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South Dakota Beef Report, 2005

Animal Science Reports

2005

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Recommended Citation

Smart, Alexander J.; Dunn, Barry H.; Xu, Lan; Johnson, Patricia S.; and Gates, Roger N., "Forecasting Forage Yield on Clayey Ecological Sites in Western South Dakota using Weather Data" (2005). *South Dakota Beef Report, 2005.* Paper 23.
http://openprairie.sdstate.edu/sd_beefreport_2005/23

Forecasting Forage Yield on Clayey Ecological Sites in Western South Dakota using Weather Data[1]

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BEEF 2005 - 22

Summary

The ability to forecast annual forage yield from weather data would be useful for making appropriate adjustments to stocking rates in order to achieve or maintain desired plant communities. Our objective was to determine the relationship between weather variables and annual forage yield from three distinct plant communities on clayey ecological sites in western South Dakota. Forage yield and weather data were collected from 1945 through 1960 at the Cottonwood Range and Livestock Research Station, in western South Dakota. Pastures stocked at 0.25, 0.40, and 0.60 AUM/acre from 1942 to 1960 developed into western wheatgrass-dominated, western wheatgrass-shortgrass co-dominated, and shortgrass dominated plant communities, respectively. Forage data were compiled from previously reported data and raw data. Spring (April-June) precipitation, the last calendar day that the minimum temperature was 30°F or below, and previous year's spring precipitation were best predictors ($R^2 = 0.81$) of forage yield in western wheatgrass dominated plant communities. Spring precipitation and the last calendar day that the minimum temperature was 30°F or below were best predictors ($R^2 = 0.69$) of forage yield in western wheatgrass-shortgrass co-dominated plant communities. Spring precipitation was the best predictor ($R^2 = 0.52$) of forage yield in shortgrass dominated plant communities. In western South Dakota, managers of these plant communities can make reliable estimates of annual forage yield by the end of June using precipitation and temperature measurements.

Introduction

The ability to forecast annual forage yield from weather data would be useful for making appropriate adjustments to stocking rates in order to achieve or maintain desired plant communities. Identifying the key weather variables that determine forage yield would help managers focus their attention on what to measure and when to make grazing decisions. Stocking rate decisions are critical in determining long-range sustainability and productivity of range ecosystems and ultimately the financial success of ranches. Over-stocking of rangeland has led to increased soil bulk density, increased runoff of water and sediment, reduced soil cover, reduced infiltration, and increased weedy forbs and woody plant species. All of these factors and others lead to a shift in species composition and to less productive vegetation which negatively impacts animal production management opportunities. Therefore enhancing the grassland manager's sensitivity to seasonal influences of weather patterns on forage production will enable managers to make stocking rate adjustments.

In a South Dakota agricultural experiment station bulletin (Johnson et al. 1951), the authors recognized that spring precipitation (April, May, and June) influenced total forage growth more than summer precipitation. Since the warm-season grasses consisted mainly of shortgrasses such as blue grama and buffalograss, late summer rainfall did little to increase the season's total forage production because the cool-season forages had already produced the majority of their biomass for that year. Heitschmidt (2004) confirmed this by examining 15 sites in the northern Great Plains and found that 91% of the annual forage was produced by July 1.

At the Cottonwood Range and Livestock Research Station from 1942 to 1960 different

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summer stocking rates were used to develop three distinct plant communities: western wheatgrass-dominated (historically referred to as excellent range condition), western wheatgass-shortgrass co-dominated (historically referred to as good range condition), and shortgrass dominated (historically referred to as fair range condition). The major tools for determining stocking rates have been condition of range site compared to its ecological potential and annual precipitation. Forecasting annual forage yield from spring weather data would help range managers make mid-season adjustments to stocking rates in order to achieve or maintain desired plant communities. Our objective was to determine the relationship between weather variables and annual forage yield by early summer from three distinct plant communities in western South Dakota.

Materials and Methods

Site Description

This study was conducted at South Dakota State University's Range and Livestock Research Station near Cottonwood, South Dakota. The research station is located in the Northern Great Plains mixed-grass prairie, approximately 75 miles east of Rapid City. Topography of the research station is gently sloping with long, rolling hills and relatively flat-topped ridges. The long-term average annual precipitation from 1909 to 2002 is 16 inches, 77% of which falls from April to September (High Plains Regional Climate Center, 2003). Predominant soil of the experimental pastures is clay developed over the Pierre shale formation. Predominant ecological site classification is Clayey. Vegetation is typical of mixed-grass prairie. Dominant species on native pastures are the cool-season mid-grass, western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Love) and warm-season shortgrasses, blue grama (*Bouteloua gracilis* [H.B.K.] Lag. Ex Griffiths) and buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.). Long-term differential season-long stocking has resulted in the development of three distinct plant communities (Table 1).

Weather Variables

Weather data were collected from the weather station at the research station headquarters approximately 1 mile from experimental pastures. Variables measured were daily minimum and maximum temperature and daily precipitation. From these variables, monthly mean minimum and maximum temperatures were calculated. Three accumulated growing degree day (GDD) indexes were calculated each year using the following equation:

GDD = ∑from March 15 to April 30, May 31, or June 30[$(T_{max} + T_{min})/2 - T_{base}$]

where T_{max}, T_{min}, T_{base} are daily maximum temperature, daily minimum temperature, and base temperature of 40°F, respectively. The last spring calendar day when the daily minimum temperature was below 30°F and the number of times the minimum daily temperature reached below 32°F after April 1 were calculated for each year. Precipitation was summed by month, growing season, and year. Previous spring (April-June), fall (September-December), and annual (January-December) precipitation were calculated for each year. Number and amount of precipitation received in daily rain event size classes from <0.24 in, 0.24 to 0.59 in, 0.63 to 1.18 in, and >1.18 in were summed from April to October for each year, respectively.

Grazing History

In the late 1930s, an experimental plan was developed by researchers to collect data on summer grazing of mixed-grass rangeland at three stocking rates (light, moderate, and heavy) at the Cottonwood station. In 1939 and 1941, rangeland was surveyed, fenced, and water sources were developed for two pastures at each stocking rate treatment (Johnson et al. 1951). Pasture sizes were 180, 133, and 80 acres for the light, moderate, and heavy stocking treatments, respectively. From 1942-1967, pastures were stocked at 0.25, 0.40, and 0.61 AUM/acre for the light, moderate, and heavy stocking rates, respectively (Lewis et al. 1983). During 1942 through 1950 pastures were grazed from May through November by Hereford cows at fixed stocking rates. In 1951, a put-and-take stocking method (the use of variable animal numbers during a grazing period or grazing season, with a periodic adjustment in animal numbers in an attempt to maintain desired sward management, i.e. degree of defoliation; Glossary of Terms in Range Management 1998) was put in place to achieve better control over forage utilization. Utilization (estimated by visual inspection and by clipping outside and inside protected cages) for the light, moderate, and heavy grazing intensities was aimed at 25, 45, and 65%, respectively. In 1953 pastures were stocked with 2-year old Hereford cows and their performance was monitored through 1959. In 1960, yearling steers were grazed on the pastures at the three stocking rates.

Forage Yield

From 1942 to 1951, forage yield was estimated in each pasture using three movable grazing exclosures (Johnson et al. 1951). At the beginning of each grazing season, grazing exclosures were relocated to different areas within the pasture to estimate the current year's forage yield. Within each exclosure, three 9-ft^2 plots were hand clipped at crown level using grass shears approximately June 15 and August 15 to estimate peak standing biomass of the cool-and-warm-season forages. Forage was air dried and weighed.

During 1952-1954 forage production was estimated by placing two movable grazing exclosures on each of eight different areas based on soil and topography within each pasture (Lewis et al. 1956). At the beginning of each grazing season, grazing exclosures were relocated to different areas within the pasture to estimate current year's forage production. Within each exclosure, three 2-ft^2 plots were clipped in June and August. In 1952 and 1953, medium height grasses were clipped to a 1 in stubble height and short grasses were clipped to crown height. In 1955 all grasses were clipped just above the first leaf. The clipped vegetation was dried in a forced air oven at 140°F for 72 hours and weighed.

From 1956 to 1960, 11 to 21 movable grazing exclosures were located on each pasture to estimate forage yield based on soil and topography. As before, exclosures were moved to new locations within each pasture at the beginning of each year. Within each exclosure, two 2-ft^2 plots were clipped to near ground level with grass shears in June and August to estimate peak standing biomass for cool- and warm-season forages. Clipped vegetation was dried in a forced air oven at 140°F for 72 hours and weighed.

Statistical Analysis

The association between approximately 60 weather variables and annual forage yield from 1945 to1960 was determined using correlation analysis [PROC CORR (SAS 1999)]. Variables that had the strongest correlation with forage yield were used to develop separate prediction equations for each plant community using multivariate, stepwise regression procedures [PROC REG (SAS 1999)]. Data from 1942-1944 were not included in the analysis because grazing treatment effects had not achieved the desired plant communities until 1945 (Johnson et al. 1951).

Results and Discussion

Western Wheatgrass Dominated Plant Communities

Forecasting annual forage yield by the end of June in western wheatgrass dominated plant communities was related best to cumulative spring (April-June) precipitation, the last spring calendar day when the daily minimum temperature was below 30°F, and spring precipitation from the previous year. When forage production in western wheatgrass dominated plant communities was predicted using only a spring precipitation variable, none of the models had an $R^2 > 0.22$. The inability of any single precipitation variable to explain a large portion of the variation in forage yield may be related to the complex dynamics of western wheatgrass dominated plant communities (Table 1). For example, forage yield for the western wheatgrass dominated plant community was highly variable as expressed by its coefficient of variation of 33%. In particular, deviation of annual forage yield from the long-term average did not coincide with similar deviations in spring precipitation. For instance, forage yield was 900 lb/acre above the long-term average in 1949 when spring precipitation was approximately 2.8 in below normal.

When the last spring calendar day when the daily minimum temperature was below 30°F was added to the model, the fraction of variation explained increased ($R^2 = 0.47$, $P = 0.02$). Pastures with western wheatgrass dominated plant communities have more cool-season midgrasses and less warm-season shortgrasses than shortgrass dominated plant communities (Table 1). Partial R^2 attributed to spring precipitation and the last spring calendar day when the daily minimum temperature was below 30°F was 0.21 ($P = 0.08$) and 0.25 ($P = 0.03$), respectively. Cool-season grasses such as western wheatgrass typically start growing in mid-April and peak in production by the end of June in the Northern Great Plains (White 1983). Cold temperatures, especially those below 32°F rupture plant cell walls and damage meristem tissue in plants (Pearce and McDonald 1978). Fructans that provide chill tolerance decreases dramatically in the spring when plants are concurrently developing stem structure (Gonzalez et al. 1990). Therefore, grass plants in a rapid growth phase would be more susceptible to freezing temperatures. As a result, plant dry weight has been reduced after being subjected to low temperatures (Humphreys and Eagles 1988).

When spring (April-June) precipitation from the previous year was added to the model the proportion of variation explained by the model increased to 82% (Table 2). Partial R^2 attributed to spring precipitation, the last spring calendar day when the daily minimum temperature was below 30°F, and spring precipitation of the previous year were 0.12 ($P = 0.07$), 0.19 ($P = 0.01$), and 0.51 ($P < 0.01$), respectively. One reason that spring precipitation was highly correlated ($r = 0.71$, $P < 0.01$) to annual forage production may be due to the fact that 48% of the annual precipitation falls between April-June (HPRCC 2003). The effect of precipitation from the previous year often had a lag effect on current year forage yield. For instance, forage yield was above the 16-year mean in 1949 when current spring precipitation was below normal, but because previous spring precipitation was above normal, there may have been abundant soil moisture for good growth that increased plant vigor in terms of roots and shoot buds for next year's season. Similarly, in 1951 forage yield was 850 lb/acre below the 16 year mean when spring precipitation was only 1.34 in below average, but because spring precipitation the previous year, 1950, was 57% below average, soil moisture and plant vigor was probably reduced in 1951. Favorable spring growing conditions (i.e. moderate temperature and adequate soil moisture) and light grazing are necessary to maintain western wheatgrass dominated plant communities.

Western Wheatgrass-Shortgrass Co-dominated Plant Communities

Forecasting annual forage yield by the end of June in western wheatgrass-shortgrass co-dominated plant communities was related best to cumulative spring precipitation of April-June and the last spring calendar day when the daily minimum temperature was below 30°F (Table 2). When forage yield was predicted by spring precipitation alone, the R^2 was 0.34. Since these plant communities are co-dominated by western wheatgrass and shortgrasses (Table 1), an explanation may be that some spring moisture is used by the cool-season grasses and some is stored in the soil and used later in the growing season for the warm-season shortgrasses. Sala et al. (1992) hypothesized that larger precipitation events tend to wet the soil to depths beyond the influence of evaporation and the more frequently a wet day follows a wet day (small or large rainfall events) the greater the probability that some water will seep deeper into the soil and remain for a longer period. Spring rainfall at Cottonwood followed this pattern. For example, 86% of the rain events were 0.59 in or less and accounted for 54% of the amount of precipitation during April-June. Only 14% of rainfall events were >0.59 in but accounted for 46% of the precipitation during April-June. Of the rain events that occurred during this period, 45% occurred following the day after a previous rain and 70% of them occurred no more than 2 days after a previous rain.

When the last spring calendar day when the daily minimum temperature was below 30°F was added to the cumulative spring precipitation, the model explained more variation in forage yield (Table 2). Partial R^2 attributed to spring precipitation and the last spring calendar day when the daily minimum temperature was below 30°F were 0.33 ($P = 0.02$) and 0.36 ($P < 0.01$), respectively. The relationship between the last spring calendar day when the daily minimum temperature was below 30°F and forage yield in western wheatgrass-shortgrass co-dominated plant communities would be similar to that previously discussed for western wheatgrass dominated plant communities. Previous spring, fall, or annual precipitation was not significantly related to current annual forage yield. This may be related to the rooting depth of warm-season shortgrasses such as blue grama and buffalograss. Blue grama has been shown to have more than 70% of its root biomass in the top 4 in of soil (Coffin and Lauenroth 1991), whereas a greater proportion of western wheatgrass root system is at lower depths (Coupland and Johnson 1965, Weaver 1958).

Shortgrass Dominated Plant Communities

Forecasting annual forage yield by the end of June in shortgrass dominated plant communities was related best to cumulative spring precipitation of April-June (Table 2). Brown and Trlica (1977) showed that blue grama dominated range in eastern Colorado had two production peaks, one in late-July and one in early-

September. The strong relationship between spring precipitation (r = 0.72, P = <0.01) and forage yield in our study indicates that soil moisture was probably being stored, as described by Sala et al. (1992), for warm-season shortgrass production later in the growing season.

Forage yield in shortgrass dominated plant communities was not related to the last spring calendar day when the daily minimum temperature was below 30^{o}F. Since the major species of these plant communities were warm-season and given that the last spring calendar day when the daily minimum temperature was below 30^{o}F averaged May 2 and ranged from April 6 to May 23, the last spring calendar day when the daily minimum temperature was below 30^{o}F would not affect warm-season dominated pastures because the warm-season grasses would not have begun their rapid growth phase until June (Dickinson and Dodd 1976). In addition, forage yield in shortgrass dominated plant communities was not related to spring, fall or annual precipitation received in the previous year. Since these plant communities were dominated by warm-season shortgrasses, which have short root systems, soil moisture stored from the previous year may have been deeper in the soil profile and therefore out of the reach of most of the root system.

Implications

The ability to explain 52-82% of the variation in forage yield from these pastures, which varied in their degree of composition and complexity, using climatic information is important. However, compared to monocultures, the fraction of variation in forage yield explained by climatic variables was less. For example, Currie and Peterson (1966) were able to explain 88% of the variation in crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] yield from April precipitation, because much of the annual growth of crested wheatgrass was completed by the end of April (Currie and Peterson 1966). Sneva and Hyder (1962) also demonstrated that forage yields from seeded ranges could be predicted accurately (R^2 = 0.80 to 0.94) with crop-year precipitation. Forage yields from native rangeland have been predicted but, with less accuracy (Dahl 1963, Lauenroth and Sala 1992, Smoliak 1956, Sneva and Hyder 1962). It is likely that native rangeland, with greater species diversity and longer duration of forage production would be less predictable from a relatively small number of climatic variables compared to seeded pasture.

Key variables derived from this long-term data set offer a reasonable explanation for the main factors that influence forage yield on these diverse plant communities in clayey ecological sites in western South Dakota. In the western South Dakota mixed-grass prairie, April, May, and June precipitation events, the last spring calendar day when the daily minimum temperature was below 30^{o}F, and spring precipitation from the previous year were useful in forecasting current annual forage yield by July 1. The usefulness is in the ability of managers to make stocking rate adjustments for the rest of the growing season. If forage is going to be below average then strategies, such as early weaning or de-stocking might be necessary to avoid over utilizing forage resources. Likewise, if forage yield is going to be above normal, forage could be stockpiled for winter grazing or more animals could be grazed for a longer period of time.

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Tables

Table 1. Percent species composition, based on biomass, and standard deviation in parenthesis from western wheatgrass dominated (WW), western wheatgrass-shortgrass co-dominated (WWSG), and shortgrass dominated (SG) plant communities averaged over 1952-1960 at the SDSU Cottonwood Range and Livestock Research Station, Cottonwood, SD.

	Plant Community		
Species	WW	WWSG	SG
	-------------------- % Composition --------------------		
Blue grama	14 (15)	22 (18)	17 (18)
Buffalograss	22 (22)	45 (24)	63 (22)
Western wheatgrass	39 (24)	17 (13)	9 (11)
Other[1]	15 (NA)	16 (NA)	11 (NA)

[1] Other is calculated by difference, standard deviation not available.

Table 2. Prediction equations of forage yield from weather variables in western wheatgrass dominated (WW), western wheatgrass-shortgrass co-dominated (WWSG), and shortgrass dominated (SG) plant communities from 1945-1960 at the SDSU Cottonwood Range and Livestock Research Station, Cottonwood, SD.

Plant Community	Variables[1]	Prediction equation[2]	R-square	P-value
WW	S, PS, DOY	$Y = 2464 + 120(S) + 153(PS) – 22(DOY)$	0.81	<0.01
WWSG	S, DOY	$Y = 2717 + 117(S) – 19(DOY)$	0.69	<0.01
SG	S	$Y = 519 + 84(S)$	0.52	<0.01

[1] S equals cumulative precipitation (in) for April-June; PS equals previous year's spring (April-June) cumulative precipitation (in); DOY equals the last spring calendar day when the daily minimum temperature was below 30°F.
[2] Y equals forage yield (lb/acre).