

# Vegetation, cattle, and economic responses to grazing strategies and pressures

W.A. MANLEY, R.H. HART, M.J. SAMUEL, M.A. SMITH, J.W. WAGGONER, JR., AND J.T. MANLEY

Authors are former research assistant, Dept. of Rangeland Ecology and Watershed Management (DREWM), Univ. of Wyoming, Laramie, Wyo. 82071; rangeland scientist, USDA, Agricultural Research Service, High Plains Grasslands Research Station, 8408 Hildreth Road, Cheyenne, Wyo. 82009; botanist (retired), USDA, ARS, Cheyenne, Wyo.; professor and associate professor, DREWM, University of Wyoming, Laramie, Wyo. 82071; and former research assistant, Dept. of Plant, Soil & Insect Sciences, University of Wyoming, Laramie, Wyo. 82071.

## Abstract

Rotation grazing strategies have been proposed to increase stocking capacity, improve animal gains, and improve forage production and range condition. We compared continuous or season-long, 4-paddock rotationally deferred, and 8-paddock time-controlled rotation grazing on mixed-grass rangeland near Cheyenne, Wyo. from 1982 through 1994. Stocking rates under light, moderate and heavy grazing averaged 21.6, 47.0, and 62.7 steer-day ha<sup>-1</sup>; grazing pressures were 11.0 to 90.1 steer-day Mg<sup>-1</sup> of forage dry matter produced. We estimated above- and below-ground biomass, botanical composition and basal cover. Bare ground and cover of warm-season grasses, forbs, and lichens were greater under heavy stocking; cover of litter, western wheatgrass, and total cool-season graminoids were greater under light stocking. Stocking rate and grazing strategy had no effect on above-ground biomass and little effect on below-ground biomass. Under heavy stocking, percent of above-ground biomass contributed by forbs increased, especially under time-controlled rotation grazing, and that of western wheatgrass decreased. Otherwise, effects of grazing strategy, level vs. slope, and north vs. south slope on vegetation were insignificant. Steer average daily gain decreased linearly as grazing pressure increased ( $r^2 = 0.44$ ); grazing strategies had no significant effect. When cattle prices are favorable, the stocking rates that are most profitable in the short run may be high enough to reduce range condition.

**Key Words:** plant communities, mixed-grass prairie, basal cover, weight gain, succession, rangeland

Grazing strategies have evolved from a need to sustain efficient use of the forage resource by livestock over long periods of time (Heady 1975), but few research projects have tested strategies over a long period. Many research projects examining the effects of grazing strategies have been shortened, replications dropped, management altered, or ended altogether. With few exceptions, long-term grazing studies have suffered major shifts in management during their existence (Hickey 1969, Ashby et al. 1993).

Time-controlled grazing strategies have been referred to as rapid rotation and cell grazing (Holechek et al. 1989), as well as short duration grazing (Savory 1978) and the Savory Grazing

Method or Holistic Resource Management (Savory 1983). Despite the many names, this is a form of rotational grazing which involves subdividing a pasture into a rather large number of paddocks and moving the cattle among paddocks relatively quickly, resulting in high stocking densities for short periods of time. When plants are growing quickly, cattle are moved frequently, and inversely, as growth slows, cattle are left on a particular paddock for a longer period (Hart et al. 1988). The premise behind this grazing strategy is that even utilization of the forage is achieved by the cattle and forage production is increased (Savory 1978).

In conjunction, cattle gains are expected to increase because animals are continually faced with younger and more nutritious forage throughout the growing season (Kothmann 1984). Additionally, the claim has been made that stocking rate can be increased, apparently due to the compensatory plant growth that occurs after the cattle are moved into the next paddock (Savory 1983). However, because regrowth occurs for only a few weeks to a few months on semi-arid rangelands (Hart et al. 1993b), regrowth rarely has a significant effect on forage quality or quantity. Under time-controlled rotation grazing, a given plant or tiller is expected to be grazed only once during a particular rotation period. However, Hart et al. (1993b) determined that western wheatgrass and blue grama tillers are rarely grazed more than once or twice in an entire grazing season, regardless of grazing strategy.

Many studies have failed to show the claimed benefits of time-controlled rotation grazing (Bryant et al. 1989; Dormaar et al. 1989; Gamougoun et al. 1984; Gillen et al. 1991, 1992; Hart et al. 1988; Heitschmidt et al. 1982a, 1982b, 1985, 1987; Dahl 1986; Taylor 1993a, 1993b; Kirby et al. 1986; Malechek 1984; Walker et al. 1989; Weltz and Wood 1986; and Wood and Blackburn 1984). However, Hart et al. (1988) confirmed that stocking rates can profitably be increased substantially above "government-prescribed stocking rates," regardless of grazing strategy; their moderate and heavy stocking rates were 130% and 175% of the rates recommended by the Natural Resources Conservation Service (Stevenson et al. 1984). However, as grazing pressure or stocking rate increased, gains of cattle on rangeland declined, usually linearly (Ashby et al. 1993; Bement 1974; Hart 1978; Hart et al. 1988; Houston and Woodward 1966; Klipple and Costello 1960; Sarvis 1941; and Sims et al. 1976).

Grazing pressure and/or stocking rate influences vegetative composition of mixed-grass rangelands, as well as the performance of grazing livestock. Under heavy grazing pressure, cover,

Address reprint requests to Dick Hart.  
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and biomass of western wheatgrass (*Pascopyrum smithii* (Rybd.) A. Love) and needleandthread (*Stipa comata* Trin. and Rupr.) decreased and that of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) and/or buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.) increased in long-term grazing trials on mixed-grass prairie in Alberta, Canada (Smoliak et al. 1972, Smoliak 1974, Dormaar et al. 1994), in Montana (Reed and Peterson 1961, Houston and Woodward 1966), in South Dakota (Pace and Thilenius 1968), and in North Dakota (Rauzi 1963, Brand and Goetz 1986). However, little change occurred after only 4 years of grazing in Montana (Vogel and Van Dyne 1966) and North Dakota (Hofmann and Ries 1989), illustrating the need for long-term studies to measure grazing impacts.

The 1993 and 1994 grazing seasons were the twelfth and thirteenth seasons of a grazing study on northern mixed grass prairie, which examined the effects of 3 grazing strategies and 3 stocking rates on plant community composition, peak standing crop, and gains of yearling steers. Results of the first 6 years were reported by Hart et al. (1988). The overall objective of the study was to determine which grazing strategy and stocking rate were most beneficial for stocker steer production in the northern Great Plains of the United States. The objectives of the summers of 1993 and 1994 were to continue monitoring: 1) basal cover of the plant community, 2) peak standing crop and changes in plant community composition, and 3) weights of steers. Peak standing crop had not been determined by category since the projects inception in 1982 and 1983.

The null hypotheses were: 1) no differences in steer gains caused by grazing strategy will be detected, 2) steer gains will respond the same to stocking rate under all grazing strategies, and 3) no difference in peak standing crop or basal cover will be caused by grazing strategy.

## Experimental Methods

The High Plains Grasslands Research Station (HPGRS) is located about 10 km northwest of Cheyenne, Wyo. The study site is characterized by mixed grass prairie on rolling hills ranging in elevation from about 1,900 to 1,950 m. The climate is semi-arid, the average annual precipitation was 384 mm for 1971–1994. The bulk of precipitation occurs from April to September and often includes heavy snows in April and even in May. Precipitation during 1993 and 1994 was 122% and 76%, respectively, of the 24-year average. The growing season averages 127 days, with wide variations in daily and seasonal temperatures. The area receives warming down-slope winds from the Laramie Range to the west, particularly in the spring and winter (Stevenson et al. 1984). Soils are coarse and well drained, comprised mainly of Albinas, Ascalon, and Altvan loams (mixed mesic Aridic Argiustolls), Cascajo gravelly loam (mixed mesic Aridic Calciorthids) and Larim Variant gravelly loam (mixed mesic Ustollic Haplargid; Stevenson et al. 1984).

Until the current study began in 1982, the area had been lightly grazed by wildlife and occasionally by livestock. There is no year-round running water on the study site, which is serviced by a well and storage tank that supplies water to stock tanks in the various pastures, during the grazing season only.

Vegetation is predominantly grasses. Common cool-season graminoids are western wheatgrass, needleandthread, prairie

junegrass (*Koeleria cristata* Pers.), and needleleaf sedge (*Carex eleocharis* Bailey). Warm season grasses are blue grama and small amounts of buffalograss. Forbs are dominated by fringed sage (*Artemisia frigida* Willd.), scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rybd.), and Hood's phlox (*Phlox hoodii* Rich.), but include many annual and perennial species.

## Stocking Rates and Grazing Strategies

Treatment pastures were divided into 3 grazing strategies. The season-long treatments had no pasture subdivision. The rotationally deferred pastures were subdivided into 4 paddocks. A different paddock was deferred from use each year until the end of the growing season, about 1 September, while cattle grazed the other 3 paddocks simultaneously. For the balance of the grazing season, all 4 paddocks were grazed simultaneously.

The time-controlled rotation treatments were subdivided into 8 paddocks, with length of grazing on each paddock determined by estimated forage availability and rate of forage growth. These parameters were not actually measured, nor was any attempt made to develop mathematical guidelines, but when more forage was available or when forage growth slowed in a given paddock, steers grazed that paddock longer.

Three stocking rates were applied: 1) light, 0.16 to 0.23 steers ha<sup>-1</sup>; 2) moderate, 0.42 steers ha<sup>-1</sup>; and 3) heavy, 0.56 steers ha<sup>-1</sup> (Table 1). Steer numbers varied under the season-long light treatment because this pasture included replacement steers which were moved to other pasture treatments as needed when steers originally assigned to those pastures became ill or died. Grazing pressure was determined each year by dividing the number of steer days ha<sup>-1</sup> on each treatment by the mean PSC of forage in Mg (thousands of kg) ha<sup>-1</sup>.

Table 1. Grazing seasons, peak standing crop (PSC), stocking rates, and grazing pressure, 1982–1994.

Grazing season	PSC (kg ha <sup>1</sup> )	Stocking rate			Grazing pressure		
		Light	Mod	Hvy	Light	Mod	Hvy
		(Steer-days ha <sup>1</sup> )			(Steer-days Mg <sup>1</sup> forage)		
24 Jun.–19 Oct. 82	1,180	—	38.5	51.4	—	32.6	43.6
16 Jun.–27 Oct. 83	1,670	25.5	43.7	58.3	15.3	26.2	34.9
12 Jun.– 2 Oct. 84	1,140	24.2	36.8	49.2	21.2	32.3	43.2
29 May–16 Oct. 85	1,040	23.5	57.6	76.8	22.6	55.4	73.8
10 Jun.– 8 Oct. 86	1,140	21.5	50.0	66.7	18.9	43.9	58.5
3 Jun.–22 Oct. 87	870	23.7	58.8	78.4	27.2	67.5	90.1
23 Jun.–12 Oct. 88	1,160	22.0	46.0	62.0	19.0	39.7	53.4
6 Sep.–11 Oct. 89*	540	2.6	11.0	14.7	4.8	20.4	27.2
4 Jun.–10 Oct. 90	1,560	17.2	53.3	71.1	11.0	34.2	45.6
13 Jun.–23 Oct. 91	1,740	29.5	52.9	70.6	17.0	30.4	40.6
9 Jun.– 1 Oct. 92	840	17.5	47.5	63.3	20.8	56.5	75.4
2 Jun.–30 Sep. 93	930	20.7	50.0	66.7	22.3	53.8	71.7
1 Jun.–10 Aug. 94	700	12.7	28.8	38.3	18.3	41.4	55.1

\*Grazed with dry cows; not all pastures were grazed simultaneously, and cows were not weighed.

The 7 treatments were: season-long under light, moderate, and heavy stocking; rotationally deferred under moderate and heavy stocking; and time-controlled rotation under moderate and heavy stocking. All treatments except season-long light were replicated twice. Replicate I was located primarily on north-facing 0–15%

slopes, and Replicate II on south-facing 0–6% slopes. The unreplicated season-long light pasture included both aspects and slopes. A map of the pasture layout was published by Hart et al. (1988).

Yearling steers were used on the study, except in 1989 when lack of forage in other pastures made it necessary to use the study pastures for dry cows. However, the ratios among light, moderate, and heavy stocking rates were maintained the same as in other years. About half of the steers used each year were Herefords produced at HPGRS. The other steers were predominantly English × English or English × Continental crossbreeds purchased locally.

All steers were backgrounded 30–60 days, vaccinated, weighed, eartagged, and received Ralgr<sup>1</sup> prior to the onset of the grazing study each year. Steers were divided into groups of 5 animals each based on weight; each group consisted of 2 or 3 station-raised steers with the balance being purchased steers. Steers were weighed every 28 days, after being held overnight without feed or water. All steers watered from similar float-controlled stock tanks, received the same free choice salt-mineral supplement, and were observed at least twice weekly.

### Forage Production and Species Composition

During the last week of June 1993, basal cover was estimated on the continuous, rotationally deferred, and time-controlled grazing strategies at heavy stocking and the continuous strategy at light stocking. Two permanent 50-m transects were located in each pasture, 1 on a flat and 1 on a slope. A 50-m tape was stretched between 2 transect markers, and at 1-m intervals a 10-point frame (Mueller-Dombois and Ellenberg 1974) was set perpendicular to the transect line. Pins approached the ground at a 60° angle. One thousand points were recorded per pasture. Hits were recorded manually by plant species (including grasses, sedges, forbs, and lichen [*Parmelia* sp.]), litter, or bare ground.

In late July, peak standing crop (PSC) was determined inside four 1.5 m<sup>2</sup> exclosures per pasture. Exclosures were moved each year in May, but remained on similar slope and soil series. Exclosures were opened and 2 readings were taken with a capacitance meter. In each season-long light and heavy, rotationally deferred heavy, and time-controlled heavy pasture, a 0.18 m<sup>2</sup> quadrat was placed over each placement of the capacitance meter, and vegetation in the quadrat was hand clipped to ground level. Current year's forage was separated into blue grama, western wheatgrass, needleandthread, other grasses, sedges, and forbs, placed each category was placed into paper bags which were dried at 60°C and weighed. A regression equation was developed from quadrats which were both metered and clipped to estimate PSC in the remaining treatments (moderately-stocked season-long, rotationally deferred moderate, and time-controlled pastures) where PSC was estimated only with the capacitance meter.

Residual forage was measured again in October, after steers were removed from the pastures, using a capacitance meter and clipping enough of the 0.18 m<sup>2</sup> quadrats to calculate a regression equation. Utilization was calculated by subtracting residual forage from peak standing crop.

In late July, 5 soil core samples were removed along each basal cover transect in the season-long light and heavy, rotationally

deferred heavy, and time-controlled heavy pastures, and in 2 permanently ungrazed exclosures, using a tractor-mounted hydraulic soil sampling machine. Cores were 10 cm across and 30 cm deep. They were divided into two 15-cm sections; roots were washed out manually (Lauenroth and Whitman 1971), dried at 60°C, and weighed.

Basal cover was recorded the first week in July in 1994. Because the summer of 1994 was considerably drier than the summer of 1993, PSC and residual forage were measured simultaneously in mid August. In the rotationally deferred treatments, only 3 exclosures were clipped, eliminating the exclosure in the ungrazed paddock.

Soil cores were taken in May to a depth of 60 cm and divided into 0–15, 15–30, and 30–60 cm increments. During the manual washing process, roots were separated into blue grama, western wheatgrass, needleandthread, sedges, forbs, or unknown categories, dried, and weighed.

All data were subjected to ANOVA for incompletely replicated designs with the assistance of University of Wyoming PSIS statistical services. When ANOVA indicated significant differences ( $P < 0.05$ ), a highest significant difference (HSD; Tukey 1953) was calculated. The regressions of average daily gain on grazing pressure was computed using a discontinuous linear regression program developed by Hart (unpublished). Slopes and intercepts of regression lines under different strategies were compared by the methods of Steel and Torrie (1960).

## Results and Discussion

### Peak Standing Crop

Peak standing crop (PSC) ranged from 540 to 1,740 kg ha<sup>-1</sup> (Table 1, Fig. 1). In general, PSC was closely correlated with September–August precipitation, but 1987 and 1991 were exceptions. Although precipitation was above the 1951–1995 average in 1987, PSC was slightly less than average; most of the excess precipitation fell in a single 46-mm rainstorm in May while precipitation in the rest of May and in the other months was near average. In 1991, when PSC was higher than expected, yearly precipitation was 33% above average but May–August precipitation was 72% above average.

Peak standing crop was not significantly affected by either grazing strategy or stocking rate (Fig. 1), but there have been shifts in the botanical composition of PSC under heavy stocking rates. Under heavy grazing, western wheatgrass contributed about 22% of PSC by weight in 1982–83, with no differences among strategies. The contribution of western wheatgrass under heavy grazing declined to about 12% of PSC in 1993–94, which was significantly less than that under season-long light grazing, but still there were no differences among grazing strategies under heavy grazing (Fig. 2). The season-long light treatment, which was clipped in 1993–94 only, contained 35% western wheatgrass.

More blue grama was present in 1982–83 on the season-long heavy pastures, 55% of PSC by weight, than on the rotationally deferred or time-controlled rotation heavy pastures, where it made up 39% of PSC. In 1993–94, blue grama contributed a mean of 29% of PSC on all the pastures, with no differences among strategies or stocking rates.

In 1982–83, other cool-season graminoids, primarily needleandthread, prairie junegrass, and sedges, contributed less to PSC on the season-long heavy pasture than on the rotationally deferred

<sup>1</sup> Mention of a commercial product does not imply USDA-ARS endorsement of that product over similar products.

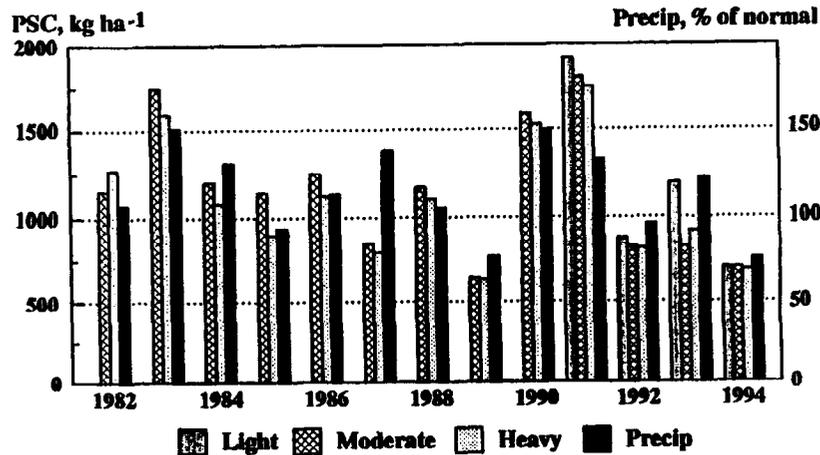


Fig. 1. Precipitation and peak standing crop (PSC) of above-ground biomass under 3 grazing strategies and light (1991–1994 only), moderate, and heavy stocking.

or time-controlled rotation pastures, 12% vs. 23%. By 1993–94, mean contribution of other cool-season graminoids on all pastures was 23%, with no differences among treatments. Of this total, 6% was sedges, 8% was needleandthread, and 9% was other cool-season grasses.

Under all grazing strategies at the heavy stocking rate, forbs appeared to increase from the mean of 13% in 1982–83. Under season-long and rotationally deferred heavy grazing, forbs contributed about 32% of PSC in 1993–94, vs. 48% under time-controlled heavy grazing. The season-long light treatment contained about 17% forbs in 1993–94.

### Basal Cover

Total plant cover, excluding lichens and mosses, decreased sharply in the first few years of grazing (Fig. 3), from 17% to 22% in 1982 to a mean of 7% in 1984. This decrease showed the effects of resuming grazing on a plant community which had been essentially ungrazed for nearly 40 years. Basal cover maintained this level until about 1989, after which it began to increase and reached approximately the initial level in 1994, ranging from 15 to 18% across treatments. No significant differences among treatments were detected except in 1990 and 1993, when cover under the 2 season-long treatments tended to be less than cover under rotationally deferred or time-controlled heavy grazing.

Percent bare ground (Fig. 3) covered a wide range in 1982, but was nearly the same under all 4 treatments estimated in 1983, averaging 17%. Bare ground decreased to very low levels under season-long light grazing, to less than 3% in 1985, and never exceeded 11% thereafter. Under heavy grazing, bare ground fluctuated from 9% to 27%, with significantly more bare ground under season-long heavy grazing than under rotationally deferred or time-controlled heavy grazing in 1985 and 1993. The narrow range of percent bare ground in 1994 on all 3 heavily-grazed treatments suggests the plant and litter cover is providing adequate protection from soil erosion.

Dead vegetation and fecal material comprised the litter component of cover (Fig. 3). Litter cover was almost a mirror image of bare ground, varying considerably among treatments in 1982 but very little in 1983 when the mean was 69%. Thereafter litter increased under season-long light grazing to a maximum of 88% in 1987 and then decreased to 75% in 1994. The greater litter cover under light grazing probably reflects the very low levels of utilization (3% vs. 36% under moderate and 53% under heavy grazing, 1991–1994) and the consequent large amount of standing dead biomass to be converted to litter. Litter cover was consistently less under heavy grazing, regardless of strategy, peaking at a mean of 74% in 1987 and decreasing to a mean of 60% in 1994. Litter cover tended to be less under season-long heavy grazing than under the other heavily-grazed treatments, but the difference was significant only in 1985.

Cover of perennial cool-season graminoids, which included perennial cool-season grasses and sedges, tended to increase

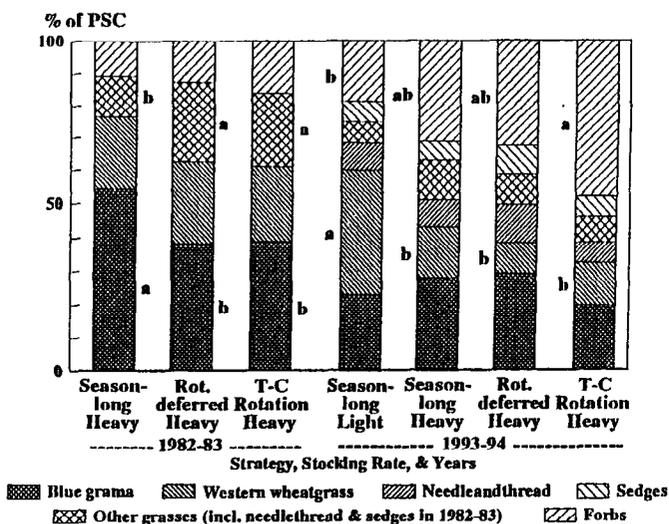
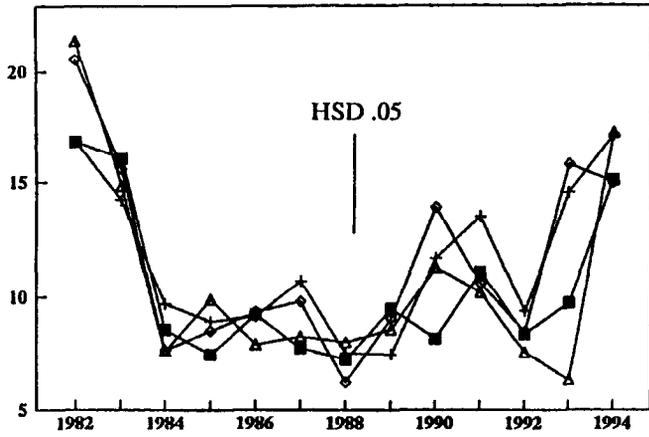


Fig. 2. Botanical composition of peak standing crop (PSC) under season-long light stocking (1993–94) and 3 grazing strategies with heavy stocking (1982–83 and 1993–94). Within years (1982–83 or 1993–94), percentages contributed by a species or species group differ significantly among treatments when labeled with different letters.

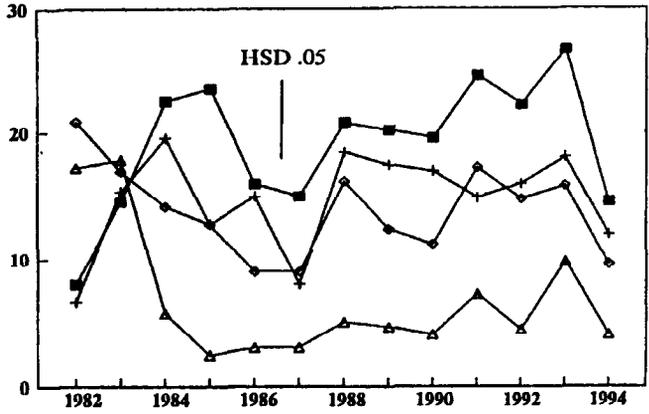
**Total Plant Cover, Except Lichens and Mosses**

Basal cover, %



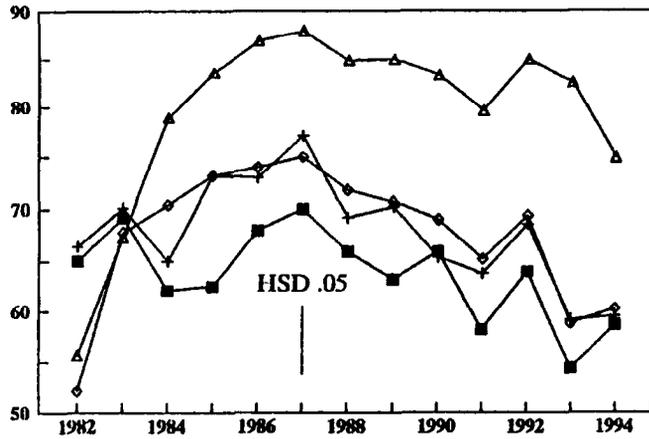
**Bare Ground**

Bare ground, %



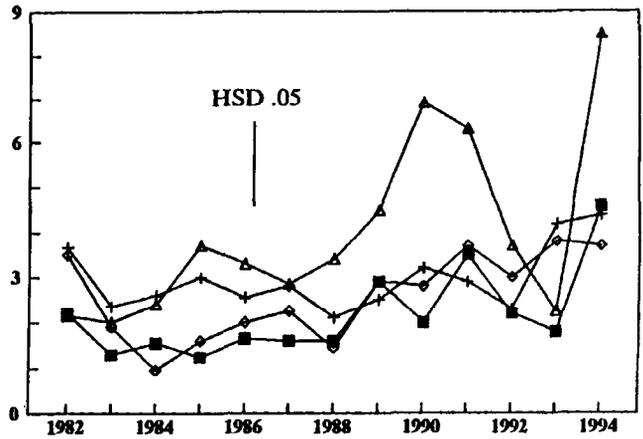
**Litter**

Litter cover, %



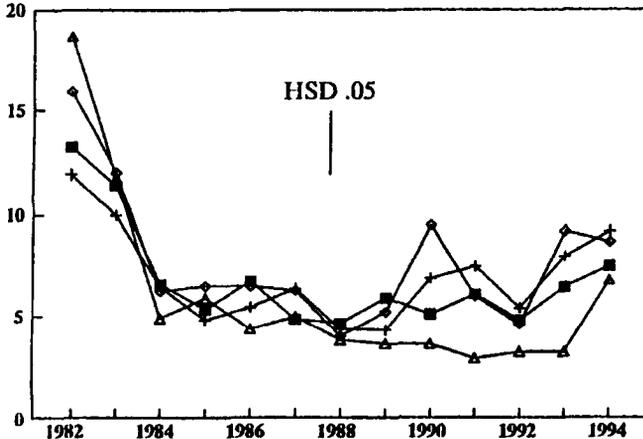
**Perennial Cool-Season Graminoids**

Basal cover, %



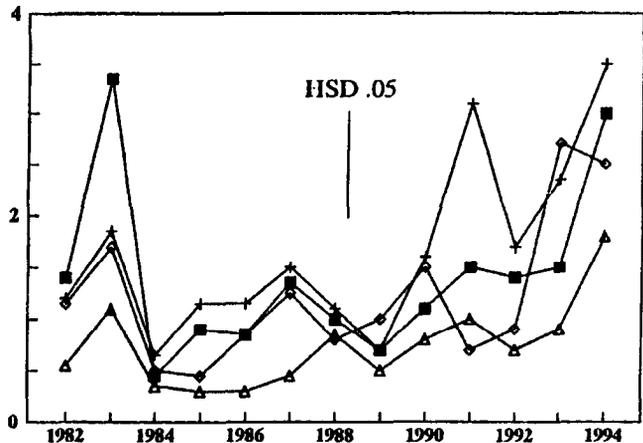
**Perennial Warm-Season Grasses**

Basal cover, %



**Forbs**

Basal cover, %



■ Season-long Heavy + Rot. deferred Heavy ◇ T-C Rotation Heavy  
 Δ Season-long Light

Fig. 3. Plant basal cover, litter cover, and bare ground under season-long light stocking and 3 grazing strategies with heavy stocking, 1982-1994.

slowly but steadily under heavy grazing from 1984 through 1994, with no differences among strategies (Fig. 3). Beginning in 1988, cool-season graminoids began to increase more under light than under heavy grazing; by 1989 the difference was significant. Under light grazing in 1992 and 1993, cover of cool-season graminoids decreased until it was no greater than under heavy grazing, but in 1994 it was again significantly higher. We could not identify any climatic or management variables to account for this fluctuation.

Western wheatgrass cover (data not shown) followed the same pattern as cool-season graminoids in general. In 1982, cover of western wheatgrass was less than 1% under season-long light and heavy grazing, and between 1% and 2% under rotationally-deferred and time-controlled heavy grazing. Cover of western wheatgrass under season-long light grazing increased to over 2% in 1994, vs. less than 1% under all heavy grazing treatments, a significant difference.

Perennial warm-season grasses were mostly blue grama, with buffalograss contributing less than 5% of total warm-season grass cover. Cover of warm-season grasses decreased sharply with the onset of grazing, dropping to about 6% in 1984, the third year of grazing (Fig. 3). Warm-season grass cover continued to decrease very slowly under season-long light grazing until it reached a minimum of less than 3% in 1991 through 1993, then increased sharply to 7% in 1994. Under heavy grazing, warm-season cover increased from about 5% in 1988 to 8% in 1994, with no differences among strategies.

Basal cover of forbs was between 0.5% and 1.5% in 1982, increased in 1983, and decreased to about 0.5% under all treatments in 1984 (Fig. 3). Forb cover was generally less under light than under heavy grazing, indicating grasses were more competitive under light grazing. In 6 of the 13 years, forb cover was significantly greater under 1 or more heavy grazing treatments than under season-long light grazing; this was true of all of the last 4 years of the study. Forb cover fluctuated considerably with timing and amount of precipitation.

Lichens provided about 5% cover on the season-long light treatment in 1982 (data not shown). A low of 1% was reached in 1987, followed by a gradual increase to 4% in 1994. From 1982 through 1992, lichen cover under heavy grazing averaged 4 or more percentage units higher than that under light grazing. Then the difference increased to 8 and 9 percentage units in 1993 and 1994, respectively. These differences may reflect the greater shading of the soil surface under light grazing.

Stocking rate had significant impacts on basal cover in each of the 7 categories. At the heavy stocking rate more bare ground and greater cover of warm season grasses, forbs and lichens was present. Conversely, at the heavy stocking rate, there was less cover of litter, western wheatgrass, and total cool-season graminoids. Effects of grazing strategy, flat vs. slope, and replication (north vs. south slope) were minor and inconsistent.

### Root Biomass

The root biomass portion of the grazing study has been incorporated into a study examining the dynamics of carbon and nitrogen cycling in rangeland soil under different grazing regimes, reported by Manley et al. (1995). The only significant differences detected among root biomass of the different treatments were at the 16–30 cm depth in July, 1993 (Table 2). Greater biomass was found on the heavily-grazed rotation deferred and time-controlled

**Table 2. Root biomass; effects of grazing treatments at 2 dates and 3 depths.**

Grazing strategy	Stocking rate	July 1993; Depth, cm		May 1994; Depth, cm		
		0–15	16–30	0–15	16–30	31–61
----- (Root weight, kg ha <sup>-1</sup> ) -----						
Ungrazed	Ungrazed	31,410	5,510b	12,880	2,260	1,620
Continuous season-long	Light	21,650	6,960ab	10,370	2,270	1,780
	Heavy	27,260	5,280b	11,410	1,600	1,160
Rotationally deferred	Heavy	22,090	8,650a	11,080	3,350	1,830
Time-controlled rotation	Heavy	28,400	8,570a	13,370	1,920	650
Mean		24,850Y	7,360Y	11,560Z	2,280Z	1,410Z

a,b Within a column, weights followed by the same lower case letter are not significantly different. Means at the same depth, followed by the same upper case letter, are not significantly different between dates.

pastures than in the exclosures; biomass did not differ among the exclosures and the season-long lightly and heavily-grazed pastures. Root biomass was smaller in May 1994 than in July 1993, because of the depletion of stored reserves and death and decomposition of roots during the winter.

In May 1994, 76%, 15%, and 9% of the roots in the top 61 cm of the profile were found in the 0–15, 16–30, and 31–61 cm depths, respectively. Of the roots in the top 30 cm, 77% and 84% were found in the top 15 cm in July 1993 and May 1994, respectively.

### Average Daily Gain of Steers

Average daily gain (ADG) of the steers decreased linearly as grazing pressure (GP) in steer-day Mg<sup>-1</sup> PSC increased, regardless of grazing strategy (Fig. 4). No evidence of constant gain at low stocking rates was detected. Slopes and intercepts of the regression equations did not differ significantly among strategies. Equations were:

All strategies:	ADG = 1.06 – 0.00527 GP	r <sup>2</sup> = 0.44
Continuous:	ADG = 1.05 – 0.00477 GP	r <sup>2</sup> = 0.48
Rotationally deferred:	ADG = 1.07 – 0.00562 GP	r <sup>2</sup> = 0.42
Time-controlled:	ADG = 0.97 – 0.00462 GP	r <sup>2</sup> = 0.29

Mean ADG over 6 years was 0.96 kg/day under the light stocking, 0.83 kg/day under moderate stocking, and 0.67 kg/day under heavy stocking.

Gain ha<sup>-1</sup>; return ha<sup>-1</sup> to land, labor, and management (R<sub>LLM</sub>); and stocking rate at maximum R<sub>LLM</sub> can be calculated for any level of PSC and buying and selling prices by a modification of the method of Hart et al. (1988), or they can be calculated with the STEERISK spreadsheet (Hart 1991). The values in Table 3 were calculated with STEERISK, assuming a 128-day grazing season, steers weighing 333 kg at the beginning of the season, 11% interest rate, and miscellaneous costs of \$0.25 steer<sup>-1</sup> day<sup>-1</sup>.

Prices and PSC determined the optimum stocking rate, defined as the stocking rate producing the greatest R<sub>LLM</sub>. As PSC decreased from 1,445 to 624 kg ha<sup>-1</sup>, R<sub>LLM</sub> decreased 56%. Peak standing crop higher than 1,445 or lower than 624 kg<sup>-1</sup> can each be expected about 1 year in 10 (Hart 1991). When prices declined from typical 1987 levels (steers bought for \$1.76 kg<sup>-1</sup> in the spring sold for \$1.65 kg<sup>-1</sup> in the fall) to 1996 levels (steers bought for \$1.54 kg<sup>-1</sup> in the spring are expected to sell for \$1.32 kg<sup>-1</sup> in the fall), R<sub>LLM</sub> declined 79%.

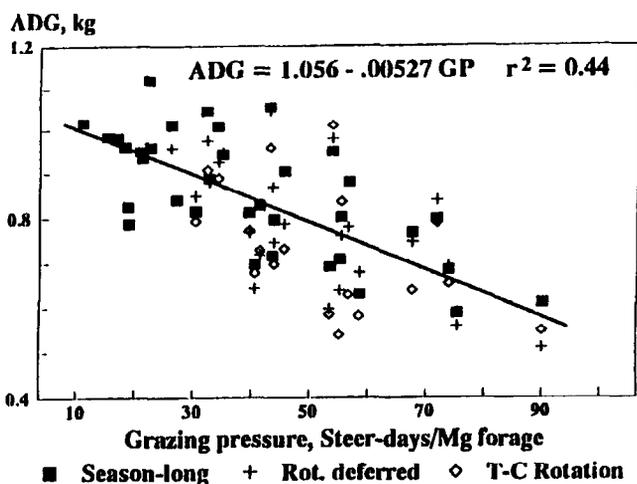


Fig. 4. Grazing pressure and average daily gain (ADG) of steers under 3 grazing strategies.

Although the regressions of ADG on grazing pressure (GP) did not differ significantly among strategies, it is interesting and possibly informative to compare optimum stocking rates, gains, and  $R_{LLM}$  among them. We made these comparisons only at the average level of PSC, 1,034 kg ha<sup>-1</sup>. Calculated  $R_{LLM}$  from time-controlled rotation was 79% of that from season-long grazing at 1987 prices and 61% at 1996 prices. This contradicts simulated results from the SMART model (Hart 1989), which predicts 4% higher gains and proportionately higher  $R_{LLM}$  from 8-paddock time-controlled rotation grazing. In SMART, rotation is based on complete knowledge of forage availability and growth rate in each paddock, which is not possible in real-time real-life applications of rotation grazing. The lack of sufficient knowledge to always rotate to the proper paddock at the proper time may explain part of the smaller  $r^2$  value for the regression of ADG on GP in time-controlled grazing.

Regression of ADG on GP accounted for less than half the variation in ADG; a number of factors contributed to the residual variation. These include inter-year variation in initial weight and condition of steers and length of grazing season, and inter- and intra-year variations in patterns of forage growth and quality.

Research is underway to identify and quantify sources of variation other than GP and to incorporate them into STEERISK.

#### Management Implications

Some rangeland managers have reported large increases in ADG of their livestock, in combination with a higher rangeland successional state, increased plant vigor, and greater forage production after a time-controlled rotation strategy had been implemented. These changes were not observed in this study, and are probably not a result of the grazing strategy, but are a by-product of an increased level of management (Lehnert 1985, Laycock 1983). Cross-fencing and water development are important to achieve more nearly uniform utilization of forage and minimize energy costs of grazing (Hart et al. 1993a). However, the expense of extensive paddock development may be unwarranted unless the area to be subdivided is very large, on the order of several thousand hectares, and subdivision is complemented by adequate water development.

Under heavy grazing, the observed changes in the botanical composition of peak standing crop were substantial. As stocking rate/grazing pressure increased, blue grama, western wheatgrass, and other graminoids decreased (Fig. 2). Forbs increased, particularly on the time controlled rotation. This is not an improvement in successional state. The lower palatability of fringed sage and some other forbs and half-shrubs may make these species less desirable than the diminishing graminoid community as forage for livestock.

The optimum, i.e. the most immediately profitable, stocking rates in a year of favorable prices (Table 3) usually lay between the moderate and heavy stocking rates of this study (Table 1). This might suggest that cattle producers should resist the temptation to stock heavily in years of favorable prices to avoid possible permanent damage to rangeland plant communities. However, heavy stocking in the occasional year of favorable prices might not alter plant communities as much as heavy stocking every year. In years of average or unfavorable prices, optimum stocking rates approximate or are lower than the moderate rates of this study.

Management of the forage base, as well as the livestock, is the key to improved livestock performance. The methods chosen for monitoring vegetation do not have to be elaborate, as long as they are used consistently. The use of proper monitoring tools will allow the producer to adjust stocking rate, and time and length of grazing, to reflect the forage capabilities of that particular year.

Table 3. Simulated optimum stocking rates, steer gain ha<sup>-1</sup>, and return ha<sup>-1</sup> to land, labor, and management; effects of levels of PSC, buying and selling price kg<sup>-1</sup>, and grazing strategy.

PSC (kg ha <sup>-1</sup> )	P of greater PSC (%)	Strategy	Favorable prices; Buy at \$1.76, sell at \$1.65			Unfavorable prices; Buy at \$1.54, sell at \$1.32		
			Optimum stocking rate (Steer- days ha <sup>-1</sup> )	Gain ha <sup>-1</sup> (kg)	Return to LL&M (\$ ha <sup>-1</sup> )	Optimum stocking rate (Steer- days ha <sup>-1</sup> )	Gain ha <sup>-1</sup> (kg)	Return to LL&M (\$ ha <sup>-1</sup> )
624	90	All	37.1	27.7	\$19.23	19.0	17.1	\$4.04
854	70	All	50.8	37.9	26.32	26.0	23.4	5.54
1,034	50	All	61.5	45.9	31.87	31.5	28.5	6.70
		Season-long	70.3	51.0	37.58	37.7	33.0	8.65
		Rot. deferred	61.5	45.2	33.90	33.8	30.0	8.21
		T-C rotation	63.6	43.6	29.82	30.0	5.1	5.30
1,215	30	All	72.3	54.0	37.45	37.0	33.3	7.88
1,445	10	All	86.0	64.2	44.54	44.1	39.6	9.37

<sup>1</sup>Stocking rate, gains, and returns calculated from pooled regression pooling over all grazing strategies.

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