strawberry clover (*Trifolium fragiferum* L.). A single-probe capacitance meter was used to estimate herbage mass over 2 yr. Daily growth rate was calculated during the rest periods on 16 rotationally-grazed paddocks. Maximum and minimum daily air and soil temperature, and solar irradiance were recorded by a California Irrigation Management Information System (CIMIS) weather station located within the pasture. Average daily weather values and the herbage mass at the beginning of the rest period were independent variables in regression with DGR. Solar irradiance was the variable most closely correlated with growth rate, and when combined with beginning herbage mass in multiple regression, predicted DGR with R^2 = 0.71 ($S_{y.x}$ = 9.7) in year 1 and R^2 = 0.68 ($S_{y.x}$ = 5.5) in year 2. Maximum air temperature with beginning herbage mass predicted DGR with R^2 = 0.67 ($S_{y.x}$ = 10.4) for year 1 and R^2 = 0.67 ($S_{y.x}$ = 5.6) for year 2. All weather variables were highly correlated with each other and had similar effects on growth rate. Daily growth rate increased with increasing beginning herbage mass up to 2500 lb dry matter (DM)/acre. While the climatic variables in this study were not strong predictors of DGR, they may be useful for adjusting long term DGR averages to actual weather conditions.

FEED PLANNING and time-controlled grazing have been shown to increase profitability of livestock operations through the efficient use of forage resources. Milligan et al. (1987) demonstrated how feed budgets were used to meet production targets by balancing the forage demand of livestock with the supply of forage in the pasture. Feed budgeting requires an estimation of the expected DGR of pasture.

In New Zealand, monthly DGRs for several locations are available from the Ministry of Agriculture and Fisheries (Milligan and McConnell, 1976). These average DGRs are a good starting point for forage budgeting, but are likely to require modification for a particular farm to account for local variations in climate, soil fertility, and other pasture conditions. Similar information is not readily available to California pasture managers. While irrigated pasture growth rates have been reported for several harvests within a growing season (Peterson and Hagan, 1953, Martin et al., 1965), estimates of pasture growth rate on a monthly or more frequent interval have not been reported.

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Daily growth rate will vary between years due to variations in weather and herbage mass. Modification of regional DGRs for a particular farm could be improved if the relationship between DGR and weather variables or herbage mass was known. Radcliffe and Baars (1987) reported a strong relationship between soil temperature and the growth of a perennial ryegrass (*Lolium perenne* L.)-white clover (*Trifolium repens* L.) pasture (R^2 = 0.75 in spring and R^2 = 0.70 in fall). Brougham (1959) reported seasonal changes in growth rate were correlated with seasonal differences in solar irradiance (r = 0.98), maximum air temperature (r = 0.73), and minimum air temperature (r = 0.61). Lemaire and Salette (1982), however, found variations of spring growth of tall fescue were related only to temperature and not solar irradiance. When herbage mass is extremely low (<1000 lb DM/acre) or high (>2500 lb DM/acre) DGR may be depressed (Korte et al., 1987). Brougham (1956) showed an increasing growth rate as the height, leaf area, and therefore light interception, of the sward increased.

The objectives of this study were to (i) determine DGR for a rotationally grazed irrigated pasture, (ii) determine the influence of seasonal changes in solar irradiance and temperature on DGR, and (iii) determine the influence of herbage mass on DGR.

MATERIALS AND METHODS

The irrigated pasture used in this study is located in the southern part of Sutter County, California. The 120-acre pasture was seeded to a grass-legume mixture and had been established for 15 yr. The dominant species are tall fescue and strawberry clover. Ladino white clover, perennial ryegrass, and orchardgrass (*Dactylis glomerata* L.) are also present. The pasture had been divided into 16 equal-sized paddocks by a two-wire electric fence 1 yr prior to the start of this study.

The soil series, a Capay silty clay with 0 to 2% slopes, is classified as a fine, montmorillinitic, thermic Typic Chromoxeret. This is a very deep, moderately well-drained soil suited for irrigated crops (Lytle, 1982).

The pasture was grazed by beef cattle (*Bos taurus*), with the grazing season between April and December. Stock density during this time was approximately 180 pairs of cows and calves or 200 yearlings. Each paddock was grazed for 1 to 3 d before cattle were moved to a new paddock. The number of days spent in each paddock depended on the stock density, the herbage mass before grazing, and the desired residual dry matter after grazing.

Irrigation began in April or May, depending on the amount of spring precipitation. The fields were flood-

Abbreviations: BHM, beginning herbage mass; CIMIS, California Irrigation Management Information System; CMR, corrected meter readings; DGR, daily growth rate; DM, dry matter.

irrigated on a 2-wk schedule that varied due to weather, amount of vegetative cover present, and the grazing schedule. To avoid soil compaction, fields were not irrigated within 5 d prior to grazing. The pastures were fertilized with 48 lb N/acre, 26 lb P/acre and 45 lb S/acre (300 lb/acre 16-20-0-15) in November and March.

Herbage mass was estimated with a microprocessor-controlled capacitance meter (Pasture Probe Mk III, Design Electronics, Palmerston North, New Zealand). This capacitance probe is thought to measure sward surface area and to be less sensitive than other models to herbage water content (Vickery et al., 1980). Changes in capacitance between sward and the above sward atmosphere are translated by the microprocessor into corrected meter readings (CMR). Herbage mass is estimated from the CMR using one of the seven programmed regression equations stored in the microprocessor. Each equation is developed for seasonal changes in herbage composition and pasture condition. These equations were developed by the New Zealand Ministry of Agriculture and Fisheries (Richardson, 1984) on perennial ryegrass-white clover pastures in New Zealand. Robbins et al. (1989) demonstrated that with proper equation selection, the programmed equations were suitable for California irrigated pastures dominated by tall fescue or orchardgrass with strawberry or white clover.

To ensure the correct programmed equation was being used for accurate herbage mass estimation, the probe was calibrated by double-sampling. Probe readings were taken within randomly placed plots (1 sq-ft quadrats) before and after clipping. The plots were clipped to a height of approximately 1 in. The clipped herbage was dried at 160°F for 48 h and then weighed. The difference in CMR before and after clipping was regressed against the weight of the clipped samples. The regression equation from the clipped plots was compared with the most similar programmed equation using a goodness of fit test. If there was no significant ($\alpha = 0.05$) difference between equations, the programmed equation was used.

To estimate herbage mass on each sampling date, two transects were sampled through each of the paddocks. Thirty-five probe readings were taken along each transect (or 70 probe readings per paddock) and were averaged to give the herbage mass for each paddock.

The pasture probe is sensitive to high temperatures and wind (George, 1989). The transects were sampled in the morning before the temperature reached 90°F and sampling was avoided on windy days. Sampling dates were adjusted to avoid standing water in paddocks because earlier studies had shown that the probe overestimates herbage mass under these conditions (George, 1989).

Daily growth rates were calculated during the rest period of the grazing cycle. The increase in herbage mass since the previous sample date, divided by the number of days between sampling gave the average DGR.

Herbage mass was estimated weekly from May through September, biweekly from mid-February through April and October through mid-November, and monthly in the winter. Sampling frequency increased with increasing DGR. When DGR was slow, sampling frequency was decreased because it took longer to accumulate a measurable increase in herbage mass. In November and December, when DGR is normally slow (George et al., 1992), the ranch manager opened the paddock gates and the pasture was set-stocked. During set-stocking DGR calculations were not attempted because herbage was removed by grazing between sampling dates.

Weather data were recorded from a CIMIS weather station (Nicholas, Sutter County) that is located near the middle of the pasture (Integrated Pest Management Program, 1991). Weather variables measured included solar irradiance, and minimum and maximum daily air and soil temperature. Solar irradiance was measured by a pyranometer with a LICOR sensor. Air temperature was recorded at a height of 5 ft and soil temperature at a depth of 6 in.

Beginning herbage mass (BHM) is the herbage mass present on the first sampling date after grazing (at the beginning of the rest period). The BHM variable was used to determine the effect of residual herbage mass on DGR.

Data cases were assembled by including BHM and average daily weather values with DGRs for each paddock. Since all 16 paddocks were very similar in species composition and were managed similarly, data cases from

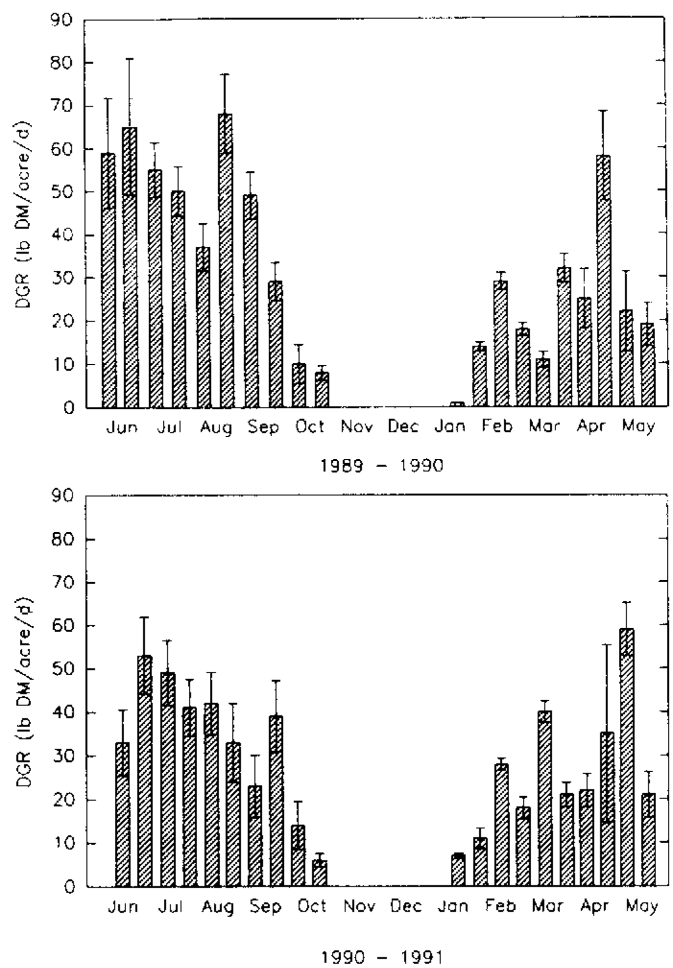

Fig. 1. Seasonal daily growth rates (lb/acre/d) for 1989–1990 and 1990–1991. Values are means and error bars are ± 1 SE of the mean for 16 paddocks.

all paddocks were analyzed together. Data cases were analyzed separately for the 2 yr; year 1 was from 1 June 1989 to 31 May 1990 and year 2 was from 1 June 1990 to 31 May 1991.

Independent weather variables included: daily maximum and minimum 5 ft air and 6 in. soil temperatures (°F), solar irradiance (ly/d), and BHM (lb DM/acre). To determine which subset of variables best explained variations in DGR, stepwise multiple regression (BMDP2R; Dixon, 1983) and all possible subsets regression (BMDP9R; Dixon, 1983) were used. An F-test on the extra sums of squares was used to determine if a quadratic equation, which included the square of the independent variable, would describe the response of DGR better than a linear equation.

RESULTS AND DISCUSSION

The pasture probe is equipped with seven programmed regression equations to convert the measured electronic signal into lb DM/acre. Regression equations derived from double-sampling (probe meter reading vs. clipped sample) were not statistically different ($P < 0.05$) from the most similar programmed equation. Based on double sampling, we found that the regression (calibration) equations from September 1989 to March 1990 ($r = 0.74$) and November 1990 to February 1991 ($r = 0.74$) were not statistically different ($P < 0.05$) from programmed equation 4, while the regression (calibration) equations from June 1989 to September 1989 ($r = 0.63$), April 1990 to October 1990 ($r = 0.73$), and March 1991 to June 1991 ($r = 0.84$) were not statistically different ($P < 0.05$) from programmed equation 5. These results agree with the recommendations of Robbins et al. (1989).

Daily growth rates for 1989-1990 and 1990-1991, except for November and December are shown in Fig. 1. Set-stocking during November and December resulted in no rest period during which to measure regrowth. George et al. (1992) reported DGRs less than 10 lb/acre/d for interior locations during November and December. Mild winter temperatures at coastal locations may result in DGRs exceeding 10 lb/acre/d from November through January.

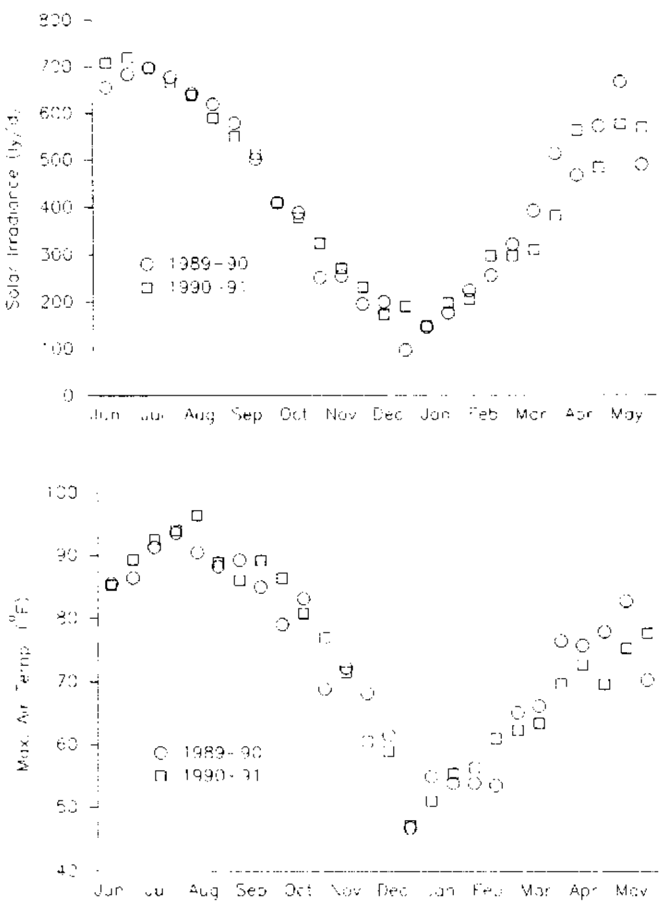

Fig. 2. Mean daily solar irradiance (ly) and maximum air temperature (°F) averaged over 14-d periods in 1989-1990 and 1990-1991.

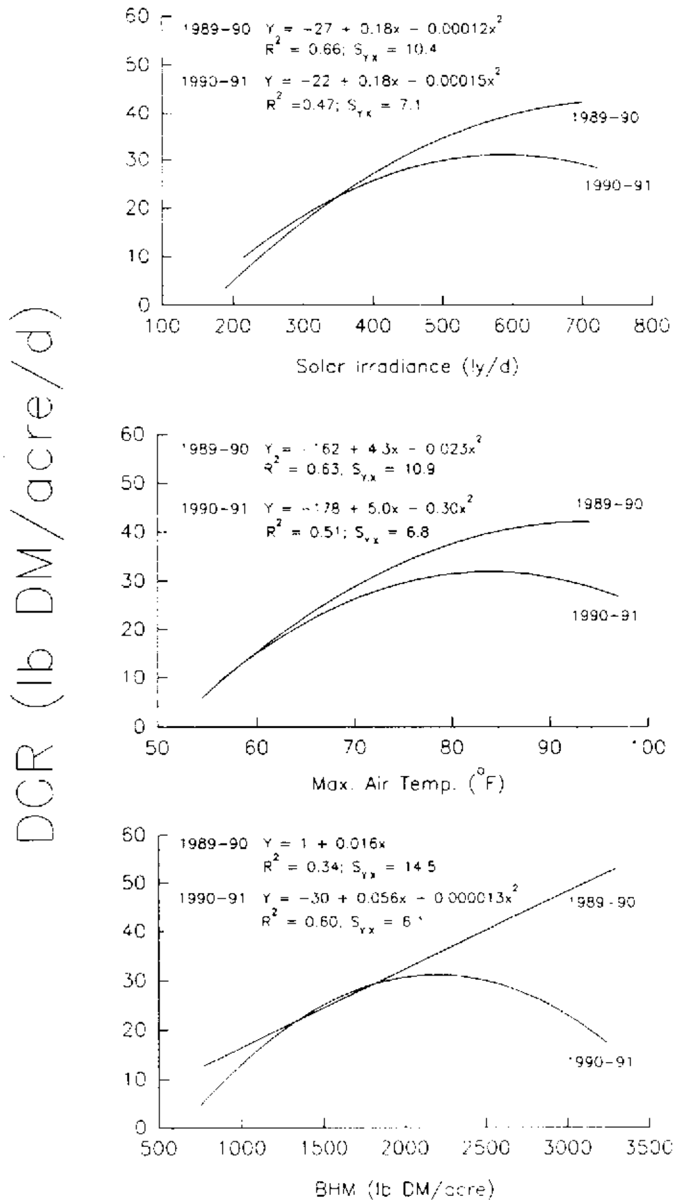

Fig. 3. Daily growth rate response to solar irradiance, maximum daily air temperature, and beginning herbage mass ($S_{y.x}$ = standard error of the estimate).

High DGRs recorded in late April 1990 and May 1991 were followed in both years by a noticeable decline in DGR over the next few weeks. Seasonal averages of daily solar irradiance and daily maximum air temperature are shown in Fig. 2. Daily growth rate was positively correlated with solar irradiance and maximum daily air temperature (Fig. 3). Data analysis using extra sums of squares showed significant curvature in DGR response to solar irradiance and maximum air temperature in both years. Therefore, the squares of these variables were added to form quadratic equations. As the light saturation point is approached, solar radiation is used with decreasing efficiency (Chang, 1968). Summer maximum daily air temperatures exceed the optimum range for temperate grass growth (Mitchell, 1956) on most days. This may explain the curvilinear response of DGR to the high temperatures and levels of solar irradiance observed in the summer.

Solar irradiance and maximum air temperature were the weather variables most closely related to DGR. The other weather variables had similar effects on DGR but had lower coefficients of determination. These results agree with Brougham (1959). The coefficients of determination (R^2) of the quadratic for minimum air temperature, maximum soil temperature, and minimum soil temperature were 0.60, 0.60, and 0.57 (year 1) and 0.48, 0.45, and 0.46 (year 2), respectively.

Daily growth rate increased with increasing BHM until BHM reached approximately 2500 lb DM/acre. At BHM of more than 2500 lb DM/acre, DGR decreased (Fig. 3). At high herbage mass, DGRs can be expected to decline, because aging and shading of leaves reduce the photosynthetic capacity of the sward (Jewiss and Woledge, 1967; Woledge, 1977). Very few BHM levels in year 1 were high enough to reduce growth rate, but several occurred in year 2. Therefore, in year 1, DGR showed a linear response to BHM, while in year 2 a quadratic equation gave the best fit. Bircham and Korte (1984) reported that DGR for ryegrass-white clover pastures increased as herbage mass increased until herbage mass reached 2200 to 2700 lb DM/acre. Consequently, the New Zealand Ministry of Agriculture and Fisheries (1985) recommends that ryegrass-white clover pastures be kept under 2500 lb DM/acre to maintain maximum DGR.

The equations that best describe the relationship of DGR to the independent variables used in multiple regression are given in Table 1. Multiple regression analysis showed that in year 1 the subset of independent variables that best predicted DGR was solar irradiance, solar irradiance squared, and BHM ($R^2 = 0.71$). In year 2, the best subset was solar irradiance, solar irradiance squared, BHM, and BHM squared ($R^2 = 0.68$).

Although solar irradiance was the best weather variable for predicting DGR, using maximum daily air temperature, which may be more readily available, gave similar results. The subset of maximum air temperature, maximum air temperature squared, and BHM gave a strong coefficient of determination ($R^2 = 0.67$) with DGR in year 1. Adding BHM squared to the subset resulted in an equally strong coefficient of determination ($R^2 = 0.67$) in year 2.

Table 1. The relationship betweeen DGR and the independent variables for each year.

1989–1990

$$DGR = -21 + 0.21\ SR - 0.012\ BHM - 0.00011\ SR^2 \quad (R^2 = 0.71;\ n = 96;\ S_{y.x} = 9.7)$$

$$DGR = -217 + 6.0\ AT - 0.0099\ BHM - 0.32\ AT^2 \quad (R^2 = 0.67;\ n = 96;\ S_{y.x} = 10.4)$$

1990–1991

$$DGR = -47 + 0.18\ SR + 0.034\ BHM - 0.00015\ SR^2 - 0.0000091\ BHM^2 \quad (R^2 = 0.68;\ n = 101;\ S_{y.x} = 5.5)$$

$$DGR = -128 + 2.9\ AT + 0.036\ BHM - 0.016\ AT^2 - 0.0000092\ BHM^2 \quad (R^2 = 0.67;\ n = 101;\ S_{y.x} = 5.6)$$

where
DGR = lb DM/acre/d
SR = average daily solar irradiance (ly)
AT = average daily maximum air temperature (°F)
BHM = beginning herbage mass (lb DM/acre)
$S_{y.x}$ = Standard error of the estimate.

All weather variables considered in this study were highly correlated with each other. With such a high degree of correlation, including more than one weather variable did little to improve the regression equation.

Physiological differences that occur in plants over the course of a year must be considered as a source of variation in the response of growth to weather. During the spring flush of growth, DGRs are likely to be higher than those predicted by weather variables and herbage mass. As the inflorescence begins to mature, dry matter production will slow. With more years of data, patterns of departure from the predicted line may become clear.

Individual ranches and pastures may have variations in soil condition and fertility, irrigation practices, species composition, and adaptations of pasture plants to the local environment, which will effect DGR. This study, however, has shown the nature of the relationships between DGR and weather and has also demonstrated how grazing management can influence DGR.

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