Relationships Between Chihuahuan Desert Perennial Grass Production and Precipitation

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Abstract

Perennial grass production on the Chihuahuan Desert Rangeland Research Center in south-central New Mexico was correlated with precipitation characteristics over a 34-year period. Total December through September precipitation was highly correlated ($r = +0.77$, $n = 34$) with perennial grass production. Practical generalized indices were developed that could be broadly applied by managers for predicting perennial grass production from precipitation characteristics. Perennial grass production and precipitation data on 3 separate pastures were collected over a 6-year period to evaluate the reliability of models to predict perennial grass production. Simple linear, 2-variable, quadratic, and polynomial regression models gave perennial grass production estimates that were well correlated with actual values ($r = +0.85$ to $+0.91$, $n = 17$) across the 3 pastures. The quadratic regression model ($Y = 4.04 - 0.24X + 0.012\ X^2$, X = December through September precipitation, Y = forage production, $n = 34$, $r = 0.85$) gave the most accurate predicted values. Our quadratic regression model should be of practical use to ranchers and range managers on Chihuahuan Desert upland rangelands receiving 200–300 mm annual precipitation, with loamy to sandy loam soils and in mid- to late-seral ecological condition. These conditions match those generally found on Chihuahuan Desert Uplands. We consider our quadratic regression model to be highly useful over large areas to ranchers in southern New Mexico, southeastern Arizona, southwestern Texas, and north-central Mexico.

Resumen

La producción de zacates perennes en el Centro de Investigación de Pastizales del Desierto Chihuahuense en la región sur-central de New Mexico se correlacionó con las características de precipitación de un periodo de 34 años. La precipitación total de Septiembre a Diciembre estuvo altamente correlacionada ($r = +0.77$, $n = 34$) con la producción de zacates perennes. Se desarrollaron índices prácticos generalizados que pudieran ser aplicados ampliamente por los manejadores para predecir la producción de zacates perennes a partir de las características de precipitación. Los datos de precipitación y producción delos zacates perennes de tres potreros separados se colectaron en un periodo de 6 años para evaluar la confiabilidad delos modelos para predecir la producción de zacates perennes. Modelos de regresión lineal simple, de dos variables cuadráticos y polinomiales dieron estimaciones de la producción de zacates perennes que estuvieron bien correlacionados con los valores actuales ($r = +0.85$ a $+0.91$, $n = 17$) a través de los 3 potreros. El modelo cuadrático de regresión ($Y = 4.04 - 0.24X + 0.012\ X^2$, X = precipitación de Septiembre a Diciembre, Y = producción de forraje, $n = 34$, $r = 0.85$) dio los valores de predicción más certeros. Nuestro modelo de regresión cuadrática debe ser de uso practico para los rancheros y manejadores de pastizales de la parte alta del Desierto Chihuahuense que reciben una precipitación anual de 200–300 mm y con suelos de textura franca a arenosa y con una condición ecológica de etapa seral media a final. Estas condiciones se cumplen para aquellas áreas generalmente encontradas las tierras altas del desierto Chihuahuense. Consideramos que nuestro modelo cuadrático de regresión pudiera ser altamente útil para los rancheros de grandes áreas del sur de New México, Arizona y Suroeste de Texas y el Norte-centro de México.

Key Words: cattle, climate, forage, rainfall, rangelands

INTRODUCTION

Stocking rate is considered the most important aspect of successful range management (Vallentine 1990; Heady and Child 1994; Holechek et al. 2004). Sound procedures for determining sustainable stocking rates for particular rangelands have been available for many years (Holechek 1988; Troxel and White 1989; Holechek and Pieper 1992; Galt et al. 2000). Various stocking rate procedures all depend on reliable estimates of annual forage production. Determination of forage production is typically time consuming and expensive. It has long been recognized that forage production on rangelands is closely associated with annual precipitation amount and timing. Regression equations that are reasonably reliable for predicting forage production from precipitation characteristics have been developed for some rangeland biomes, including sagebrush-grassland (Sneva and Hyder 1962), mountain grassland (Mueggler 1983), pinyon-juniper (Pieper et al. 1971), midgrass prairie (Launchbaugh 1967), and Sonoran desert grassland (Cable

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Table 1. Monthly median and monthly mean precipitation (ppt; in mm) for Pasture 1 on the Chihuahuan Desert Rangeland Research Center (1969–2002).

Year	Monthly Precipitation (mm)												Mean Monthly ppt (mm)	Median Monthly ppt (mm)	Annual ppt (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
1969	12	2	0	0	5	7	50	44	53	27	0	32	19	10	232
1970	0	0	12	0	3	9	73	7	11	21	0	5	12	6	141
1971	6	0	0	8	0	0	29	39	27	49	23	13	16	10	194
1972	6	0	0	0	18	36	43	86	23	53	0	37	25	21	303
1973	18	40	6	0	46	9	32	32	0	0	0	0	15	8	183
1974	16	0	0	0	0	0	74	23	24	90	6	18	21	11	251
1975	20	17	0	11	0	0	48	9	73	0	0	14	16	10	192
1976	10	15	0	9	20	9	42	29	23	15	20	0	16	15	193
1977	9	18	9	22	1	6	47	23	45	32	9	9	19	14	230
1978	1	20	5	0	24	23	11	67	65	39	99	20	31	21	374
1979	35	6	0	9	19	14	63	55	30	0	0	32	22	17	262
1980	21	31	1	16	32	0	19	35	58	20	10	3	20	19	245
1981	23	0	13	7	46	6	43	71	34	11	14	1	23	14	271
1982	10	8	0	0	3	6	6	35	90	6	13	69	21	7	246
1983	19	14	2	19	3	11	16	12	44	39	23	5	17	15	206
1984	10	0	8	1	19	42	22	83	8	56	27	46	27	20	322
1985	28	6	18	9	0	11	56	60	65	70	3	3	27	15	330
1986	1	9	8	2	1	52	71	111	38	47	79	44	39	41	462
1987	4	10	7	2	1	28	28	98	5	3	8	30	19	7	223
1988	2	32	3	9	1	6	84	63	28	30	0	30	24	19	289
1989	9	14	14	0	1	0	39	50	8	15	3	13	14	11	167
1990	6	8	10	10	10	0	87	47	58	4	20	19	23	10	279
1991	11	14	12	0	7	2	72	69	40	0	19	121	31	13	367
1992	39	4	7	22	89	10	11	109	8	24	13	46	32	18	382
1993	34	12	1	0	5	19	58	67	4	7	15	11	19	11	233
1994	8	2	4	4	11	4	18	11	12	23	36	36	14	11	168
1995	26	14	1	0	0	18	21	41	42	0	2	6	14	10	170
1996	7	1	0	15	0	25	57	21	52	18	5	0	17	11	200
1997	16	14	18	3	11	42	57	68	26	10	12	36	26	17	312
1998	1	8	11	1	0	3	60	35	13	59	15	7	18	10	214
1999	10	0	7	0	11	62	39	65	65	20	0	11	24	11	290
2000	0	0	17	2	0	121	15	16	1	53	38	3	22	9	265
2001	10	11	3	1	10	6	22	22	68	0	4	6	14	8	162
2002	4	21	0	0	5	0	28	15	17	25	7	34	13	11	157
Total	434	349	197	181	401	587	1 440	1 619	1 159	865	525	759	710	460	8 514
Grand median	10	9	4	2	5	9	43	42	29	20	9	13	20	11	239
Grand mean	13	10	6	5	12	17	42	48	34	25	15	22	21	14	250

and Martin 1975). Detailed information on perennial grass production and monthly precipitation has been collected for 34 years on the Chihuahuan Desert Rangeland Research Center (CDRRC) in south-central New Mexico. Our objective was to evaluate the relationship between perennial grass production and precipitation characteristics for these data using correlation and regression analyses. Development of a predictive model for perennial grass production that could be broadly applied by managers was our ultimate goal. Procedures of Sneva and Hyder (1962) were used in evaluating our data and developing models that could be broadly applied. We tested the predictive accuracy of our best models using data collected over a 6-year period from 3 separate pastures on the CDRRC.

MATERIALS AND METHODS

Study Area Description

The 4 000-ha study area was located on the New Mexico State University (NMSU) CDRRC (latitude 32°32′30″N, longitude 106°52′3″W) operated by NMSU, 37 km north of Las Cruces, New Mexico, in Dona Ana County. This flat to gently rolling area is in the southern portion of the Jornada del Muerto Plains between the San Andres Mountains to the east and the Rio Grande Valley to the west. Elevation varies from 1 188 to 1 371 m. Soils of the CDRRC are fine loamy, mixed, thermic, typic haplargids of the Simona-Cruces association (Tembo 1990) underlain by calcium carbonate hard pan (caliche) at depths varying from a few centimeters to 1 m or more (Valentine 1970). In areas in which the groundcover is sparse, sand dunes form around the invading mesquite (*Prosopis glandulosa* Torr.) plants (Wood 1969).

Climate

The climate on the CDRRC is arid, with an average of 200 days in the frost-free period. The only permanent water sources are wells and pipelines provided for livestock use. Temperatures are high, with a mean maximum of 36°C during June and a mean maximum of 13°C during January (Pieper and Herbel 1982). Temperature differences are substantial between day and night. Strong winds in the spring cause severe erosion and water stress plants (Pieper and Herbel 1982).

Annual precipitation is bimodal. Summer precipitation (July–September) is from localized convectional storms of high intensity but low frequency. Winter precipitation (December–February) is relatively gentle and evenly distributed. Mean annual precipitation is 230 mm, with 52% of the annual rainfall occurring during summer.

Vegetation

Primary grass species on the study area include black grama (*Bouteloua eriopoda* Torr.), dropseeds (*Sporobolus* sp.), threeawns (*Aristida* sp.), bush muhly (*Muhlenbergia porteri* Kunth.), fluffgrass (*Erioneuron pulchellum* Tateoka), and tobosa (*Hilaria mutica* Buckley). The most commonly encountered shrub species is honey mesquite (*Prosopis glandulosa* Torr.), which dominates the overstory and has increased over the past 100 years (Pieper and Herbel 1982). Other shrubs include broom snakeweed (*Gutierrezia sarothrae* Pursh), soaptree yucca (*Yucca elata* av.), and creosotebush (*Larrea tridentata* [Pursh] Nutt.). Leatherweed croton (*Croton pottsii* Lam.), the primary forb, is an important food for livestock and pronghorn antelope (*Antelocapra americana*).

History

A detailed history of the study area (Pasture 1) on the CDRRC is provided by Holechek et al. (1994). The study area has flat terrain and is 1 300 ha in size. It was predominantly black grama grassland with a minor woody component when the CDRRC was established in 1927. Although information is vague, stocking rates for cattle averaged 40 ha per animal unit (AU), forage production averaged near 360 $kg \cdot ha^{-1}$, and forage use averaged about 35% during the 1930s and 1940s. A continuous (year-long) grazing system has been used from the past to the present. Black grama cover was greatly reduced during extended drought in the 1953–1956 period. Herbicide treatments to control brush were applied to approximately 37% of the study area (Pasture 1) in the 1958–1964 period (McNeely 1983; Holechek et al. 1994). Mesquite kill varied from 64% to 93%. Specific treatments involved application of 2,4,5-T to 80 ha in 1958 (93% kill mesquite), application of Monureen to 330 ha in 1964 (65% kill), and application of Fenuron to 67 ha in 1964 (70% kill). More details and locations of these treatments are provided by McNeely (1983).

Grazing has been carefully controlled since 1967, when the stocking rate was initially reduced to 67 $ha \cdot AU^{-1}$ (Beck 1978; Holechek 1991; Holechek et al. 1994). During the 34-year period from 1968 to 2002, forage utilization averaged about 30%. From 1992 to 1997, ecological condition based on the quantitative climax approach (Dyksterhuis 1949) has averaged 66% of the climax vegetation or late-seral (Molinar 1999).

Table 2. Total annual (January–December) precipitation, crop-year (December–September) precipitation, current growing season (July–September) precipitation, previous growing season (July–September) precipitation, and forage production ($kg \cdot ha^{-1}$) by years for Pasture 1 on the Chihuahuan Desert Rangeland Research Center.

Year	January through December Precipitation (mm)	December through September Precipitation (mm)	Current Growing Season (July–September) Precipitation (mm)	Previous Growing Season (July–September) Precipitation (mm)	Forage Precipitation ($kg \cdot ha^{-1}$)
1969	232	190	147	175	94
1970	141	148	92	147	59
1971	194	114	95	92	24
1972	303	225	152	95	141
1973	183	221	65	152	150
1974	251	137	121	65	114
1975	192	195	131	121	103
1976	193	172	95	131	134
1977	230	180	115	95	226
1978	374	224	143	115	283
1979	262	251	148	143	258
1980	245	244	111	148	110
1981	271	248	149	111	258
1982	246	159	131	149	85
1983	206	207	71	131	56
1984	322	198	113	71	143
1985	330	299	181	113	244
1986	462	296	219	181	541
1987	223	226	131	219	206
1988	289	257	175	131	347
1989	167	167	97	175	212
1990	279	248	192	97	302
1991	367	246	180	192	547
1992	382	419	127	180	840
1993	233	246	129	127	227
1994	168	84	41	129	7
1995	170	198	104	41	57
1996	200	183	130	104	93
1997	312	254	151	130	304
1998	214	169	108	151	308
1999	290	265	168	108	384
2000	265	183	32	168	246
2001	162	155	112	32	97
2002	157	97	61	112	22
Median	239	203	128	129	178
Mean	250	209	124	127	212
SD	75	64	42	42	174
CV	30	31	34	33	82

Table 3. Long-term precipitation (ppt) and forage production characteristics for different rangeland biomes in North America.

Rangeland Type	No. Years of Study	Avg Annual ppt (mm)	Avg Annual Forage Production ($kg \cdot ha^{-1}$)	CV in ppt	CV in Forage Production	Range in Forage Production ($kg \cdot ha^{-1}$)	Reference
Chihuahuan Desert (NM)	34	250	212	30	82	7–840	Present study
Sagebrush grassland (NM)	6	340	156	—	26	111–211	McDaniel et al. (1992)
Pinyon-juniper (NM)	21	380	771	—	41	193–1 324	Chili et al. (1998)
Chihuahuan Desert (NM)	32	250	401	34	64	5–1 509	Herbel and Gibbens (1996)
Midgrass prairie (CO)	10	390	1 405	—	11	1 215–1 674	Sims et al. (1976)
Midgrass prairie (KS)	10	560	3 308	—	26	1 288–5 628	Launchbaugh (1967)
Annual grassland (CA)	14	510	997	32	27	433–1 665	Bentley and Talbot (1951)
Midgrass prairie (SD)	9	370	1 774	37	23	990–2 090	Johnson et al. (1951)
Southern pineforest (LA)	11	1 470	2 041	—	25	912–2 675	Pearson and Whitaker (1974)
Northern mixed prairie (Alberta, Canada)	19	310	414	—	34	140–773	Smoliak (1974)
Salt Desert Shrubland (UT)	13	170	212	31	46	90–505	Hutchings and Stewart (1953)
Shortgrass prairie (WY)	13	380	1 116	—	33	540–1 740	Manley et al. (1997)
Southern mixed prairie (OK)	8	620	1 168	—	32	618–1 652	McIlvain and Shoop (1965)
Shortgrass prairie (CO)	6	300	774	30	20	520–879	Klipple and Costello (1960)
Shortgrass prairie (NE)	10	330	1 404	26	20	1 033–1 866	Burzlaff and Harris (1969)
Sonoran desert (AZ)	13	430	427	25	46	140–857	Cable and Martin (1975)
Sonoran desert (AZ)	10	320	403	—	50	274–707	Martin and Sieverson (1988)

Procedures

From 1967 through 1994, a total of 92 randomly located, fixed transects, each about 67 m in length, were sampled annually (McNeely 1983). These transects were located at various distances from water. Each transect was oriented in an east-to-west direction and was bounded at each end by a permanent steel stake. Grass production was measured annually at the end of the growing season by clipping 5 (5 cm × 6 m) plots systematically (12-m increments) located on each transect to a 2-cm height with hand-operated clipping shears. Because of the destructive nature of clipping, plots were shifted 1 m forward each year to avoid previously clipped areas. Vegetation was hand separated by species in the field, oven dried, and weighed. Only the current year's growth was measured.

Grazed plants were adjusted to equivalent weight of ungrazed plants by clipping ungrazed plants of similar height and basal diameter outside of quadrats. These adjustments were minimal, because very few plants within quadrats showed visible grazing use.

Beginning in autumn of 1995, a different system was used to evaluate perennial grass production and total standing crop. Ten key areas evenly spaced across the study area were used. Autumn perennial grass and total standing crop were determined by clipping twenty 0.5-m^2 quadrats at 10-m intervals along two 100-m line transects on each key area (Molinar 1999). We have found that this sampling approach gives biomass estimates that are comparable to the previous approach (McNeely 1983), and we have found that this approach is more rapid.

From 1997 through 2002, 3 other pastures on the CDRRC, one that were similar in size (1 098 ± 126 ha), were also sampled for perennial grass production using the procedures previously discussed (10 evenly spaced key areas per pasture) (Molinar 1999). Pasture 4 was in late-seral condition (64% remaining climax), and Pastures 2 and 3 were in mid-seral condition (37% and 32% remaining climax, respectively). Data from these pastures were used to test predictive accuracy of regression models developed from Pasture 1. Periodically, forage production data from the study area pastures has been summarized and published (McNeely 1983; Molinar 1999). A total of 5 rain gauges, evenly distributed across Pasture 1, were used to evaluate monthly precipitation throughout the 1969–2002 study period (Table 1). Two to three rain gauges were used to measure monthly precipitation on the 3 pastures used to evaluate accuracy of regression models developed from Pasture 1.

We evaluated relationships between perennial grass production and precipitation characteristics using linear regression and correlation analyses (Neter and Wasserman 1974). Regression analyses were performed using the Proc Reg command in SAS. The approach of Sneva and Hyder (1962) was used to organize, evaluate, and standardize our data into an index. Regression models from Pasture 1 with predictive capability were tested using data from Pastures 2 through 4. Linear correlation and regression were used to evaluate the relationship between actual and predicted perennial grass production for combined data for Pastures 2 through 4.

RESULTS AND DISCUSSION

Variation in forage production for perennial grass production on Pasture 1 averaged 212 $kg \cdot ha^{-1}$ over the 34-year period (1969–2002) (Table 2), ranging from 7 $kg \cdot ha^{-1}$ in 1994 to 840 $kg \cdot ha^{-1}$ in 1992. Our study is consistent with Herbel and Gibbens (1996) on the Jornada Experimental Range in showing that variation in forage production among years is extreme in

Table 4. Correlation coefficients ($n = 34$) for forage production and precipitation characteristics for Pasture 1 on the Chihuahuan Desert Rangeland Research Center for the years 1969 through 2002.

Period of Precipitation	Correlation Coefficient (r)
Jan	0.20
Feb	0.0091
Mar	0.22
Apr	0.20
May	0.49**
Jun	0.22
Jul	0.17
Aug	0.66**
Sep	−0.073
Oct	0.013
Nov	0.24
Dec	0.41*
Annual	.76**
Crop year	0.68**
Nov through Sep	0.75**
Dec through Sep	0.82**
Jan through Sep	0.77**
Feb through Sep	0.77**
Mar through Sep	0.77**
Apr through Sep	0.75**
May through Sep	0.73**
Jun through Sep	0.58**
Current growing season	0.54**
Previous growing season	0.43*
Previous Jul	0.29
Previous Aug	0.26
Previous Sep	0.14
Jul and Aug only	0.65**
Jul and Sep only	0.078
Aug and Sep only	0.51**
Spring	0.50**
Fall	0.35*
Winter	0.31

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

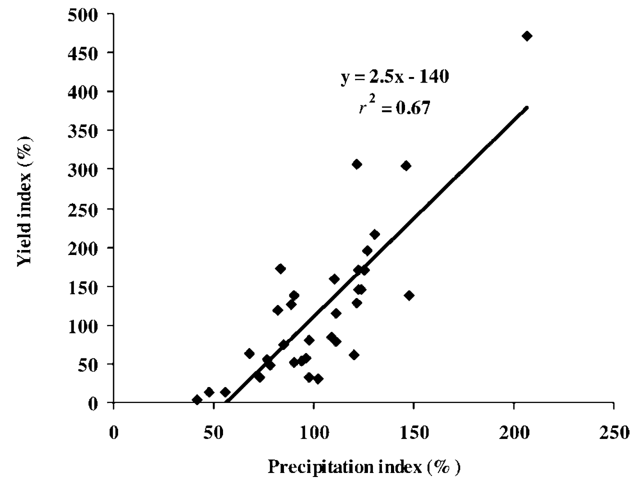

Figure 1. Simple linear relationship of perennial grass production index and total December through September precipitation index for Pasture 1 on the Chihuahuan Desert Rangeland Research Center for the years 1969 through 2002.

the Chihuahuan Desert (Table 3). It had the highest coefficient of variation of all range biomes for which we found data.

Perennial grass production on Pasture 1 was 50% or more above the mean in 15% of the years and 50% or more below the mean in 32% of the years. Complete or nearly complete destocking was necessary in about 2 out of every 10 years.

Interestingly, the coefficient of variation in annual precipitation on Pasture 1 is much lower than that for perennial grass production and is similar to that of other range types (Tables 2 and 3). The coefficient of variation in annual precipitation was near 30% for all range types (Table 3).

Several researchers have advocated that light to conservative grazing intensities (25%–35% use of forage) be applied to Chihuahuan Desert rangelands because of low grazing resistance and extreme annual fluctuations in forage production (Paulsen and Ares 1962; Galt et al. 2000; Holechek et al. 2003). Our study supports this approach to grazing management. New and prospective ranch owners need to be aware that Chihuahuan Desert ranching is riskier than in other range biomes as a result of the greater amount of variation in precipitation among years (Galt et al. 2000).

Total precipitation for December through September was the single variable that showed the highest correlation with perennial grass production ($r = 0.82$) (Table 4; Fig. 1). August precipitation was better correlated ($r = 0.66$) with perennial grass production than any other single month or total growing season precipitation.

Table 5. Correlation coefficients and regression equations for perennial grass production and precipitation indices for Pasture 1 on the Chihuahuan Desert Rangeland Research Center for the years 1969 through 2002.

Model	Correlation Coefficient (r)	Regression Equation
January through December precipitation (%) (X)	0.77	$Y = 2.38X - 130.3$
December through September precipitation (%) (X)	0.82	$Y = 2.5X - 139.7$
December through September (X_1) and previous season precipitation (%) (X_2)	0.84	$Y = -178.82 + 2.32X_1 + 0.59X_2$
Quadratic function, December through September precipitation (%) (X)	0.85	$Y = 4.04 - 0.24X + 0.012X^2$
Polynomial (cross-products) function, December through September (X_1) and previous season precipitation (%) (X_2)	0.88	$Y = 98 - X_1 + 0.0034X_1^2 - 1.45X_2 - 0.0014X_2^2 + 0.023X_1X_2$

Table 6. Total annual (January–December) precipitation, crop-year (December–September) precipitation, current growing season (July–September) precipitation, previous growing season precipitation, and perennial grass production indices (% of median) by years (1969–2002) for Pasture 1 on the Chihuahuan Desert Rangeland Research Center.

Year	January through December Precipitation (%)	December through September Precipitation (%)	Current Growing Season Precipitation (i.e., July–September) (%)	Previous Growing Season Precipitation (i.e., July–September) (%)	Forage Production (%)
1969	97	94	115	135	53
1970	59	73	72	115	33
1971	81	56	74	72	13
1972	127	111	119	74	79
1973	77	109	50	119	84
1974	105	68	95	50	64
1975	80	96	102	95	58
1976	81	85	74	102	75
1977	96	89	90	74	127
1978	157	111	112	90	159
1979	110	124	116	112	145
1980	102	120	87	115	62
1981	113	122	116	87	145
1982	103	79	102	116	48
1983	86	102	56	102	31
1984	135	98	89	56	81
1985	138	148	142	89	137
1986	193	146	171	142	304
1987	93	111	102	171	116
1988	121	127	137	102	195
1989	70	82	76	137	119
1990	117	123	150	76	170
1991	154	121	141	150	307
1992	160	207	100	141	472
1993	98	121	100	100	128
1994	70	41	32	100	4
1995	71	98	81	32	32
1996	84	90	101	81	52
1997	131	125	118	101	170
1998	89	83	85	118	173
1999	121	131	131	85	216
2000	111	90	25	131	138
2001	68	76	87	25	55
2002	66	48	47	87	13

Predictive models for perennial grass production and precipitation characteristics were improved using multiple regression equations (Table 5). Our best multiple regression equation was a polynomial with cross products using total December through September and previous growing season precipitation (Table 5).

In developing our generalized predictive model (Tables 5 and 6) we used median rather than mean precipitation based on recommendations by Sneva and Hyder (1962) and Thurow and Taylor (1999). The median best represents our precipitation

Table 7. Characteristics of the simple linear, 2-variable, quadratic, and polynomial indices used to predict perennial grass production on Pastures 2 through 4.

Regression Models for Predicting Perennial Grass Production from Precipitation	Correlation Between Actual and Estimated Perennial Grass Production	Sample Size (n)	Regression Equation between Actual and Estimated Perennial Grass Production	Mean Difference between Predicted and Actual Values	Standard Error of Difference between Predicted and Actual Values
Simple linear[1]	+0.90	17	$Y = 1.029X + 11.91$	21.96	4.96
Two-variable[2]	+0.87	17	$Y = 1.045X + 13.42$	26.07	5.20
Quadratic[3]	+0.91	17	$Y = 0.940X + 16.91$	17.98	4.34
Polynomial[4]	+0.85	17	$Y = 0.998X + 9.70$	24.98	5.48

[1]Simple linear model: $Y = 2.5X - 139.7$ (X = December through September precipitation).
[2]Two variable model: $Y = -178.82 + 2.32X_1 + 0.59X_2$ (X_1 = December through September precipitation, X_2 = Previous growing season precipitation).
[3]Quadratic model: $Y = 4.04 - 0.24X + 0.012X^2$ (X = December through September precipitation).
[4]Polynomial model: $Y = 98 - X_1 + 0.0034X_1^2 - 1.45X_2 - 0.0014X_2 + 0.023X_1X_2$ (X_1 = December through September precipitation, X_2 = Previous growing season precipitation).

data set because there were fewer wet years than dry years. During our 34-year study, there were 8 years during which precipitation was 120% or more of the mean, but 11 years during which precipitation was 80% or less of the mean. Therefore, the arithmetic mean is not a statistically valid indicator of the average, because the data are not normally distributed.

Our approach assumes that a median amount of precipitation will produce a median perennial grass yield for similar range areas. These two median values were enumerated as 100 for all areas. The percentage of precipitation and yield amounts are expressed as indices, transforming precipitation and yield data from different areas into normalized terms. They have practical application on areas within the Chihuahuan Desert with similar precipitation amounts, soil types, and ecological condition. This involves areas with 200–300 mm annual precipitation, loamy to sandy loam soils, and those in a mid- to late-seral stage.

Other research on forage production and precipitation relationships in the southwestern United States is limited to that of Pieper et al. (1971) and Cable and Martin (1975). On loamy blue grama (*Bouteloua gracilis* [H.B.K] Lag ex Griffiths) rangeland at the Fort Stanton Experimental Range in central New Mexico, Pieper et al. (1971) found that total herbage production was significantly correlated ($r^2 = 0.71$) with total annual growing season (June–September) precipitation. Multiple correlation and regression procedures were not used in the Pieper et al. (1971) study. On the Santa Rita Range in south-central Arizona, Cable and Martin (1975) found that August precipitation was most highly correlated with annual perennial grass production ($r = 0.63$). This agrees with our study ($r = 0.66$) (Table 4). In the Cable and Martin (1975) study, multiplying the previous growing season precipitation by the current August precipitation gave the best predictive equations ($r = 0.80$–0.95). Multiple regression equations did not improve predictive value over the interaction of previous growing season and current August precipitation alone. Both their study and

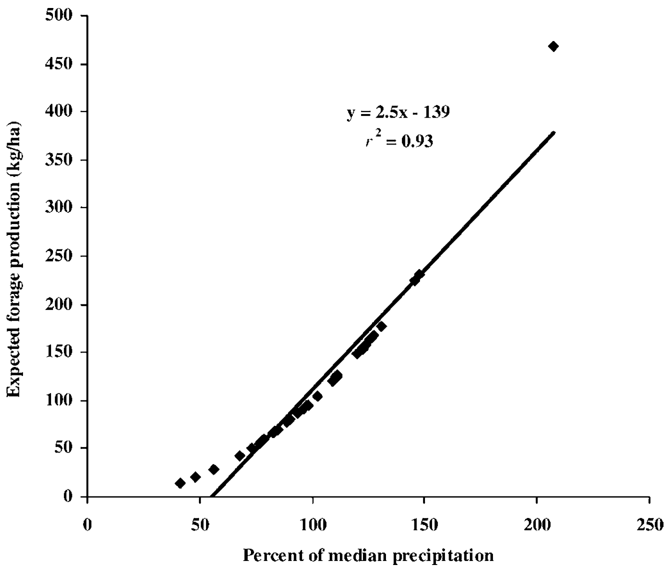

Figure 2. A curve showing expected forage production (calculated from the quadratic model) and percent of median precipitation for Pasture 1 on the Chihuahuan Desert Rangeland Research Center for the years 1969 through 2002.

our study show that previous summer precipitation plays an important role in perennial grass production.

The last step in developing our perennial grass production prediction models was to evaluate their accuracy using data from Pastures 2 through 4 on the CDRRC collected over a 6-year period (1997–2002). All the models had strong correlations ($r = 0.85–0.91$) between predicted and actual perennial grass production (Table 7), with the simple linear and quadratic models being superior to the two variable and polynomial models in their predictive capability (Figs. 1 and 2). The quadratic model using only December through September precipitation gave the best predictions based on the mean difference from actual values (Table 7). This model is relatively simple and would be easy for range managers and ranchers to apply.

Perennial grass production on Pastures 2 through 4 was predicted with adequate accuracy for most stocking rate decisions. These upland pastures are characterized by loamy to sandy loam soils and are in mid- to late-seral ecological condition. This type of rangeland predominates in the Chihuahuan Desert (Navarro et al. 2002).

MANAGEMENT IMPLICATIONS

Our 34-year study using multiple correlation and regression procedures showed perennial grass yields could be predicted from total December through September precipitation with adequate accuracy for most stocking rate decisions. We developed a generalized index from our data using median precipitation and perennial grass production values of 100. This index should be of practical use to ranchers and range managers for Chihuahuan Desert rangelands receiving 200–300 mm annual precipitation, with loamy to sandy loam soils and in mid- to late-seral ecological condition. These conditions are typical of large portions of the Chihuahuan Desert in southern New Mexico, southeastern Arizona, southwestern Texas, and north-central Mexico. We believe our index has greatest utility for annual stocking rate decisions and for adjusting forage production estimates to the median for carrying capacity estimates. In the Chihuahuan Desert, ranchers typically make stocking rate decisions in late October/early November, after perennial grasses complete growth (Paulsen and Ares 1962). Our prediction models may have application to other range types, but this determination will require further study.

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