J. Range Manage.
46:346-350, July 1993

Effects of mechanical treatments and climatic factors on the productivity of Northern Great Plains rangelands

MARSHALL R. HAFERKAMP, JERRY D. VOLESKY, MICHAEL M. BORMAN, RODNEY K. HEITSCHMIDT, AND PAT O. CURRIE

Authors are range scientist USDA-ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, Mont. 59301; research animal scientist USDA-ARS, Forage and Livestock Research Laboratory, El Reno, Okla. 73036; range ecologist USDI-BLM, Oregon State University, Corvallis, Ore. 97331; range scientist and research leader, and range scientist (retired) USDA-ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, Mont. 59301.

Abstract

Impacts of 7 range treatments and climate on late spring herbage standing crops (SC) were measured in rangelands near Miles City, Mont., from 1983 to 1990. Treatments, established in 8 pastures at 2 sites, were: (1) untreated control + season long grazing (SL); (2) soil tillage (ST) + SL; (3) ST + drill seeding legumes (DS) + SL; (4) brush control (BC) + ST + DS + switchback grazing (utilizing 2 pastures); (5) BC + ST + DS + SL; (6) ST + nitrogen fertilization + SL; and (7) contour furrowing (CF) + aerial seeding legumes + SL. Data were analyzed using years as a repeated measure. Treatments increased ($p \leq 0.05$) total SC 320 kg/ha over controls, but did not affect species/species group composition. Treated pastures produced similar ($p \geq 0.10$) SC of 881 kg/ha. Total SC averaged 490 kg/ha more ($p \leq 0.05$) in 1983, 1986, 1987, 1989, and 1990 than in 1984, 1985, and 1988. Perennial cool-season grass SC was greatest in 1986 (651 kg/ha). Peak annual grass SC (337–506 kg/ha) occurred in 1983 and 1984, the 2 years following ST or CF, and 1989 and 1990, the 2 years following severe drought. Although regression analyses showed fall, winter, and spring precipitation and temperature were closely related to spring SC, less than 50% of the variation in SC was accounted for when precipitation and temperature were summed on a 1-month, 2-month, or 3-month basis. Above-average fall and spring precipitation (September and April) resulted in the greatest total SC. Species composition varied temporally with changing weather conditions and management strategies.

Key Words: climate, temperature, precipitation, western wheatgrass, Japanese brome, drought, standing crop, annual grass competition

The magnitude of secondary productivity in grazed ecosystems is largely dependent upon primary production. To successfully increase livestock production in most grazed ecosystems often requires an increase in forage production. The broad objective of this study was to quantify the integrated impacts of soil tilling, legume interseeding, brush removal, nitrogen fertilization, and climate on herbage production of Northern Great Plains rangelands. This objective was founded on the results of previous research conducted at various locations in the Northern Great Plains which has shown precipitation and ambient air temperatures are the principal factors affecting plant growth and development (Sims and Singh 1978, White 1985, Sala et al. 1988, Frank 1988), and that dynamic shifts in herbage production occur with addition of nitrogen (Goetz et al. 1978, Wight 1976, Wight and Black 1979), removal of woody plants (Vallentine 1980), and mechanical disturbance of soil (Lacey et al. 1985, White et al. 1981, Wight et al. 1978, Kartchner et al. 1983). Moreover, the relative impacts of these treatments have been shown to vary temporally in concert with climatic variations, soil type, slope, and post treatment management tactics (White et al. 1981, Gartner 1988). This study was designed to examine the integrated effects of these factors on herbage production at a single location over several years.

Study Areas and Methods

Study Areas

Research was conducted at 2 sites on the Fort Keogh Livestock and Range Research Laboratory (46°22'N 105°5'W) near Miles City, Mont. Regional topography ranges from rolling hills to broken badlands with small intersecting ephemeral streams flowing into large rivers located in broad, nearly level valleys. Indigenous vegetation on the 22,500-ha research station is a grama-needlegrass-wheatgrass (*Bouteloua-Stipa-Agropyron*) mix (Küchler 1964). Long-term annual precipitation averages 338 mm with about 60% received during the April through August growing season (NOAA 1982–90). Total annual precipitation during the 8-year study was below average in 6 of the 8 years (Fig. 1). Temperatures often exceed 38° C during summer and decrease to –40° C or less during winter. The average frost-free period is 150 days.

The 2 study sites were located about 6 km apart. Topography of both sites ranged from gently sloping (<2%) to nearly level. Soils at site 1 were primarily a composite of Absher and Gerdrum series (heavy clay and claypan soils) (Borollic Natrargids). Soils at site 2 were silty clay loams and loams of the Ethridge and Pinelli series (Borollic Camborthids). Vegetation at both sites was indicative of a low seral stage when the study was begun. Dominant perennial grasses were: western wheatgrass [*Agropyron smithii* Rydb.; = *Pascopyrum smithii* Rydb. (Love)]; bluegrama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths]; Sandberg bluegrass (*Poa secunda* Presl.); needle-and-thread (*Stipa comata* Trin. & Rupr.); june grass [*Koeleria pyramidata* (Lam.) Beauv.], and tumblegrass [*Schedonnardus paniculatus* (Nutt.) Trelease]. Threadleaf sedge (*Carex filifolia* Nutt.) was the dominant grass-like species and

The authors express appreciation to Kevin Peterson, Cheryl Murphy, Tom Hilken, Todd Walton, and several summer aids for their assistance in conducting the experiment; Brad Knapp for assistance with statistical analyses; Bill Creamer for assistance with data management; and Mary Ellen French for assistance with graphics.
This paper is a contribution from the USDA-ARS and Montana Agricultural Experiment Station, Miles City, Mont.
Publication has been approved by the Director of the Montana Agr. Exp. Sta., Journal Ser. J-2777.
Manuscript accepted 22 Nov. 1992.

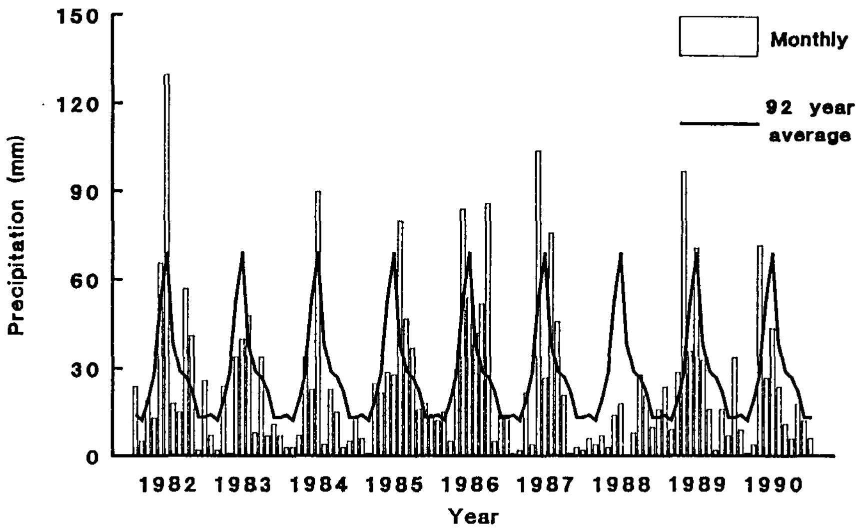

Fig. 1. Actual (Jan.-Dec., 1982-1990) and long-term (92 year) average precipitation for Miles City, Mont.

downy (*Bromus tectorum* L.) and Japanese brome (*B. japonicus* Thunb.) were the dominant annual grasses. Wyoming big sagebrush (*Artemisia tridentata* Pursh. subsp. *wyomingensis* Beetle and Young) was the dominant shrub.

Treatments

Seven treatments were established in eight 12-ha pastures at both sites in 1982. Treatments were: (1) untreated control + SL; (2) ST + SL; (3) ST + DS + SL; (4) BC + ST + DS + SB; (5) BC + ST + DS + SL; (6) ST + NF + SL; and (7) CF + AS + SL, where

BC = brush control
SL = season long grazing
SB = 2 pasture, 1 herd switchback SL grazing (treatment 4)
ST = soil tilling with Range Improvement Machine (RIM) (Currie et al. 1989)
CF = contour furrowing (Kartchner et al. 1983)
DS = drill seeding with RIM
AS = aerial seeding, and
NF = nitrogen fertilization.

Interseeded legumes were alfalfa 'Spreador II' (*Medicago falcata* L.) and cicer milkvetch (*Astragalus cicer* L.). Both were seeded at a rate of 2.2 kg/ha with the RIM (DS) or 4.4 kg/ha aerially (AS). Brush was controlled (BC) at Site 1 by mechanical chopping during the winter of 1982 whereas at Site 2 control was achieved by ground spraying with 2,4-D [(2,4-dichlorophenoxy) acetic acid] at a rate of 2.8 kg/ha before legumes emerged. Level of control at both sites was near 100%. Nitrogen fertilizer (NF) was applied with the RIM, as a single application of 56 kg N/ha of ammonium nitrate in 1982. All treatments, with the exception of BC at Site 1, were applied in spring.

All treatments were grazed during summer beginning in 1983. Grazing intensity was moderate with 3 to 5 yearling steers (avg. initial wt. = 360 kg) allotted to each SL pasture. Generally an equal number of steers grazed each pasture except for the SB treatment. Usually 10 steers grazed the 2 SB pastures (treatment 4). In this treatment, steers grazed the initial pasture until near the midpoint of the grazing season, and then they were switched to the second pasture. The pasture grazed first was alternated each year. A put-and-take stocking strategy was implemented in 1987 and 1988 in an attempt to maintain similar levels of grazing pressure among treatments. Initial stocking rates were based on standing crop estimates made before the start of grazing, and adjustments were based on standing crop estimates made during the grazing season. Dates grazing was initiated varied among years (15 May to 10 June) depending upon the spring growing conditions. Length of grazing seasons varied among years depending upon annual growing conditions, ranging from 30 days in 1988 to 90 days in 1983, 1984, 1986, and 1987.

Field sampling

Herbage standing crops were estimated annually in all pastures just before the beginning of the grazing season by hand harvesting

Table 1. Degrees of freedom (df), mean squares (MS), and F values for AOV models used to statistically analyze spring (adjusted to 5 June) standing crops for 2 sites, 7 treatments, and 5 species/species groups across 8 years (1983–1990).

	Species/Species Group			Total		
Model	df	MS	F	df	MS	F
Site (Blocks)	1	171380.9		1	856904.6	
Treatment (Trt.)	6	53847.9	4.7*	6	269239.7	4.7*
Error a	6	11536.2		6	57681.0	
Species (Sp.)	4	2739769.8	116.0**			
Trt. × Sp.	24	21008.8	0.8 NS			
Error b	28	23613.0				
Year (Yr.)	7	212219.5	13.9**	7	1061097.3	13.1**
Yr. × Trt.	42	5762.4	0.4 NS	42	28811.9	0.4 NS
Yr. × Sp.	28	134105.2	8.8**			
Yr. × Trt. × Sp.	168	6709.9	0.5 NS			
Error c	245	15304.3		49	80861.4	

*significant differences $p \leq 0.05$
**significant differences $p \leq 0.01$

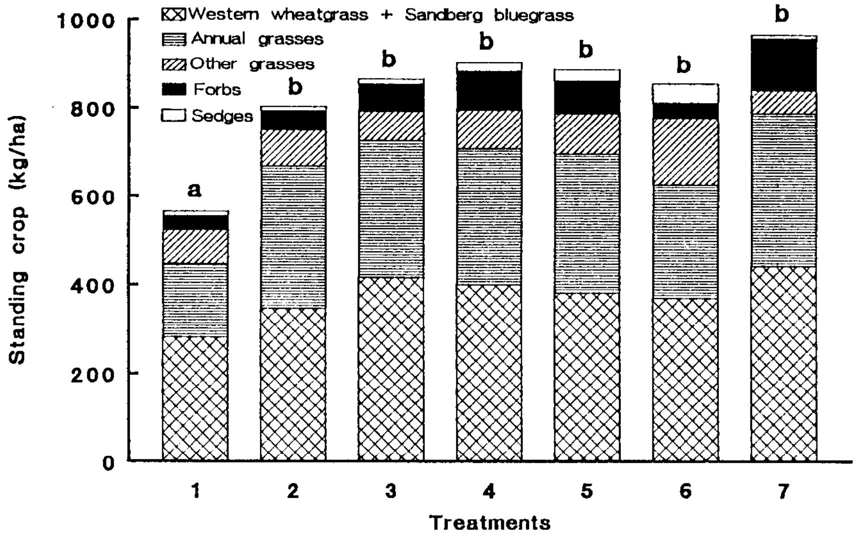

Fig. 2. Least square mean herbage standing crops by treatment (see methods for treatment definitions) averaged across 2 sites and 8 years ($LSD_{0.05}$ = 199 kg/ha). Means between columns, followed by the same letter, are not significantly different at ($p \geq 0.05$).

all current year's herbage above a 25-mm stubble height in fifteen 30 by 60-cm plots per pasture. Herbage was separated by species, oven dried in a forced draft oven at 100° C, and weighed.

Data Analyses

Experimental design was a randomized, complete block design (site = blocks). Because clipping dates varied among years all data were adjusted to day 156 (5 June) using regression. Total, individual species, and species groups (western wheatgrass + Sandberg bluegrass, annual grasses, other grasses, sedges, and forbs) standing crops were analyzed using year as a repeated measure factor (Table 1). Means were separated where appropriate using Fisher's Least Significant Difference ($p \leq 0.05$).

Regression subset analyses were used to quantify relationships between precipitation and temperature occurring during September through May, and total, western wheatgrass + Sandberg bluegrass, and annual grass standing crops. Precipitation (mm) and temperatures (° C) were entered as independent variables on a 1-month, 2-month, or 3-month basis.

Table 2. Annual least square mean standing crops on 5 June by species/species groups averaged across 7 treatments and 2 range sites near Miles City, Mont.

	Species Groups					
	Grasses					
Year	W. wheatgrass S. bluegrass	Annual	Other	Sedges	Forbs	Total
	kg/ha					
1983	268d[1]	384b	235a	28	116	1032ab
1984	190d	337bc	67b	18	30	642c
1985	219d	190d	58b	12	58	537cd
1986	651a	205d	83b	24	100	1064ab
1987	486c	264cd	66b	20	77	914b
1988	275d	26e	59b	7	40	408d
1989	428c	418ab	57b	12	64	920b
1990	524b	506a	67b	30	57	1184a
	$LSD_{0.05}$ =87				$LSD_{0.05}$ =206	

[1]Means within a column followed by same letters are not significantly different at ($p \geq 0.05$).

Results

Treatments

Treatments increased spring total standing crops an average of 320 kg/ha (Fig. 2). Differences among treatments in total standing crop were not significant and the absence (Table 1) of significant 2 and 3-way treatment interaction effects confirmed species/species group composition did not vary among treatments during the 8-year study period. The largest components of the standing crops at both sites were western wheatgrass + Sandberg bluegrass and annual grasses (Fig. 2).

Years

Total standing crops were significantly (Table 1) greater in 1983, 1986, 1987, 1989, and 1990 than in 1984, 1985, and 1988 (Table 2). Western wheatgrass + Sandberg bluegrass standing crop was greatest (651 kg/ha) in 1986 and least (<300 kg/ha) in 1983, 1984, 1985, and 1988 (Table 2). Standing crops of western wheatgrass averaged 526 and 438 kg/ha in 1986 and 1987 and 310 and 459 kg/ha in 1989 and 1990. Sandberg bluegrass standing crops were 18 and 29% of the perennial cool-season component in 1986 and 1989, respectively, averaging 123 kg/ha.

Annual grasses contributed 37 and 52% of the standing crops produced in 1983 and 1984. During the 2 years following the severe drought of 1988 annual grasses contributed 43%. Annuals, however, contributed only 6 to 29% of the standing crop in 1986 through 1988. Japanese brome and downy brome contributed 60 to 96% of the annual grass standing crop from 1984 to 1990. Other annual grass species included little barley (*Hordeum pusillum* Nutt.) and 6-weeks fescue [*Vulpia octoflora* (Walter) Rydb.]. Brome species were not separated in 1983, so percentages were not determined. From 1984 to 1990, species composition of the annual grass component ranged from 28 to 72% Japanese brome and from 20 to 60% downy brome. Japanese brome averaged >50% of the annual grass standing crop in 1984, 1985, 1988, 1989, and 1990, whereas downy brome averaged >50% in 1986 and 1987.

The remaining components of the herbage (other grasses, sedges, and forbs) were only minor components of standing crops during the study (Table 2). These categories did not vary significantly among years except for the decline in other grasses after 1983 (Table 2). The decline in other grasses may have been related to the stimulatory effect of mechanical range treatments on western wheatgrass + Sandberg bluegrass (Wight et al. 1978, White et al. 1981, Gartner 1988).

Climate

Since there was no significant interaction between treatments, species/species groups, and years, the standing crops data were pooled to examine the effect of precipitation and temperature on the total standing crop and those of the 2 dominant (see Fig. 2 and Table 2) species groups; perennial cool-season (western wheatgrass + Sandberg bluegrass) and annual grasses (Table 3). Monthly precipitation in October and November accounted for 44% of the variation in total standing crop the following spring. Two-month precipitation totals for September + October and November + December precipitation accounted for 44% of the variation, and 3-month totals of precipitation and average temperature for December–February accounted for 40% of the variation.

Table 3. Regression equations and coefficients of determination that best describe the relationship between monthly precipitation and average monthly temperature during September through May and total, western wheatgrass + Sandberg bluegrass, and annual grass standing crops.

Total species	
1-month	R^2
$y = 714.139 + 15.227\ J$[1]	0.06
$y = 310.065 + 15.711\ 0 + 32.153\ N$	0.44
2-month	
$y = 408.852 + 17.940\ ND$	0.34
$y = 204.064 + 4.028\ SO + 18.341\ ND$	0.44
3-month	
$y = 614.385 + 0.228\ (DJF)^2$	0.27
$y = 865.354 + 0.242\ (DJF)^2 + 47.850\ TDJF$	0.40
$y = 619.866 + 10.590\ DJF + 2.245\ MAM + 50.010\ TDJF$	0.43
Western wheatgrass + Sandberg bluegrass	
1-month	R^2
$y = 226.28 + 1.158\ (N)^2$	0.40
$y = 292.583 + 1.104\ (N)^2 - 0.739\ (TD)^2$	0.50
2-month	
$y = 294.847 + 0.114\ (ND)^2$	0.15
3-month	
$y = 151.34 + 2.467\ MAM$	0.23
$y = -205.101 + 0.185\ (DJF)^2 + 5.443\ (TMAM)^2$	0.42
$y = -170.866 - 27.748\ DJF + 0.663\ (DJF)^2 + 72.217\ TMAM$	0.49
Annual grasses	
1-month	R^2
$y = 140.383 + 10.570\ D$	0.22
$y = -191.476 + 10.911\ D + 4.259\ (TO)^2$	0.34
$y = 171.310 + 8.765\ 0 - 21.878\ J + 5.798\ A$	0.38
2-month	
$y = 76.797 + 8.824\ ND$	0.24
$y = 223.500 + 4.313\ MA + 30.680\ TJF$	0.36
3-month	
$y = 579.817 - 3.948\ (TMAM)^2$	0.14
$y = 430.707 + 1.302\ MAM - 3.559\ (TMAM)^2$	0.20
$y = 212.186 + 9.236\ MAM - 0.042\ (MAM)^2 - 4.577\ (TMAM)^2$	0.30
$y = -265.437 + 11.726\ MAM + 37.050\ TSON - 0.053\ (MAM)^2 - 3.517\ (TMAM)^2$	0.36

[1]S-Sept., O-Oct., N-Nov., D-Dec., J-Jan., F-Feb., M-March and May, A-April, T-temperature

At least 49% of the variation in standing crops of western wheatgrass + Sandberg bluegrass was explained by monthly precipitation in November and average temperature in December, and 3-month precipitation totals in December–February and average temperature in March–May. Monthly precipitation in October, January, and April; 2-month precipitation totals in March + April and average temperature in January + February; and 3-month precipitation totals in March–May and average temperatures in March–May and September–October were the most important factors affecting annual grass production.

Discussion

We conclude from the results of this 8-year study that the mechanical disturbance of the soil surfaces was the dominant component of the 6 established treatments associated with the observed increases in herbage standing crops, and that annual variations in climatic conditions tended to have a greater impact on standing crops than did the treatments. Maximum year-to-year effect in our study was about 1.6 the treatment effect. Results suggest the increase in forage production was not attributed to major shifts in species composition over time. This finding is in contrast to the results from most studies which have shown that mechancial furrowing increased yield of perennial (Wight et al. 1978, White et al. 1981, Griffith et al. 1985, Gartner 1988) or annual (Gartner 1988, Klemmedson and Smith 1964) cool-season grasses. We assume the pretreatment dominance of western wheatgrass and annual grasses in our study areas limited species response to treatments.

Definitive trends in species response to annual variation in climatic conditions were apparent. Forage production of Sandberg bluegrass tended to increase following drought, and both Sandberg bluegrass and western wheatgrass increased when fall and spring precipitation were above average. Several authors have reported increases in Sandberg bluegrass following drought (Hurtt 1951, Reed and Peterson 1961, Whitman et al. 1943) and a positive relationship between production of perennial and annual cool-season grasses and amounts of fall and spring precipitation (Sneva 1982, Smoliak 1986, White 1985, Whisenant 1990).

Standing crops of annual grasses were greatest the 2 years immediately following mechanical disturbance of the soil and the 2 years immediately following the severe drought of 1988. Annual grasses have been shown previously to increase with soil disturbance in the Great Basin (Klemmedson and Smith 1964) and South Dakota (Gartner et al. 1986) similar to that resulting from the establishment of contour furrows. Japanese brome often invades in South Dakota without disturbance (Whisenant 1990, Whisenant and Uresk 1990), with its invasion enhanced by wet falls or the presence of a dense cover of ground litter when fall precipitation is average or less.

The permanency of the increase in annual grasses, particularly Japanese brome, that occurred following the severe drought in 1988 is unknown. It seems reasonable to assume, however, that annual grasses will continue to increase in stature throughout the northern mixed prairie particularly on areas where fire and/or intensity of grazing by large herbivores has been greatly reduced (Whisenant 1990). We suspect also that because the range in climatic condition during this 8-year study was broad (e.g., severe drought in 1988) and because contour furrowing has been shown to dampen year-to-year variation in forage production (Wight et al. 1978, White et al. 1981), the relationships revealed in the analyses may not reflect longterm trends. For example, the significant correlations during these years between September and March (r=0.37), September and May (r=0.74), October and March (r=0.31), November and April (r=0.43), and November and May (r=0.74) precipitation may have unduly impacted vegetation response and/or the statistical analyses thereof. Thus, the low R^2s relating precipitation and temperature to June standing crops were not totally unexpected.

The dynamic nature of the relationshp between environment and vegetation in the Northern Great Plains continually poses a challenge for land managers. Maintenance of a viable livestock industry requires special management skills especially in a region characterized by large and rapid changes in forage production, resulting from periods of above- and below-average precipitation. Predictive equations or models (Wight et al. 1984) are needed that can be used by livestock producers early in the growing season to predict or determine the potential forage production for that year.

This should permit more efficient management of livestock and enhance management of rangeland in the region.

Literature Cited

Currie, P.O., D.A. Adams, and J.D. Volesky. 1989. Herbage dynamics and plant-animal performance on altered Northern Great Plains rangeland, p. 573–574. *In:* Proc. XVI Int. Grassl. Congr. Nice, France.

Frank, A.B. 1988. Physiological and morphological responses of forage grasses, p. 16–20. *In:* R.S. White and R.E. Short (eds.) Achieving efficient use of rangeland resources. Fort Keogh Res. Symp., September 1987, Miles City, Mont.; Montana Agr. Exp. Sta.

Gartner, F.R. 1988. Improvement practices that increase range efficiency, p. 86–91. *In:* R.S. White and R.E. Short (eds.). Achieving efficient use of rangeland resources, Fort Keogh Res. Symp., September 1987, Miles City, Mont.; Montana Agr. Exp. Sta.

Gartner, F.R., E.M. White, and R.I. Butterfield. 1986. Mechanical treatment and burning for high quality range forage, p. 135–140. *In:* South Dakota Beef Report, Animal Range Sciences Dep., Agr. Exp. Sta., Coop. Ext. Serv., South Dakota State Univ., Brookings.

Goetz, H., P.E. Nyren, and D.E. Williams. 1978. Implication of fertilizers in plant community dynamics of Northern Great Plains rangelands, p. 671–674. *In:* Hyder, D.N. (ed.) Proc. First Int. Rangeland Congr. 14 August. Denver, Colo.

Griffith, L.W., G.E. Schuman, F. Rauzi, and R.E. Baumgartner. 1985. Mechanical renovation of shortgrass prairie for increased herbage production. J. Range Manage. 38:7–10.

Hurtt, L.C. 1951. Managing Northern Great Plains cattle ranges to minimize effects of drought. USDA Circ. 865.

Kartchner, R.J., J.R. Wight, J.L. Bishop, and R.A. Bellows. 1983. Beef and forage production on contoured furrowed rangeland interseeded with alfalfa. J. Range Manage. 36:479–482.

Klemmedson, J.O., and J.G. Smith. 1964. Cheatgrass (*Bromus tectorum* L.). Bot. Rev. 30:226–262.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. Amer. Geog. Soc. Spec. Pub. 36. Amer. Geog. Soc. N.Y.

Lacey, J.R., J.R. Wight, and J.P. Workman. 1985. Investment rationale for range improvement practices in eastern Montana. J. Range Manage. 38:2–6.

National Oceanic and Atmospheric Administration. 1982–1990. Climatological data annual summary, Montana. 85–93:(13).

Reed, M.J., and R.A. Peterson. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains Range. USDA Tech. Bull. 1252.

Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. Primary production of the central grassland region of the United States. Ecology 69:40–45.

Sims, P.L., and J.S. Singh. 1978. The structure and function of ten western North American grasslands. III. Net primary production, turnover, and efficiencies of energy capture and water use. J. Ecol. 66:573–597.

Smoliak, S. 1986. Influence of climatic conditions on production of *Stipa-Bouteloua* prairie over a 50-year period. J. Range Manage. 39:100–103.

Sneva, F.A. 1982. Relation of precipitation and temperature with yield of herbaceous plants in eastern Oregon. Inter. J. Biomet. 6:263–276.

Vallentine, J.F. 1980. Range development and improvements. 2nd ed. Brigham Young University Press. Provo, Utah.

Whisenant, S.G. 1990. Postfire population dynamics of *Bromus japonicus*. Amer. Midl. Natur. 123:301–308.

Whisenant, S.G., and D.W. Uresk. 1990. Spring burning Japanese brome in a western wheatgrass community. J. Range Manage. 43:205–208.

White, E.M., F.R. Gartner, and R. Butterfield. 1981. Range claypan soil improvement: response from furrowing and ripping in northwestern South Dakota. J. Range Manage. 34:119–125.

White, L.M. 1985. Stand age, precipitation, and temperature effects on forage yield. J. Range Manage. 38:39–43.

Whitman, W., H.C. Hanson, and R. Peterson. 1943. Relation of drouth and grazing to North Dakota range lands. North Dakota Agr. Exp. Sta. Bull. 320.

Wight, J.R. 1976. Range fertilization in the Northern Great Plains. J. Range Manage. 29:180–185.

Wight, J.R., and L.A. Black. 1979. Range fertilization: plant response and water use. J. Range Manage. 32:345–349.

Wight, J.R., E.L. Neff, and R.J. Soiseth. 1978. Vegetation response to contour furrowing. J. Range Manage. 31:97–101.

Wight, J.R., C.L. Hanson, and D. Whitmer. 1984. Using weather records with a forage production model to forecast range forage production. J. Range Manage. 37:3–6.