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Long-term cattle gain responses to stocking rate and grazing systems in northern mixed-grass prairie ☆

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Abstract

The effects of stocking rate and grazing system on gains of yearling beef cattle grazing rangelands have largely been addressed in short-term (<10 years) studies, and often stocking rates are confounded within grazing systems with higher stocking rates for short-duration rotational grazing systems compared to season-long grazing. A grazing system (season-long and short-duration rotational grazing) × stocking rate (light: 16 steers/80 ha, 18.0 animal unit days/ha; moderate: 4 steers/12 ha, 30.1 animal unit days/ha; and heavy: 4 steers/9 ha, 40.1 animal unit days/ha) study was initiated in 1982 on northern mixed-grass prairie. Here, we report on the final 16 years (1991–2006) for yearling beef cattle gains. Average daily gains (kg/head/day) across all years with season-long grazing decreased with increasing stocking rate and grazing pressure. Heavy stocking rates reduced average daily gain by 16% and 12% compared to light and moderate stocking rates, respectively. In contrast to average daily gain, beef production (kg/ha) increased with increasing stocking rate and grazing pressure. Cattle gains were reduced by 6% with short-duration rotation compared to season-long grazing over the study period, with differences between systems observed in years with average, but not dry or wet, spring (April + May + June) precipitation. Grazing season gains (kg/head) and beef production both exhibited significant increasing hyperbolic relationships with spring precipitation, with the percentage of variation explained by spring precipitation substantially higher (62–83%) for beef production compared to grazing season gains (32–45%). The influence of spring precipitation on cattle gains suggests that incorporation of these relationships into modeling efforts for strategic planning and risk assessment will assist land managers in better matching forage and animal resources for greater sustainability in this highly variable environment.

Keywords: Average daily gain; Continuous grazing; Grazing pressure; Rotational grazing; Short-duration grazing; Spring precipitation

1. Introduction

Responses of livestock weight gains to stocking rates have been well-studied in rangelands with productivity per animal decreasing with increasing stocking rate, and productivity per unit area increasing until scarcity of forage reduces nutrient intake of livestock and productivity decreases (Bement, 1969; Holechek et al., 1998).

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In addition, livestock weight gains have been evaluated in many studies comparing season-long continuous grazing and rotational grazing systems in numerous rangeland ecosystems (Holechek et al., 1998). Effects of grazing systems on livestock weight gains are inconsistent. Studies have demonstrated advantages of season-long grazing, benefits of rotational grazing, or conclusions of no difference between grazing systems. A lack of consensus in the scientific literature on this topic is likely attributed to the confounding effect of stocking rate between the grazing systems studied. Often greater stocking density and stocking rates were employed with rotational grazing to reduce patch grazing (i.e., selectivity) of grazing animals that occurs with season-long grazing under low to moderate stocking rates (Teague and Dowhower, 2003). Comparisons between grazing systems with the same stocking rates are largely lacking in the literature. Two notable exceptions are a study conducted in tallgrass prairie (McCollum and Gillen, 1998; McCollum et al., 1999) and another in northern mixed-grass prairie (Hart et al., 1988, 1993; Manley et al., 1997) of the North American Great Plains. These studies evaluated yearling beef cattle gains for 5 years (McCollum et al., 1999) and 13 years (Manley et al., 1997) and concluded that gains per head decreased with increasing stocking rates and grazing system did not affect gains (Manley et al., 1997) or that gains were reduced with rotational grazing (McCollum et al., 1999).

Evaluation of livestock gains between grazing systems is also problematic given that most studies are short-term (3–5 years) although vegetation changes in rangelands often occur over longer periods (e.g., Manley et al., 1997). Perhaps some of the non-significant responses of livestock gains to rotational grazing systems may be manifest in the lack of substantial vegetation change that would feedback to nutritive quality, grazing behavior and intake rates and subsequent animal performance. Unfortunately, there is a paucity of studies comparing grazing systems over many (>10) years. This can be attributed to the inherent logistical constraints of maintaining infrastructure, treatment integrity and commitment to the needed frequency of vegetation sampling and animal performance responses over this lengthy time period. Here, we report on the final 16 years (1991–2006) of a study established in 1982 to evaluate effects of grazing systems (season-long and short-duration rotational grazing), stocking rates (light, moderate and heavy stocking), and their interaction on yearling beef cattle weight gains on northern mixed-grass prairie in southeastern Wyoming. Findings from earlier years of this study have previously been reported (Hart et al., 1988; Manley et al., 1997).

Our objective was to assess long-term (1991–2006) effects of stocking rates and grazing systems on livestock gains in northern mixed-grass prairie. Our specific objectives were to determine the influence of 1) stocking rate, 2) grazing system, and 3) stocking rate × grazing system interactions on livestock gains. Because forage production increases with increasing spring (April–June) precipitation at this study site (Derner and Hart, 2007), we also evaluated if spring precipitation amounts influenced livestock gains because of greater forage production. We hypothesize that 1) stocking rate, but not grazing system, nor their interaction, influences yearling beef cattle weight gains, and 2) weight gains will be positively related to spring precipitation amounts due to increased forage production.

2. Materials and methods

2.1. Site description

An experiment was initiated in 1982 on northern mixed-grass prairie at the USDA-Agricultural Research Service High Plains Grasslands Research Station, approximately 7 km northwest of Cheyenne, Wyoming, USA (41°11′ N, 104°53′ W). Mean annual precipitation (132 years) is 381 mm with a peak in May. Soils are coarse and well-drained, comprised mainly of Albinas, Ascalon and Altvan loams (mixed mesic Aridic Agriustolls) and Cascajo gravelly loam (mixed mesic Aridic Calciorthid) (Stevenson et al., 1984). Vegetation is predominately grasses. Perennial cool-season graminoids include *Pascopyrum smithii* [Rydb] *A.* Love (western wheatgrass), *Hesperostipa comata* [Trin. & Rupr.] Barkworth (needle-and-thread), *Koeleria macrantha* [Ledeb.] J.A. Schultes (prairie junegrass) and *Carex duriuscula* C.A. Mey (needleleaf sedge). *Bouteloua gracilis* [H.B.K.] Lag. ex Griffiths (blue grama) is the primary perennial warm-season grass, *Sphaeralcea coccinea* [Nutt.] Rydb).scarlet globemallow) is the primary forb, and *Artemisia frigida* Willd).fringed sage) is the primary sub-shrub. Warm-season grasses and forbs increase, and cool-season grasses decrease, with heavy stocking rates at this site (Manley et al., 1997).

2.2. Grazing treatments

In 1982, 2 grazing systems were initiated using a randomized block design on the study area that had previously been grazed very lightly by livestock and wildlife. The grazing systems were 1) season-long grazing and 2) short-duration rotational grazing having 8 paddocks with 4 grazing cycles of approximately 2, 3, 5 and 7-day grazing periods. Grazing periods were shorter in the early growing season to match timing of peak precipitation and resultant forage production (Derner and Hart, 2007), and lengthened as the growing season progressed. Pastures were targeted to be grazed from early-June to early-October with yearling steers having entry

Table 1
Grazing periods, stocking rates [steers-day/ha and animal unit days (AUD)/ha], spring (April + May + June) and annual precipitation (mm) at the High Plains Grasslands Research Station, near Cheyenne, WY, USA (1991–2006)

				Stocking rate								
	Grazing period			Light		Moderate		Heavy		Precipitation		
Year	Begin	End	Days	Steer-days/ha	AUD/ha	Steer-days/ha	AUD/ha	Steer-days/ha	AUD/ha	Spring	Class	Annual
1991	June 18	October 23	127	25.4	19.1	42.3	31.8	56.4	42.3	256.3	Wet	513.5
1992	June 16	October 1	107	21.4	16.1	35.7	26.8	47.6	35.7	123.8	Average	396.0
1993	June 6	September 30	116	23.2	17.4	38.7	29.0	51.6	38.7	196.1	Average	492.7
1994	June 1	August 9	70	14.0	10.5	23.3	17.5	31.1	23.3	99.4	Average	306.4
1995	June 21	October 12	113	22.6	17.0	37.7	28.3	50.2	37.7	329.9	Wet	575.3
1996	June 6	September 26	112	22.4	16.8	37.3	28.0	49.8	37.3	156.9	Average	393.3
1997	June 4	September 24	112	22.4	16.8	37.3	28.0	49.8	37.3	206.3	Average	578.4
1998	June 10	September 30	112	22.4	16.8	37.3	28.0	49.8	37.3	176.5	Average	315.3
1999	June 10	October 17	129	25.8	19.4	43.0	32.3	57.3	43.0	264.1	Wet	432.8
2000			0	0	0	0	0	0	0	64.2	Dry	303.5
2001	June 6	October 12	128	25.6	19.2	42.7	32.0	56.9	42.7	154.4	Average	302.7
2002			0	0	0	0	0	0	0	42.4	Dry	204.4
2003	June 9	October 17	130	26.0	19.5	43.3	32.5	57.8	43.3	160.6	Average	345.2
2004	June 9	October 15	128	25.6	19.2	42.7	32.0	56.9	42.7	127.8	Average	359.2
2005	June 7	October 14	129	25.8	19.4	43.0	32.3	57.3	43.0	195.6	Average	379.5
2006	June 7	August 24	78	15.6	11.7	26.0	19.5	34.7	26.0	72.8	Dry	254.0

Spring precipitation was classified as average if amount was within the mean ± 1 SD of the 16 years record (164.0 ± 77.4 mm), dry if less than the mean minus 1SD, and wet if greater than the mean plus 1SD.

weights across the study years of 247 ± 24 kg (mean ± 1 SD, range 209–276 kg). Cattle did not graze pastures in 2000 and 2002 due to severe drought and very low forage production (< 100 kg/ha, Derner and Hart, 2007), and grazing seasons were shortened in 1994 and 2006 due to drought. Three stocking rates were applied to the season-long grazed pastures: light (16 steers/80 ha, about 35% below recommended rate), moderate (4 steers/12 ha, the recommended rate) and heavy (4 steers/9 ha, 33% greater than the recommended rate) (Hart et al., 1988). Moderate and heavy stocking rates were used for short-duration rotational grazing with individual paddock size of 1.5 ha for the moderate rate and 1.125 ha for the heavy rate. Light, moderate and heavy stocking rates across years with full grazing seasons were 24.1, 40.0 and 53.4 steer-days/ha,

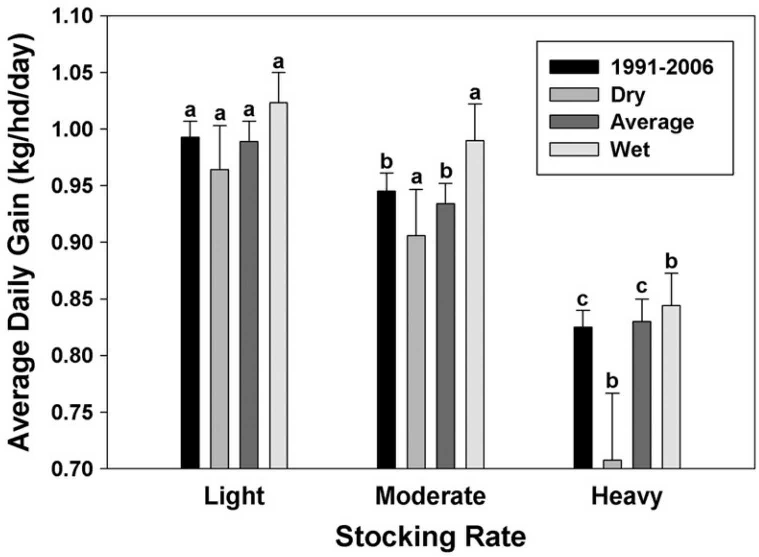

Fig. 1. Average daily gains (kg/head/day, mean ± 1SE) with season-long (mid-June to mid-October) grazing on northern mixed-grass prairie at the High Plains Grasslands Research Station, near Cheyenne, WY, USA, with light, moderate and heavy stocking rates for the 1991–2006 study years, and for dry, average and wet springs during this period. Letters indicate significant ($p < 0.05$) differences among stocking rates within a classification.

respectively. Using 0.75 as an animal unit equivalent for the yearling steers (Holechek et al., 1998), light, moderate and heavy stocking rates across years with full grazing seasons were 18.0., 30.1 and 40.1 animal unit days/ha, respectively. Two pastures were used for each stocking rate × grazing system combination with the exception of the lightly-stocked, season-long grazed treatment because of limitations with the original pasture layout.

2.3. Yearling beef cattle gains

Yearling steers, mostly Hereford with the remainder crossbred English breeds, were used throughout the study. Steers were weighed prior to and following the grazing season, after being held overnight without feed or water. Grazing season gains (kg/head) were determined by subtracting starting from end weights, average daily gains (kg/head/day) determined by dividing seasonal gains by the days of actual grazing, and beef production (kg/ha) calculated by multiplying grazing season gains by the number of steers in the treatment and dividing the product by hectares.

2.4. Statistical analyses

To determine the influence of stocking rate on cattle gain responses, we limited grazing treatments to only the season-long grazing system and initially analyzed data using a repeated measures Analysis of Variance (ANOVA) with stocking rate (light, moderate and heavy) as the single factor, acknowledging that the light stocking rate was not replicated, and year as the repeated factor. To further investigate the influence of stocking rate on cattle gains, we classified years as average if precipitation during April–June was within the mean ± 1 SD of the 16 years record (164.0 ± 77.4 mm), dry if less than the mean minus 1SD, and wet if greater than the mean plus 1SD, and used a one-factor ANOVA to analyze peak standing crop within each classification. To determine the influence of grazing system and grazing system × stocking rate interaction on cattle gain responses we used the season-long and short-duration rotational grazing systems with moderate and heavy stocking rates. A repeated measures ANOVA was used with stocking rate (moderate and heavy) and grazing system (season-long and short-duration rotational) as the two factors. To determine if spring precipitation affected our findings, we classified spring precipitation as previously described and conducted a two-factor ANOVA (grazing system and stocking rate) within each spring classification. Regression analyses were used to determine relationships between 1) grazing pressure (defined as animal unit days/Mg forage), stocking rate and cattle gains, and 2) spring precipitation and cattle gains. Forage production data from this study is reported in Derner and Hart (2007). Relationships between cattle gains and April, May and June monthly precipitation, and all possible combinations of these months, were fit with linear, power and hyperbolic functions using SigmaPlot 2000 (SPSS Inc., Chicago, IL). The model with the greatest r^2 value was used as the best fit (Derner et al., 2004). The alpha level of 0.05 was used in all comparisons to determine significance.

3. Results

3.1. Precipitation

Annual and spring (April + May + June) precipitation amounts exhibited substantial variation over this 16 year study period (Table 1). Spring precipitation exhibited an 8-fold difference from the low (42.4 mm, 2002) to high (329.9, 1995) values. Annual precipitation exhibited a 2.8-fold difference with 2002 being the driest year (204.4 mm) and 1997 (578.4) the wettest. Ten of the

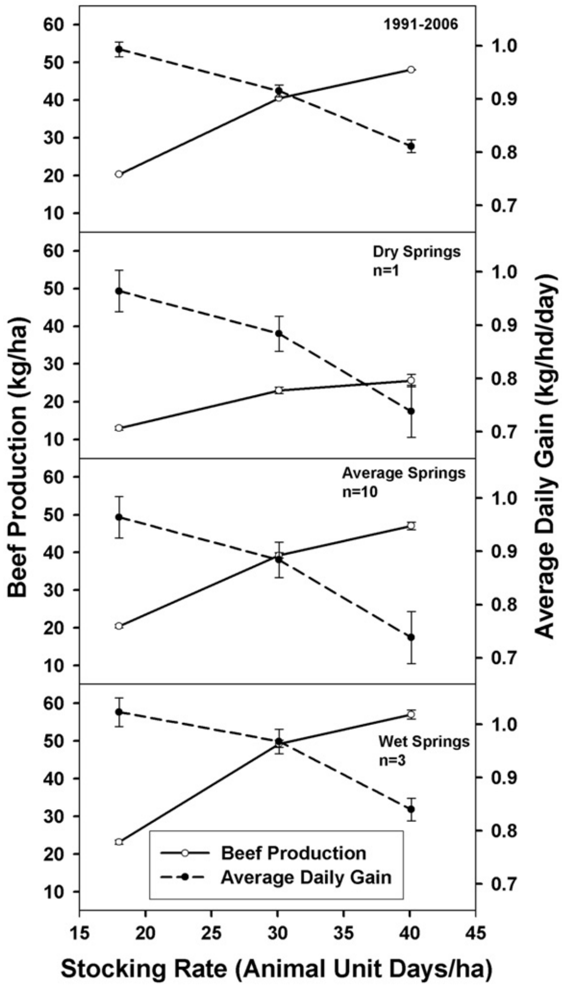

Fig. 2. Responses of beef production (kg/ha, mean ± 1SE, open circles) and average daily gain (kg/head/day, mean ± 1SE, filled circles) to stocking rate across grazing systems on northern mixed-grass prairie at the High Plains Grasslands Research Station, near Cheyenne, WY, USA, for the 1991–2006 study years, and for dry, average and wet springs during this period.

sixteen springs were classified as average using the criterion of spring precipitation being within ± 1 SD of this study period. Three springs each was classified as wet (> 1SD) and dry (< 1SD), with all three dry springs occurring since 2000. Cattle gain data was only obtained for one year classified with a dry spring (2006); animals did not graze the study pastures in the other two years (2000 and 2002).

3.2. Stocking rate

With season-long grazing average daily gains (ADG, kg/head/day) across all years decreased with increasing stocking rate (Fig. 1). Gains were 5% higher with light (0.993 ± 0.0140 kg/head/day) than moderate (0.945 ± 0.016) stocking rates (Fig. 1). Heavy stocking rates (0.825 ± 0.015) reduced ADG by 16% and 12% compared to light and moderate stocking rates, respectively. Springs with average precipitation exhibited this same relationship between stocking rate and ADG. However, springs classified as dry or wet did not exhibit a significant difference between light (dry: 0.964 ± 0.039 kg/head/day; wet: 1.023 ± 0.027) and moderate (dry: 0.906 ± 0.041 kg/head/day; wet: 0.990 ± 0.032) stocking rates for ADG. Heavy stocking rates reduced ADG by 22–26% in the single year with a dry spring (0.708 ± 0.059 kg/head/day), and by 15–18% in the three years with wet springs (0.844 ± 0.029). In contrast to ADG, beef production (kg/ha) increased with increasing stocking rate (Fig. 2). For this study period, the stocking rate at which both ADG and beef production was optimized was determined to be the moderate rate (30 animal unit days/ha) for all study

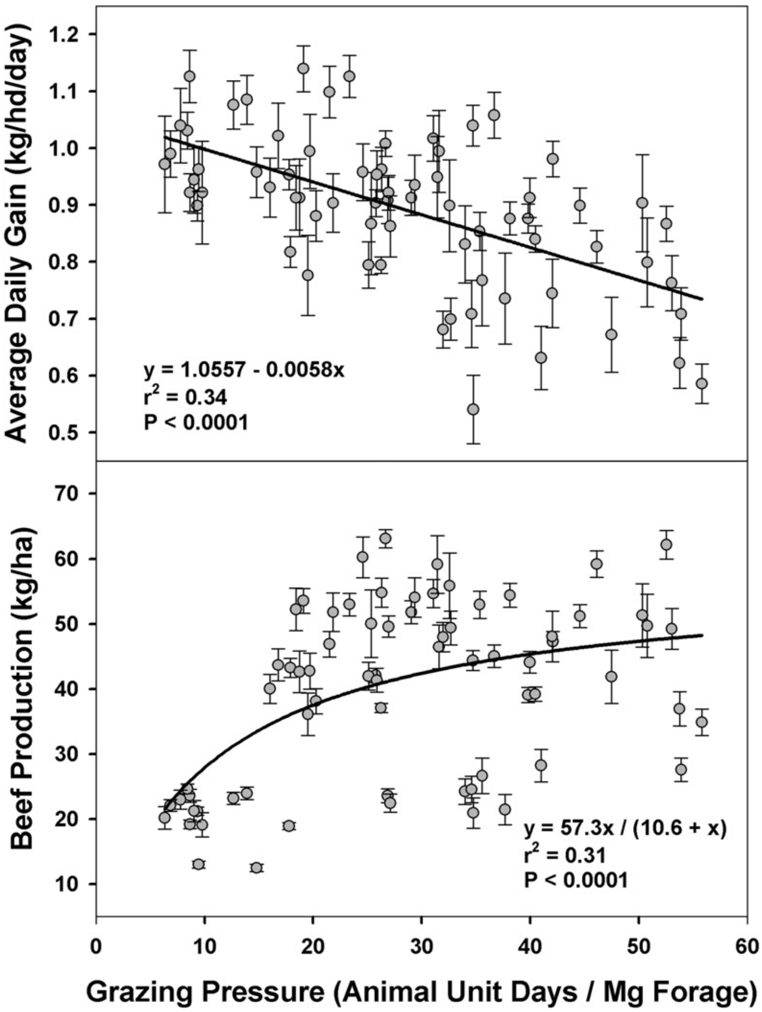

Fig. 3. Relationships between average daily gain (kg/head/day, mean ± 1SE) (upper panel), beef production (kg/ha, mean ± 1SE) (lower panel) and grazing pressure (animal unit days/Mg forage) on northern mixed-grass prairie at the High Plains Grasslands Research Station, near Cheyenne, WY, USA, for the 1991–2006 study years.

years, as well as the average and wet springs. Similar to observed findings between stocking rate and cattle gains, ADG decreased linearly with increasing grazing pressure (animal unit days/Mg forage)(Fig. 3), but no relationship existed between ADG and stocking rate (Fig. 4). Beef production exhibited a hyperbolic increase with increasing grazing pressure (Fig. 3), and a strong linear response to stocking rate (Fig. 4).

3.3. Grazing system and stocking rate

Grazing system and stocking rate, but not their interaction, affected ADG. Gains were reduced by 6% with short-duration rotation (0.841 ± 0.013 kg/head/day) compared to season-long grazing (0.885 ± 0.012) over the study period, with differences between systems observed in years with average (0.826 ± 0.016 vs. 0.883 ± 0.014 kg/head/day, short-duration vs. season-long), but not dry (0.815 ± 0.048 vs. 0.807 ± 0.043 kg/head/day), or wet (0.891 ± 0.023 vs. 0.916 ± 0.024 kg/head/day), spring precipitation (Fig. 5) over the final sixteen years of this twenty-five year study. Heavy stocking rates consistently reduced ADG by 10–16% compared to moderate stocking across all years (0.811 ± 0.012 vs. 0.915 ± 0.011 kg/head/day, heavy vs. moderate) and for each spring precipitation classification.

3.4. Spring Precipitation and Cattle Gains

Grazing season gains (kg/head) and beef production both exhibited significant hyperbolic relationships with spring precipitation. For each stocking rate × grazing

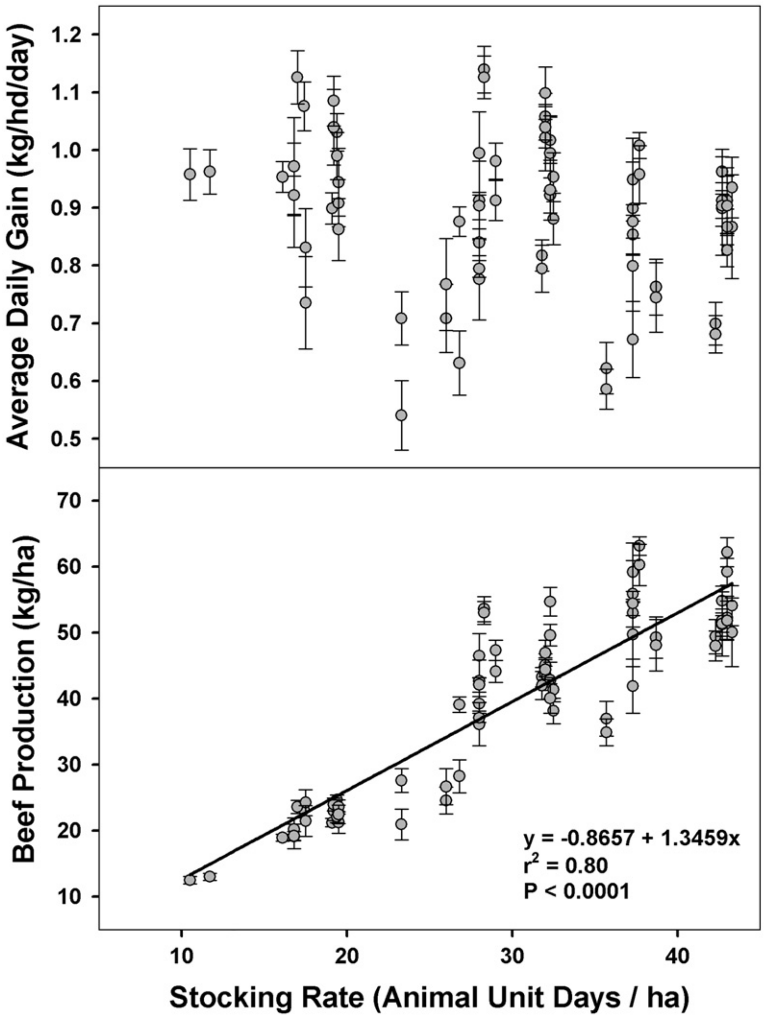

Fig. 4. Relationships between average daily gain (kg/head/day, mean ± 1SE) (upper panel), beef production (kg/ha, mean ± 1SE) (lower panel) and stocking rate (animal unit days/ha) on northern mixed-grass prairie at the High Plains Grasslands Research Station, near Cheyenne, WY, USA, for the 1991–2006 study years.

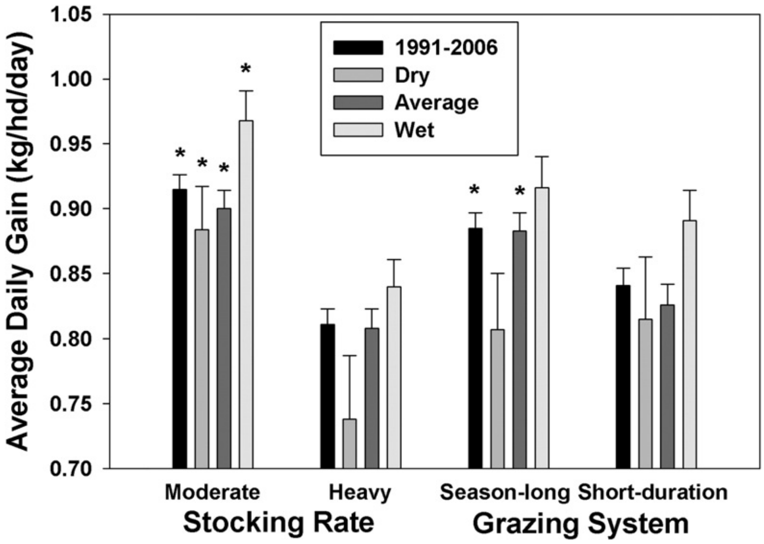

Fig. 5. Average daily gains (kg/head/day, mean ± 1SE) for moderate and heavy stocking rates across season-long (mid-June to mid-October) and short-duration rotational grazing, and for season-long and short-duration rotational grazing across stocking rates on northern mixed-grass prairie at the High Plains Grasslands Research Station, near Cheyenne, WY, USA, for the 1991–2006 study years, and for dry, average and wet springs during this period. Asterisks indicate significant ($p<0.05$) differences between stocking rates, and between grazing systems for each classification.

system combination, grazing season gains increased with increasing spring precipitation with the percentage of variation explained by spring precipitation similar (32–45%) (Fig. 6). Likewise, beef production increased with increasing spring precipitation for all stocking rate × grazing system combinations, but the percentage of variation explained by spring precipitation was substantially higher (62–83%) (Fig. 7).

4. Discussion

Long-term (1982–2006) grazing treatments of stocking rate and grazing system, but not their interaction, influenced cattle gain responses over the final sixteen years (1991–2006) of this study in northern mixed-grass prairie of the North American Great Plains. Increasing stocking rate reduced individual animal gains but resulted in greater beef production per unit land area. The short-duration rotational grazing system reduced cattle gains by a marginal (6%) but significant level compared to season-long grazing. Cattle gains increased with increasing amounts of spring (April–June) precipitation, which is consistent with prior findings regarding forage production at this study site (Derner and Hart, 2007).

Reductions in average daily gain, but increases in beef production, with increasing stocking rate and grazing pressure are consistent with previous findings from this ecosystem (Hart et al., 1988; Manley et al., 1997) as well as many other rangeland systems (e.g., Bement, 1969; Holechek et al., 1998; McCollum et al., 1999). This study showcases that livestock performance can be influenced by spring precipitation as average daily gains did not differ between light and moderate stocking rates when spring precipitation substantially deviated (i.e., dry or wet) from average amounts. In this rangeland, forage production is similar across stocking rates in dry years (Derner and Hart, 2007) further providing evidence that differences in cattle gain responses should not be expected between light and moderate stocking rates under these conditions. Average daily gain was substantially reduced with the heavy stocking rate in the dry spring year. This result can be explained by contrasting species composition in these treatment pastures compared to the lighter stocking rates (Manley et al., 1997). Because perennial warm-season (C4) grasses and forbs increase, and cool-season (C3) grasses decrease with heavy stocking rates, the limited precipitation received during spring 2006 resulted in little green forage during the early grazing season. Therefore, cattle on this treatment would have had a higher proportion of residual forage with lower quality in their diets compared to the other stocking rate treatments. In contrast to the effects produced by a dry spring, springs with abundant precipitation amounts overcome intrinsic forage production potential differences between these two stocking rates (Derner and Hart, 2007). Gillen and Sims (2006) noted that

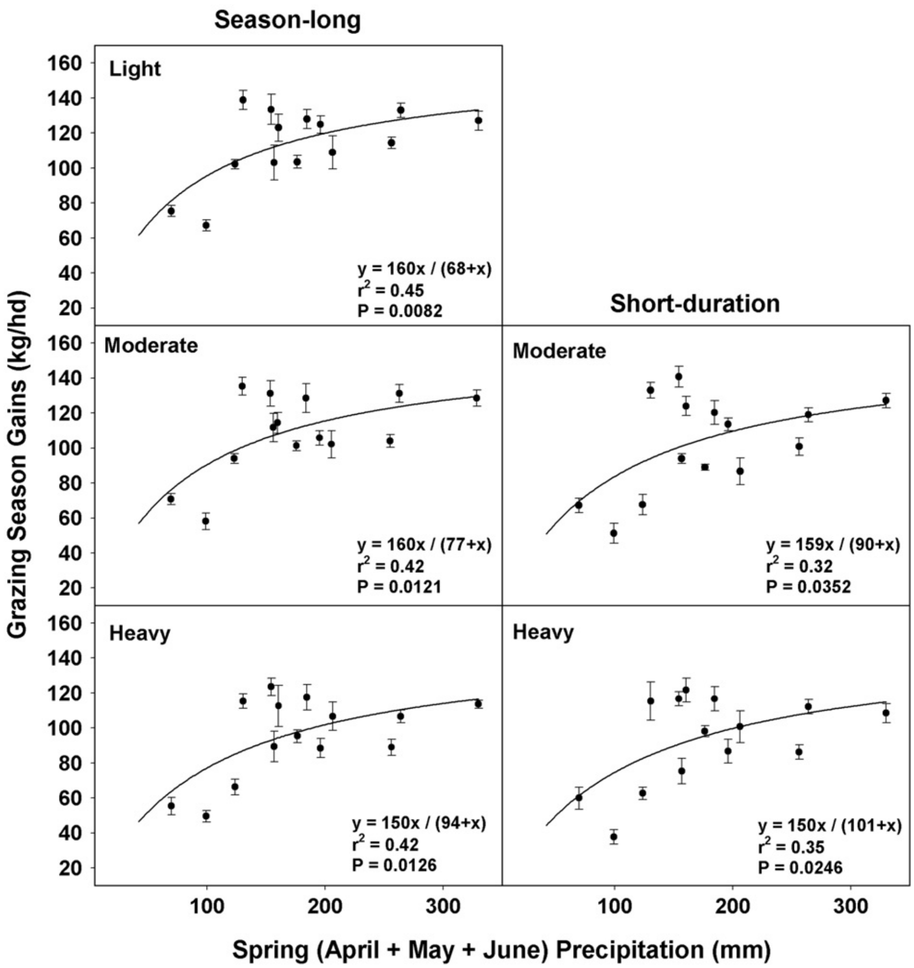

Fig. 6. Hyperbolic relationships between grazing season gains (kg/head, mean ± 1SE) and spring (April ± May ± June) precipitation (mm) for season-long grazing at light, moderate and heavy stocking rates, and for short-duration rotational grazing at moderate and heavy stocking rates on northern mixed-grass prairie at the High Plains Grasslands Research Station near Cheyenne, WY, USA for the 1991–2006 study years.

vegetation metrics were responsive to stocking rate when precipitation was favorable, but not during drought.

The intersection of responses of average daily gain and beef production to stocking rate represents the rate at which both of these responses are optimized for livestock production (e.g., Bement, 1969). Our results across this sixteen year study period suggest that the optimum stocking rate is the currently recommended moderate stocking rate. Bement (1969) determined that economic returns per hectare were highest at moderate stocking rates in shortgrass steppe. Hart et al. (1988) found that the recommended moderate stocking rate for northern mixed-grass prairie was lower than the rate which produced the greatest economic return per hectare. Yet, they cautioned that the increase in economic returns between the two stocking rates was small and likely would not compensate land mangers for the potential risk of degradation associated with increasing stocking rates. Additionally, Manley et al. (1997) calculated that the most profitable stocking rates in years with favorable prices were intermediate between moderate and heavy, but in years with average or unfavorable prices, the optimum stocking rate is moderate or slightly lower.

Grazing system had less effect on animal responses than stocking rate, which is consistent with previous investigations (Hart et al., 1988; Manley et al., 1997; McCollum and Gillen, 1998; McCollum et al., 1999). Forage production did not differ between grazing systems at this site (Derner and Hart, 2007), suggesting that the observed reduction in animal gains (6%) with rotational grazing is likely attributable to decreased intake and energy losses associated with movement of animals between paddocks (McCollum and Gillen,

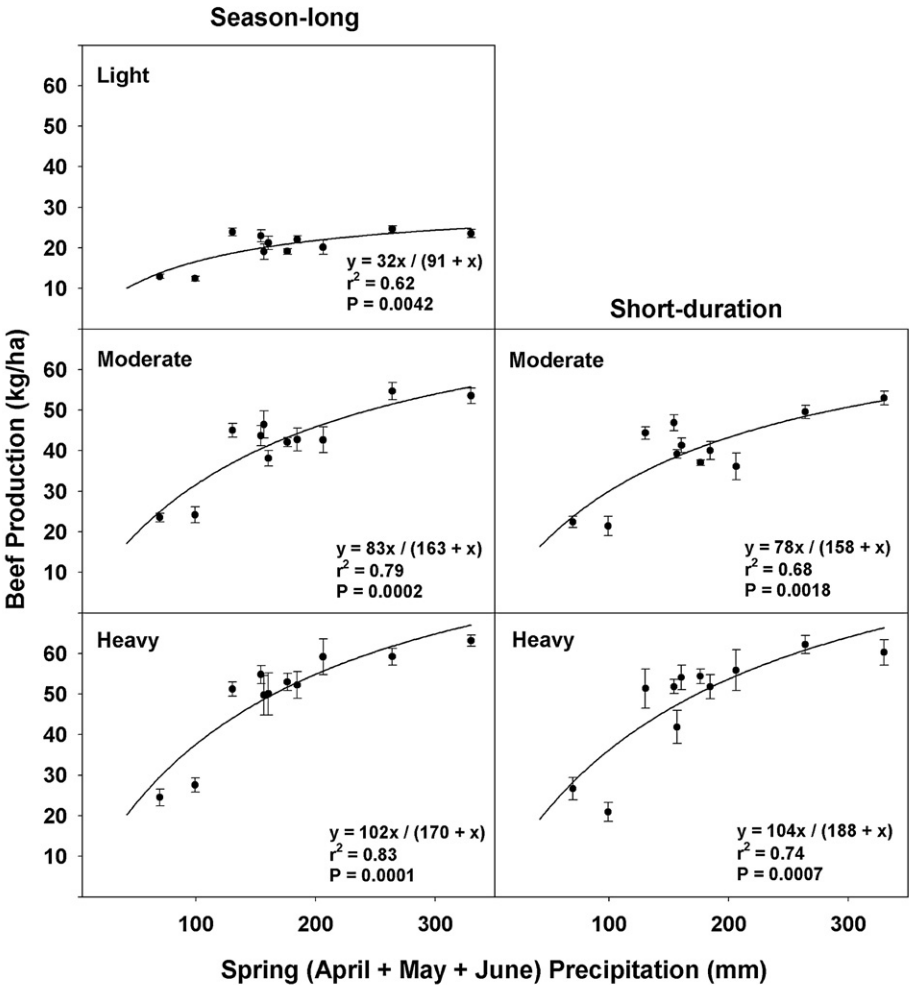

Fig. 7. Hyperbolic relationships between beef production (kg/ha, mean ± 1SE) and spring (April + May + June) precipitation (mm) for season-long grazing at light, moderate and heavy stocking rates, and for short-duration rotational grazing at moderate and heavy stocking rates on northern mixed-grass prairie at the High Plains Grasslands Research Station near Cheyenne, WY, USA for the 1991–2006 study years.

1998). In a comprehensive literature review of experimental studies evaluating animal production responses to grazing systems on rangelands, 92% of the studies reported similar or greater individual animal production responses with season-long compared to rotational grazing (Briske et al., 2008). Eighty-four percent of the studies reported similar or greater animal gain per unit land area responses with season-long compared to rotational grazing. Rotational grazing is a viable management strategy for rangelands, but it is not superior to season-long grazing (Briske et al., 2008).

Our evidence showing the relationships between spring precipitation and cattle gain responses (average daily gain and beef production), and linear relationships of average daily gain responses to grazing pressure can be used to extend the utility of existing plant-animal models. These relationships can be incorporated into current system models to assessing production risks for land managers in these ecosystems with erratic precipitation (Andales et al., 2006). For example, combining predictions of forage production with expected livestock performance can provide land managers a viable tool to assist in enterprise decision-making.

5. Conclusion

This long-term (25 year) study addressing the influence of stocking rate and grazing system on cattle gain responses of northern mixed-grass prairie in the western portion of the North American Great Plains provides clear evidence that stocking rate is primarily responsible for observed differences in weight gains.

Although rotation grazing did significantly reduce cattle gains compared to season-long grazing, this reduction was marginal (6%) and considerably less than the reductions observed with stocking rate. Forage productivity has been reduced by 16–34% with moderate and heavy stocking rates in this system (Derner and Hart, 2007) which has resulted in a negative feedback to livestock average daily gains with increasing grazing pressure. The influence of spring precipitation on cattle gains, however, does suggest that incorporation of these relationships into modeling efforts for strategic planning and risk assessment will assist land managers in more properly matching forage and animal resources for greater sustainability in this highly variable environment.

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