Influence of Climatic Conditions on Production of Stipa-Bouteloua Prairie Over a 50-Year Period

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Abstract

Range forage yields obtained over a 50-year period at the Research Substation near Manyberries in southeastern Alberta were analyzed in relation to several climatic factors. The basic variables were precipitation, pan evaporation, temperature, hours of sunlight, and wind velocity. The precipitation from April through July was highly correlated with range forage production and this relationship could be utilized to predict the annual forage production by 1 August each year. A slightly better correlation was obtained when range forage production was related to the total of the previous September plus the current April through July precipitation. Pan evaporation totals, mean temperature, and hours of sunlight were negatively correlated with forage production, while wind velocity during the growing season showed a low relationship to forage production. Stepwise regression analysis showed that the inclusion of May and June mean temperatures with June and July precipitation accounted for 63% of the variation in range forage production. The predicted forage yield would be useful in making management decisions or adjustments, especially during drought periods, while the long-term forage yield data can be utilized in range forage models or in validating their effectiveness.

Studies on the response of mixed prairie to weather and climatic fluctuations have been mostly concerned with changes in floristic composition, with less attention to the relationship between climatic variations and range forage yields. Such relationships could provide ranchers with some method of predicting suitable stocking rates on native rangelands and aid ecologists in understanding short-term and long-term rangeland ecosystem dynamics.

The relationship between precipitation and yield of range vegetation was investigated as early as 1922 in north-central Montana by Patton (1927). More recent studies by Rogler and Haas (1947) in North Dakota, Smoliak (1956) in southeastern Alberta, Rauzi (1964) in Wyoming, Hulett and Tomanek (1969) in western Kansas, and Ballard (1974) in Montana explored the relationship between precipitation during the growing season and range forage yields. The good correlations that they found could be utilized to predict seasonal range forage production as early as 1 July. Other studies showed that fall-through-summer precipitation better explained the variation in total forage production but spring precipitation best predicted grass production (Noller 1968, Whitman and Haugse 1972).

Range forage production has also been related to soil type. In a study of 14 sites, Cannon (1983) found that thickness of mollic epipedon of range soils was significantly related to forage production and that using thickness and mean annual precipitation improved the estimate of range forage production.

Weather fluctuations on Mixed Prairie grassland in the Northern Great Plains were shown to result in a dominance of xeric species during drought periods and mesic species under more favorable growing conditions (Coupland 1958, 1959). Provision of more favorable growing conditions through weather modification may be a possibility with cloud seeding to increase precipitation. Hausle (1972) concluded that the amount of forage production that could result from additional precipitation could be predicted by statistical methods where long-term production and climatological data are available. Ballard and Ryerson (1973) indicated that increased precipitation resulting from weather modification will probably have a significant effect on range forage production only when combined with good livestock and grazing management practices. They suggested that such an increase should not be used as a basis for increasing stocking rates but rather should be used for increasing production efficiency and as a forage reserve in low production years. The response of Northern Great Plains grasslands to added water is complex and highly variable (Perry 1976) and timing of added precipitation is very important (Collins and Weaver 1978).

A rangeland production model has been developed (Wight 1983) to provide a basis for management decisions by predicting herbage yields, livestock production, runoff, and erosion. However, testing of the model has been a major problem as useable long-term field data are limited.

Most investigations on the relationship of range forage production to several meteorological factors have been based on relatively short terms of 20 years or less. However, the study reported here relates range forage production of a *Stipa-Bouteloua* prairie to several meteorological factors over a period of 50 years.

Methods

The study area was located on the Agriculture Canada Research Substation, Manyberries, in southeastern Alberta. The soil was a loamy Aridic Haploboroll. The vegetation belongs to the *Stipa-Bouteloua* faciation of the Mixed Prairie Association. Principal forage species include needle-and-thread (*Stipa comata* Trin. and Rupr.), western wheatgrass (*Agropyron smithii* Rydb.), blue grama (*Bouteloua gracilis* (HBK) Lag.), junegrass (*Koeleria cristata* (L.) Pers.), Sandberg's bluegrass (*Poa secunda* Presl.), and threadleaf sedge (*Carex filifolia* Nutt.), in order of decreasing yield. Abundant forbs are moss phlox (*Phlox hoodii* Richards.) and clubmoss (*Selaginella densa* Rydb.), while common shrubs include fringed sage (*Artemisia frigida* Willd.) and silver sagebrush (*A. cana* Pursh.).

Meteorological data during the study period were recorded at the Substation. Although several fields were used in the study, all clipping sites were less than 4.5 km away from the official weather station.

From 1930 to 1943, 36 plots (3.34-m^2) were clipped annually, and in 1947 and 1948, 15 (1-m^2) plots were clipped in a field protected from grazing. During 1949 to 1983, 15 (0.84-m^2) plots, protected from grazing by portable cages, were clipped annually. The portable cages were randomly distributed in large fields that were grazed by cattle at a moderate rate throughout the study period. All plant growth was removed prior to protection with portable cages the previous fall, thus the harvested vegetation was the current year's growth. Forbs and shrubs were included with grasses to represent total production. Vegetation was clipped at ground level with hand shears after the forage was mature, usually in late September. The 1930 to 1943 harvested samples were air-dried, while the 1947 to 1983 samples were oven-dried. No forage yield data were available for 1941, 1944, 1945, and 1946.

The analytical methods used to determine the effect of the meteorological factors on range forage production employed simple correlation and regression and stepwise multiple regression analyses. A total of 45 variables, mainly those during the growing season, were used in the analysis. The basic ones were precipitation, pan evaporation, temperature, hours of sunlight, and wind velocity.

Results

There were considerable fluctuations in range forage production and the measured meteorological factors over the 50-year period

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(Table 1). Forage yields varied from a low of 96 kg/ha in 1961 to a high of 925 kg/ha in 1942, with a mean of 388 kg/ha. Highest precipitation amounts were recorded in 1965 for the period April through July, annual, and previous year plus January through July while the lowest amounts recorded were in 1936 for April through July and the previous year plus January through July, and in 1943 for annual. Mean amounts of precipitation were 164 mm for April through July, 327 mm for the annual, and 558 mm for the previous year plus January through July total. Evaporation during May through July averaged 584 mm, but ranged from a low of 322 mm in 1955 to a high of 947 mm in 1973. Mean temperature during April through July was 12.8° C, with a low of 10.0° C in 1967 and a

Table 1. Forage production and selected meteorological values at Manyberries, Alberta, over a 50-year period.

Year	Forage yield (kg/ha)	Precip. (mm) Apr. - July	Evap. (mm) May - July	Mean temp. (°C) Apr. - July	Sunlight (hr) Apr. - July	Mean wind speed (km/hr)* Apr.-July	Annual precip. (mm)	Precip. (mm) previous year plus Jan. - July
1930	257	138	546	13.6	1051	—	294	508
1931	280	148	580	13.6	1055	—	237	462
1932	409	195	435	13.4	994	—	339	450
1933	295	160	607	13.2	1088	—	313	513
1934	247	116	560	14.0	1189	—	243	468
1935	325	132	499	11.5	1057	—	209	421
1936	183	67	683	15.4	1141	19.0	237	325
1937	280	96	503	13.9	1106	20.9	230	390
1938	434	158	374	13.2	968	15.9	370	456
1939	350	129	576	13.6	1003	18.7	249	599
1940	444	186	512	13.0	930	16.2	327	500
1942	925	291	537	12.2	910	16.4	416	691
1943	252	102	494	12.8	909	19.0	194	560
1947	343	109	565	13.6	1099	17.7	246	506
1948	213	157	337	12.7	1006	—	252	448
1949	101	113	539	14.6	1117	19.0	284	430
1950	303	148	484	11.6	930	19.3	283	487
1951	471	155	412	11.8	1016	18.8	459	538
1952	460	132	398	12.8	1055	19.0	281	675
1953	547	213	356	10.7	941	18.3	305	547
1954	567	202	361	10.7	875	20.6	428	569
1955	695	337	322	11.2	913	20.0	408	802
1956	549	208	394	12.6	996	24.1	365	669
1957	426	112	430	13.3	1054	22.7	350	534
1958	419	128	508	13.3	1029	17.0	334	564
1959	276	148	558	12.4	1108	21.1	306	539
1960	270	137	574	13.1	1080	17.0	285	506
1961	96	78	721	13.8	1003	17.5	215	386
1962	214	167	494	13.2	943	17.8	287	437
1963	267	146	544	13.1	972	18.0	266	500
1964	279	159	568	13.2	998	19.6	384	513
1965	736	419	483	11.6	861	18.7	600	851
1966	558	155	802	12.2	1097	22.5	345	814
1967	518	178	762	10.0	1080	—	430	693
1968	519	126	779	11.4	840	20.3	320	600
1969	308	100	755	13.3	933	19.8	243	508
1970	359	219	763	13.2	1067	20.0	352	514
1971	354	157	731	12.6	1128	18.7	316	595
1972	296	125	750	12.6	1100	21.1	334	526
1973	188	98	947	12.7	1147	—	219	442
1974	476	216	757	13.4	1144	19.3	385	500
1975	593	295	604	10.7	1051	18.7	572	755
1976	439	175	737	13.4	1231	18.8	300	795
1977	257	114	851	13.7	1252	—	286	431
1978	707	220	576	12.4	1110	19.6	513	632
1979	558	117	710	11.9	1209	17.5	342	752
1980	222	162	767	14.8	1342	17.9	333	570
1981	362	190	622	12.7	1143	20.3	311	582
1982	437	189	653	11.4	1144	19.5	459	655
1983	326	153	697	12.5	1049	—	290	668
Mean	388	164	584	12.8	1049	19.1	327	558

*39 years only.

high of 15.4°C in 1936. Total hours of sunlight during April through July ranged from a low of 840 in 1968 to a high of 1,342 in 1980, with a mean value of 1,049. Mean wind velocity during April through July over a 39-year period was 19.1 km/hr, and ranged from 15.9 km/hr in 1938 to 24.1 km/hr in 1956.

Correlations between forage production and the various meteorological measurements at selected periods are shown in Table 2. Forage production was significantly correlated with precipitation for the months of April, May, June, and July, but a better correlation (0.74) was obtained with the April through July total, or seasonal precipitation. In a previous study (Smoliak 1956), May plus June precipitation was more closely related to forage production than was seasonal precipitation. Annual precipitation, when correlated with yield, also showed a correlation coefficient of 0.74, but as indicated by Le Houerou (1984), although it has no predictive value for the current summer grazing season, it does have a probabilistic value for long-term planning. Seasonal precipitation therefore gives a better predictive value of the current year's forage production than the annual total and could be used more effectively in management application especially if rangelands are grazed during the growing season (Shiflet and Dietz 1974). The various combinations of seasonal precipitation did not improve the relationship when correlated with forage yield.

The regression equation derived from the relationship of forage yield and April through July precipitation is $Y = 72.2 + 1.93 X$, where Y is the estimated yield of forage in kilograms per hectare and X is the total April through July, or seasonal, precipitation in millimeters. This equation may be used as an estimate of annual forage production as early as 1 August each year to make management adjustments in the event of drought, to devise grazing plans for fall or winter grazing, or to prepare grazing management plans for the next year.

There was a low but significant relationship between precipitation recorded the previous year, the total previous winter snow, precipitation recorded the previous September or during the previous two years, and forage production. The inclusion of several monthly totals of precipitation improved the above relationships greatly with the highest correlation coefficient (0.77) being obtained with the addition of April through July precipitation to the previous September total (Table 2). The regression equation for this relationship was $Y = 36.6 + 1.87 X$, where Y is the estimated forage yield and X is the precipitation for the previous September plus the April through July total. The relationship between the previous year through July precipitation and forage yield also showed a high correlation ($r = 0.74$).

Pan evaporation totals, mean temperature, and hours of sunlight were negatively correlated with forage production (Table 2). The highest correlation coefficient (−0.62) was obtained between the relationship of April through July mean temperature and forage production. Wind velocity recorded during the growing season did not show any relationship to forage production.

Stepwise multiple regression analyses conducted on yield and the monthly values of precipitation, pan evaporation, hours of sunlight, mean temperature, and average wind velocity during the growing season (April through July) which meet the 0.15 significance level required for entry into the model, are shown in Table 3. The inclusion of temperature improved the relationship between precipitation and forage yield. However, the inclusion of hours of sunlight, wind velocity, or evaporation did not improve the correlation significantly. The best relationship was with the June and July precipitation totals and the May and June temperatures which accounted for 63% ($r = 0.79$) of the variation in range forage yields.

Table 2. Single correlation coefficients (r) between certain meteorological factors and forage production over a 50-year period.

	Precipitation (mm)											Evap. (mm)	Temperature (°C)			Sunlight (hr)		Wind speed[2] (km/hr)		
Independent variable	Apr.	May	June	July	Aug.	Sept.	May + June	Apr.–July[1]	Annual	Prev. Yr. –July	Prev. Sept. +Apr. – July	May – Sept.	May	June	Apr.– July	June	Apr. – July	June	Apr. July	Forage Yield kg/ha
Apr. ppt (mm)	1.00	0.20	−0.20	0.13	−0.08	−0.05	−0.03	0.42**	0.43**	0.42**	0.45**	0.05	−0.46**	−0.10	−0.52**	0.27	−0.03	−0.01	−0.07	0.40**
May ppt (mm)	—	1.00	0.12	0.28	0.04	0.14	0.68**	0.71**	0.59**	0.35*	0.65**	−0.17	−0.36*	−0.04	−0.28*	0.24	−0.10	−0.09	−0.23	0.46**
June ppt (mm)	—	—	1.00	−0.05	0.22	0.33	0.81**	0.53**	0.41*	0.34*	0.47**	−0.23	−0.01	−0.37**	−0.19	−0.44**	−0.31*	−0.08	0.04	0.42**
July ppt (mm)	—	—	—	1.00	−0.24	−0.12	0.12	0.51**	0.28*	0.34*	0.56**	−0.30*	−0.16	0.08	−0.17	0.15	−0.21	0.45**	0.19	0.41**
Aug ppt (mm)				—	1.00	0.21	0.18	0.03	0.38**	0.14	−0.06	−0.06	−0.05	−0.16	−0.18	−0.02	0.05	0.26	0.42**	0.12
Sept. ppt (mm)						1.00	0.32*	0.20	0.41**	0.08	0.14	−0.21	−0.14	−0.12	−0.19	−0.11	−0.19	−0.02	0.01	0.26
May + June ppt (mm)							1.00	0.81**	0.65**	0.46**	0.73**	−0.27	−0.22	−0.30*	−0.31*	−0.18	−0.29*	−0.11	−0.11	0.58**
Apr. – July[1] ppt (mm)								1.00	0.78**	0.62**	0.96**	−0.31*	0.40**	−0.25	−0.50**	−0.01	−0.34*	0.05	−0.03	0.74**
Annual ppt (mm)									1.00	0.61**	0.69**	−0.18	−0.32*	−0.24	−0.53**	0.12	−0.16	0.05	0.05	0.74**
Prev. yr–July ppt (mm)										1.00	0.66**	0.08	−0.34*	−0.44**	−0.55**	0.01	−0.06	0.15	0.15	0.74**
Prev. Sept. + Apr. – July ppt (mm)											1.00	−0.28*	−0.41**	−0.29*	−0.50**	−0.05	−0.35*	0.03	−0.05	0.77**
May–Sept. evap. (mm)												1.00	0.11	0.18	0.12	0.34*	0.48**	−0.09	−0.01	−0.25
May temp (°C)													1.00	0.16	0.74**	−0.01	0.33*	−0.14	−0.03	−0.41**
June temp (°C)														1.00	0.48**	0.54**	0.25	0.18	−0.01	−0.46**
April–July temp															1.00	−0.16	0.42**	−0.15	−0.15	−0.62**
June sunlight (hr)																1.00	0.65**	0.16	−0.02	−0.11
April–July sunlight (hr)																	1.00	0.03	0.05	−0.34*
June wind (km/hr)[2]																		1.00	0.80**	0.09
April–July wind (km/hr)[2]																			1.00	0.04
Forage yield (kg/ha)																				1.00

[1]April through July, inclusive

[2]39 years only

* **significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Stepwise multiple regression equations for production (Y in kg/ha) of native rangeland as a function of monthly precipitation (mm) and temperature (°C).

	r
Y_1 = 286.0 + 3.85 × July precipitation	0.49
Y_2 = 1128.6 + 4.18 × July precipitation −55.6 × June temperature	0.70
Y_3 = 815.5 + 1.46 × June precipitation + 4.22 × July precipitation − 41.5 × June temperature	0.76
Y_4 = 1021.8 + 1.40 × June precipitation + 3.83 × July precipitation − 22.2 × May temperature −37.7 × June temperature	0.79

Discussion

Forage production of the *Stipa-Bouteloua* prairie in southeastern Alberta can be predicted with some confidence from the total of April through July, inclusive, or seasonal precipitation. For greater precision, the precipitation total recorded the previous September plus the April through July total could be utilized. Such predictions, based upon precipitation, could be used effectively in planning grazing operations after 1 August. In a previous study (Smoliak 1956), based upon 20 years of data, the May and June total of precipitation showed the best relationship when correlated with range forage yield. However, the data may be of more use in determining management schemes for the next year rather than for predicting forage yields for the current year.

The high correlations between the relationships of precipitation the previous year, or the previous September through June or July, and forage production is likely the response to accumulated soil moisture during the fall and spring periods. Soil moisture data were not available for this long-term study but Rogler and Haas (1947) and Johnston et al. (1969) found that range forage yields were greatly influenced by fall soil moisture. Caprio and Williams (1973) also noted that the amount of soil moisture at the start of the growing season is highly variable from year to year and that this available soil moisture is largely a function of the previous season's precipitation. The dependency between the previous year's and current year's yields found by Hanson et al. (1982) was attributed to soil moisture, as well as plant vigor and other biological factors.

During the 50 years that forage yields were obtained, 12 years were above-average, 26 years were average, and 12 years were below-average. The below-average and above-average values included all yields less than 0.7 or greater than 1.3 of the long-term average, respectively, as used by Hanson et al. (1982). The frequency of below-average range forage production, about once in 4 years, indicates that greater attention must be given to establishing proper stocking rates which would provide an adequate carry-over of forage during average years.

The yield data presented, in conjunction with meteorological records, can be used in range forage yield models to forecast range forage production (Wight et al. 1984, Wisiol 1984) and to prepare management plans during the grazing season. The data also can be utilized in the study of the feasibility of weather modifications in rangeland areas and in predicting the effectiveness of such manipulations. However, the predictive equations may be applicable only to the particular site as different range vegetation types or range soils would show varied estimates of production (Looman 1980; Cannon 1983; Cannon and Nielsen 1984).

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