Effects of stocking rate on quantity and quality of available forage in a southern mixed grass prairie

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Abstract

The objective of this study was to quantify the long-term (25 years) effects of heavy (HC) and moderate (MC) rates of stocking on quantity and quality of forage available. Study design required frequent harvest of standing crop on 5 range sites in twice replicated, 244 ha treatment pastures. Results from the 20-month study showed aboveground standing crop dynamics were similar in both treatments, quantity of available forage was greater in the MC than HC treatment, quality of available forage was greater generally in the HC than MC treatment, and that heavy stocking favored a dominance of warm-season shortgrasses as opposed to a dominance of warm-season midgrasses. Averaged across dates and adjusted for differences among pastures in range site composition, aboveground herbaceous standing crop averaged 1,341 kg/ha in the HC pastures as compared to 1,816 kg/ha in the MC treatment pastures. Crude protein and organic matter digestibility averaged 8.6% and 49.3%, respectively, in the HC pastures and 7.7% and 46.7%, respectively, in the MC pastures. It is concluded that the greater variation among years in cow/calf production in the HC than in the MC treatment is primarily because forage availability in the HC treatment is less than in the MC treatment.

Key Words: species dominance, range site, standing crop, crude protein, organic matter digestibility

Livestock production from rangeland is a function primarily of the the quantity and quality of forage consumed (nutrient intake), which varies primarily as a function of the quantity and quality of forage produced. Although climate is the major factor affecting quantity and quality of forage produced in grasslands (Lauenroth 1979), the major factors within a given climatic regime are the inherent productivity potential of a site (range site) and the kinds and number of plants present (range condition) (Ellison 1960, Sims et al. 1978, Bartolome 1984). A basic premise in range management is that as range condition declines, livestock carrying capacity declines also because quantity and/or quality of forage produced declines (Stoddard et al. 1975, Danckwerts and Aucamp 1984, Malechek 1984). The objective of this study was to quantify the long-term (25 years) effects of moderate and heavy rates of stocking on quantity and quality of forage available in a southern mixed-grass prairie. Subsequent papers will examine the on-going effects of these treatments on quantity and quality of forage consumed and ultimately livestock production.

Methods

Research was conducted at the Texas Experimental Ranch located (99° 14'W, 33°20'N) on the eastern edge of the Rolling Plains. Climate is continental and semiarid. Precipitation is highly variable and bimodally distributed with peak rainfall occurring in May (9.2 cm) and September (10.6) (Fig. 1). Average annual

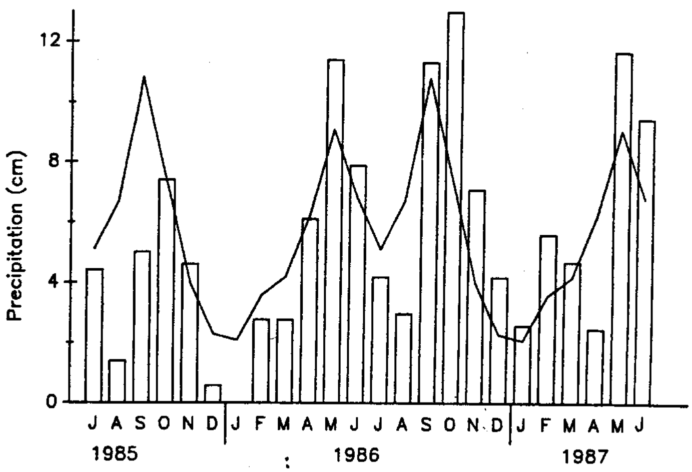

Fig. 1. *Monthly (bar graphs) and long-term (continuous line) precipitation (cm) at Texas Experimental Ranch.*

precipitation (1960–1987) is 68 cm. Average maximum daily temperatures range from a high of 36° C in July to a low of 11° C in January

Topography at the ranch is rolling and ranges from broad valleys (<1% slope) and gentle slopes (1–3%) that lead to nearly level uplands (<1%), to narrow secondary valleys with moderate (3–5%) to steep slopes (>5%). Soils range from the deep, well-drained clay and clay loams (fine, mixed, thermic Calciustolls, Typic Ustocrepts and Cumulic Haplustolls) found on the uplands, flood plains and gentle slopes, to the shallow, stony clay and clay loams (clayey, mixed, thermic Typic Ustochrepts) found on the steeper slopes. Dominant range sites are Clay Loam, Clayey Upland, Clay Slopes, Shallow Clay, Rocky Hills and Loamy Bottomland (SCS 1984). Elevation ranges from 408 to 463 m.

Vegetation is a mixed-grass complex within a light to moderate stand of honey mesquite [(*Prosopis glandulosa* (Torr.) var. *glandulosa*)]. Dominant midgrasses are Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), a cool-season perennial; sideoats grama [(*Bouteloua curtipendula* (Michx.) Torr.], a warm-season perennial; and Japanese brome (*Bromus japonicus* Thunb.), a cool-season annual. Dominant shortgrasses are buffalograsses [(*Buchloe dactyloides* (Nutt.) Engelm.] and common curlymesquite [(*Hilaria berlangeri* (Steud.) Nash], both warm-season perennials. The dominant forb is annual broomweed (*Xanthocephalum* spp.). For a more complete description of the climate, soils, and vegetation at the ranch, see Heitschmidt et al. (1985).

Grazing treatments were yearlong continuous stocked with mature F1 Angus/Hereford cows at heavy (HC) and moderate (MC) rates. The twice replicated treatments were initiated in 1960 in 4 pastures of similar condition (Heitschmidt et al. 1985) following subdivision of a single pasture. Size of pastures ranged from 218 to 266 ha. Average rates of stocking from 1960 through 1984 were about 5 and 7 ha/cow/yr, respectively. Recommended rate of

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stocking in this region for good condition range is about 8 ha/cow/yr (SCS 1984). During this 20-month study, rates of stocking were 5.0 and 6.4 ha/cow/yr.

Range site composition varied among treatment pastures (Fig. 2). The dominant range site in 3 of the 4 pastures was Clay Slopes (48%). In the fourth pasture (HC, Rep II), the dominant range site was Clay Loam (25%).

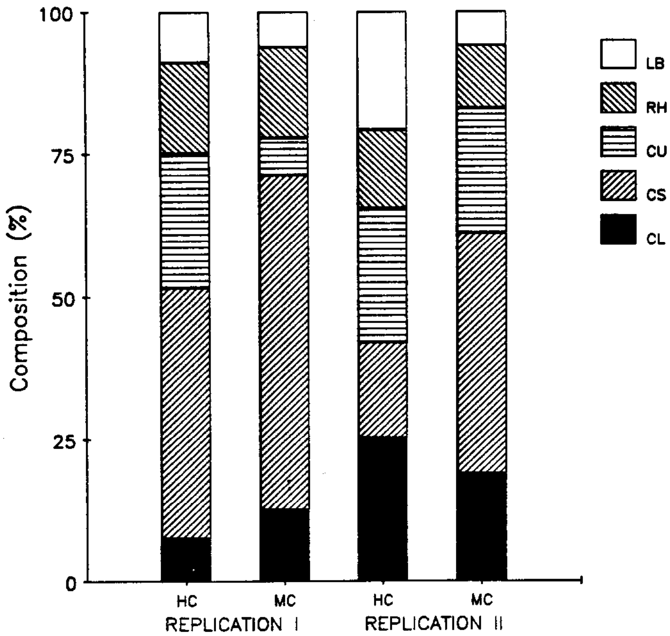

Fig. 2. *Range site composition (%) of replicate pastures in heavy (HC) and moderate (MC) continuous grazing treatments. LB = Loamy Bottomland. RH = Rocky Hills. CU = Clayey Upland. CS = Clay Slopes. CL = Clay Loam.*

Aboveground standing crop was sampled on 8 dates during the study. Sample dates were October 1985; January, April, July and November 1986; and February, March, and June 1987. On each sample date, vegetation in 15 (20 × 15 cm) quadrats was harvested at ground level by forage class (grass vs. forb) at 3 locations per range site per pasture (15 quadrats × 3 locations × 5 range sites × 4 pastures = 900 quadrats). The permanent sample locations ranged in size from about 1 to 5 ha depending upon contiguous size of mapped range site sampled. Quadrats were located within each sample location utilizing a stratified random sampling scheme. The 3 most abundant grass and forb species, in terms of standing crop, were identified and ranked in each quadrat prior to clipping. Buffalograss and common curlymesquite were considered a single species when ranked because the time required to clearly identify relative amounts of each species was excessive.

Following clipping, samples were dried at 60° C to a constant weight and weighed. The 15 grass samples per sample location were then combined and a subsample was collected for live:dead ratio and forage quality determinations (3 locations × 5 range sites 4 pastures = 60 subsamples per sample date). A portion of the subsample was hand separated by tissue color (green vs. brown) and weighed for determination of live:dead ratios. The remaining portion of the subsample was used for forage quality determinations. Percentage crude protein (CP) was estimated following standard A.O.A.C. (1975) procedures. Percentage in vitro organic matter digestibility (OMD) was estimated according to Tilley and Terry (1963) as modified by van Soest and Wine (1967).

All standing crop and rank data were summarized by location within pasture prior to statistical analyses. Rank indices for each location were calculated for each species from quantitative values assigned for relative rank in each quadrat. Assigned values were 3 (rank 1), 2 (rank 2), 1 (rank 3) and 0 (not ranked). Following summarization, all data were subjected to least squares analysis of variance utilizing a split-split plot model (Little and Hills 1978) to test for the main effect of treatment (HC vs. MC), the split-plot effect of range site, and the split-split plot effect of date. Pasture summaries were analyzed using a split-plot model following adjustment for differencs among pastures in range site composition. Percentage CP and OMD estimates were analyzed following arcsine transformations. Tukey Q ($P<0.05$) procedures (Snedecor and Cochran 1967) were used for mean separation of significant ($P<0.10$) effects. Standard linear correlation procedures were used to calculate correlation coefficients.

Results

Dominant Species

Thirty six species of grasses and 94 species of forbs were ranked at least once during the course of the study. Dominant species, which were defined as those species that had a minimum rank index of 0.5 at any of the 60 sample locations at least 10 times during the course of the study (i.e., 2% of the time), were: the buffalograss-common curlymesquite complex, Texas wintergrass, sideoats grama, hairy grama (*Bouteloua hirsuta* Lag.), Japanese brome, silver bluestem [(*Bothrichloa saccaroides* (Swartz) Rydb.], red threeawn (*Aristida longiseta* Steud.), annual broomweed, southwest carrot (*Daucus pusillus* Michx.), and western ragweed (*Ambrosia psilostachya* DC.).

The buffalograss-curlymesquite shortgrass complex and Texas wintergrass were the dominant species on all sites except the Rocky Hill site, where they were subdominants (Table 1). Sideoats grama was the dominant species on the Rocky Hills site and subdominant on all other sites. Japanese brome was a subdominant on the Clay Loam, Clayey Upland and Loamy Bottomland sites. Hairy grama and silver bluestem were subdominants on the Rocky Hills site whereas red threeawn was a subdominant on the Clay Loam site. The dominant forb on all sites was annual broomweed. Western ragweed was a subdominant on the Clay Loam site.

Averaged across range sites, rank indices were significantly greater in the HC than MC treatment for buffalograss-curlymesquite, hairy grama, and annual broomweed and were signficantly less for Texas wintergrass, Japanese brome, and western ragweed (Table 1). However, when rank indices were weighted in proportion to range site composition of pastures, only the buffalograss-curlymesquite, Texas wintergrass and annual broomweed indices varied significantly between treatments (Table 1).

The effect of sample date on rank indices was significant for all species except sideoats grama, hairy grama, silver bluestem and western ragweed (Table 2). Generally, variation across dates was related to the functional attributes of each species. For example, the rank indices for Japanese brome, the dominant cool-season annual grass, were greatest during winter and spring and least during summer whereas indices for Texas wintergrass, the dominant cool-season perennial grass, were greatest generally during spring and early summer and least during fall and early winter. However, because the rank indices for each species were a measure of relative abundance, the biological significance of differences among species across dates was difficult to assess. But the general absence of significant treatment × date interactions effects indicated species standing crop dynamics were similar in both treatments.

Herbage Standing Crop

Statistical analyses of the herbage standing crop data prior to adjusting for differences among pastures in range site composition revealed significant range site, date, and range site × date interac-

Table 1. Mean rank indices for dominant species averaged across sample dates.

Common Name	Range Site[1]					Treatment[2]		Treatment[3]	
	Clay Loam	Clayey Upland	Clay Slopes	Rocky Hills	Loamy Bottomland	HC	MC	HC	MC
Grasses									
Buffalograss-curlymesquite	1.1c[4]	1.4ab	1.3b	0.74d	1.4a	1.4a	1.0b	1.4a	1.1b
Texas wintergrass	1.8a	1.8a	1.5b	0.4c	1.5b	1.1a	1.6b	1.2a	1.7b
Sideoats grama	0.7b	0.5c	0.8b	1.4a	0.8b	0.8	0.8	0.8	0.6
Japanese brome	0.4b	0.5b	0.3c	0.1d	0.7a	0.3a	0.4b	0.3	0.4
Hairy grama	<0.1b	<0.1b	<0.1b	0.4a	<0.1b	0.1a	<0.1b	0.1	0.1
Silver bluestem	0.1cd	<0.1d	0.2c	0.4a	0.3b	0.2	0.2	0.1	0.2
Red threeawn	0.5a	0.2c	0.3b	0.3b	0.1b	0.3	0.2	0.3	0.3
Forbs									
Southwestern carrot	0.1ab	0.1ab	0.1bc	<0.1c	0.1a	0.1	0.1	0.1	0.1
Annual broomweed	0.4	0.5	0.5	0.4	0.5	0.6a	0.4b	0.6a	0.5b
Western ragweed	0.3a	<0.1c	<0.1c	<0.1bc	0.1ab	0.1a	0.4b	0.1	0.4

[1]Averaged across grazing treatments and dates.
[2]Averaged across range sites and dates.
[3]Averaged across dates and adjusted for differences among treatment pastures in range site composition.
[4]Means within a row within range sites or treatments followed by different letters are significantly different at $P<0.05$.

Table 2. Mean rank indices for dominant species averaged across range sites and grazing treatments.

Species	Date							
	Oct 85	Jan 86	Apr 86	July 86	Nov 86	Feb 87	Mar 87	June 87
Grasses								
Buffalograss-curlymesquite	1.3a[1]	1.3a	0.9c	1.3a	1.2ab	1.2a	1.0bc	1.2ab
Texas wintergrass	1.3b	1.3b	1.4ab	1.4ab	1.3b	1.4ab	1.5a	1.5a
Sideoats grama	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7
Japanese brome	0.5ab	0.7a	0.6a	<0.1d	0.1d	0.4bc	0.6a	0.3c
Hairy grama	0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1
Silver bluestem	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Red threeawn	0.2b	0.3ab	0.3ab	0.3ab	0.3ab	0.2b	0.3ab	0.4a
Forbs								
Southwestern carrot	<0.1c	<0.1c	<0.1c	0c	0c	0c	0.4a	0.3b
Annual broomweed	0.9b	0.9b	0.4c	<0.1d	<0.1d	<0.1d	0.2c	1.7a
Western ragweed	0.3	0.3	0.3	0.2	0.2	0.1	0.2	0.3

[1]Means within a row followed by different letters are significantly different at $P<0.05$.

Table 3. Herbage standing crop (kg/ha) averaged across sample dates.

Category	Range Site[1]					Treatment[2]		Treatment[3]	
	Clay Loam	Clayey Upland	Clay Slopes	Rocky Hills	Loamy Bottomland	HC	MC	HC	MC
Live grass	629b[4]	617bc	544c	269d	759a	505	622	496a	601b
Dead grass	991b	768c	776c	453d	997a	628	966	606a	961b
Total	1620b	1385c	1320c	722d	1756a	1133	1588	1102a	1562b
Forbs	222	221	230	219	334	247	244	239	254
Total	1842b	1606c	1550c	941d	2090a	1380	1832	1341a	1816b

[1]Averaged across grazing treatments and dates.
[2]Averaged across range sites and dates.
[3]Averaged across dates and adjusted for differences among treatment pastures in range site composition.
[4]Means within a row within range sites and treatments followed by different letters are significantly different at $P<0.05$.

Table 4. Percentage crude protein, organic matter digestibility and percentage live grass standing crop averaged across dates.

Category	Range Site[1]					Treatment[2]		Treatment[3]	
	Clay Loam	Clayey Upland	Clay Slopes	Rocky Hills	Loamy Bottomland	HC	MC	HC	MC
Crude Protein (%)	8.2b[4]	8.7a	8.0b	7.4c	8.3b	8.5	7.7	8.6a	7.7b
Organic matter digesibility (%)	48.3	47.2	48.7	49.3	47.3	49.5	46.8	49.3	46.7
Live (%)	37.5c	42.5a	38.9bc	36.4c	41.9ab	41.2	37.7	41.6	36.9

[1]Averaged across grazing treatments and dates.
[2]Averaged across range sites and dates.
[3]Averaged across dates and justified for differences among treatment pastures in range site composition.
[4]Means within a row within range sites and treatments followed by different letters are significantly different at $P<0.05$.

tion effects but no treatment, treatment × range site, treatment × date, or treatment × range site × date interaction effects. Live, dead, total grass (live + dead) and total (grass + forbs) standing crops were greatest on the Loamy Bottomland sites and least on the Rocky Hills site (Table 3). Standing crop was greater generally on the Clay Loam than the Clayey Upland and Clay Slopes sites. There were no significant differences among sites in forb standing crop. Although there were no significant treatment effects when the data were averaged across dates and range sites, standing crops were significantly greater in the MC than HC treatment pastures after adjustment for differences among pastures in range site composition (Table 3).

The significant date effects reflected the effect of climatic conditions on rates of herbage growth and disappearance. The significant date × range site interactions that occurred when standing crops were averaged across treatments were considered to be of minor importance when F-values were examined. For example, F-values for range site and date were 4- to 8-fold greater than F-values for the date by range site interaction. Moreover, when standing crops were adjusted for differences among treatment pastures in range site composition, only the main effects of treatment and date were significant. Thus, at the pasture level, standing crop of live and dead grass, total grass, and total herbage were significantly greater in the MC than HC treatment on all dates (Fig. 3). There was no difference between treatments in forb standing crop.

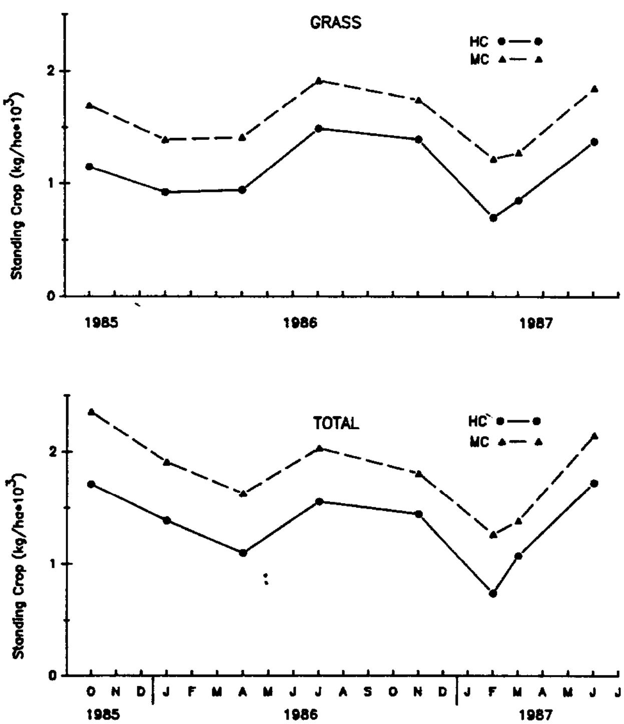

Fig. 3. *Grass and total (grass + forbs) standing crops (kg/ha) for pastures in heavy (HC) and moderate (MC) continuous grazing treatments. Treatment effects were significant ($P<0.10$) (Q_2 = 7 & 51 for grass and total standing crop, respectively). Date effects were significant ($P<0.05$) (Q_8 = 480 & 432, respectively). Treatment by date interaction was not significant in either analyses.*

Forage Quality

Percentage CP of the grass standing crop varied significantly among range sites and dates but not treatments when averaged across range sites (Table 4). Averaged across dates, percentage CP ranged from a high of 9.3% on the Clayey Upland site to a low of 7.4% on the Rocky Hills site. Averaged across range sites, percentage CP ranged from a high of 10.4% in March 1987 to a low of 5.8% in January 1986. Although there was a significant range site × date interaction effect, the effect was minor in that percentage CP was greatest on all dates, except June 1987, on the Clayey Upland site and least on all dates, except October 1985, on the Rocky Hills site. When the percentage CP data were adjusted for differences among treatment pastures in range site composition, percentage CP varied significantly between treatments (Table 4) and among dates (Fig. 4). There was no significant treatment × date interaction effect.

Percentage OMD of the grass standing crop did not vary significantly among range sites or between treatments (Table 4) regardless of method of summarization. However, percentage OMD did vary significantly among dates (Fig. 4) in a pattern similar to percentage CP. Although there was a significant range site × date interaction effect, no definitive pattern of variation was apparent in that percentage OMD ranged across dates from 49 to 65% on the Loamy Bottomland and Clay Slopes sites, 49 to 62% on the Clay Loam site, 50 to 64% on the Rocky Hill site, and from 51 to 65% on the Clayey Upland site. Moreover, there was considerable variation among range sites when they were ranked within a date according to percentage OMD. For example, ranks over the 8 dates ranged from 1 (greatest) to 5 (least) for the Clayey Upland and Rocky Hills sites, 2 to 5 for the Clay Loam and Loamy Bottomland sites and from 1 to 4 for the Clay Slopes site.

There was a relatively strong relationship between percentage CP, OMD and live standing crops (Fig. 4, Table 4). Correlation

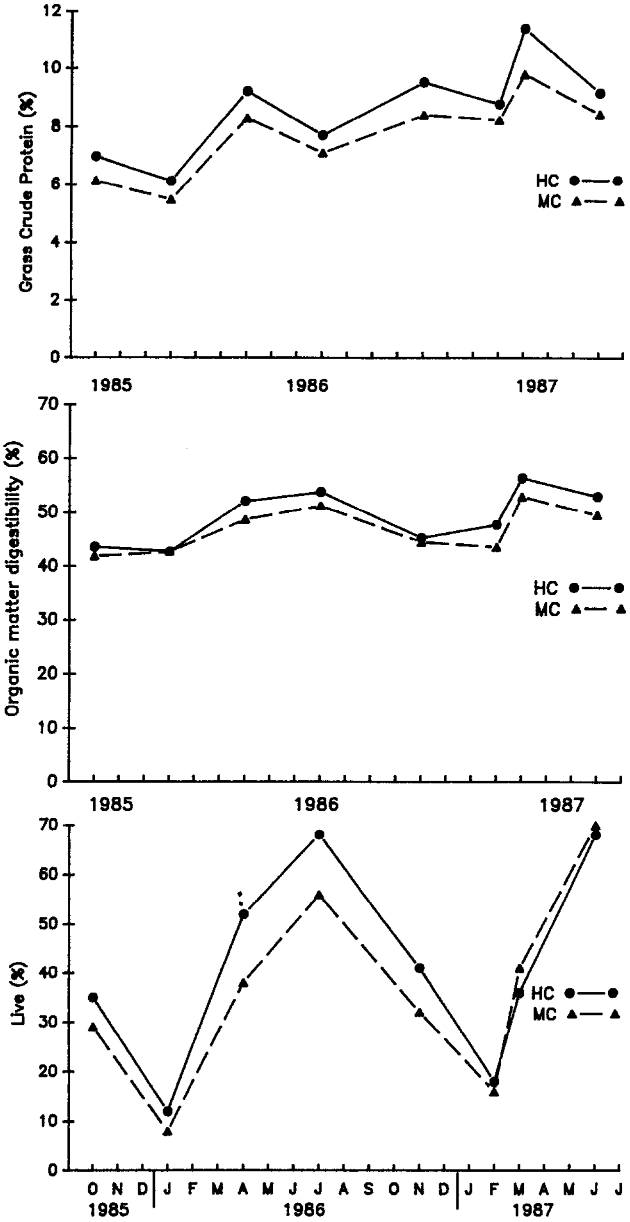

Fig. 4. *Percentage CP, OMD and live (green) standing crop for pastures in heavy (HC) and moderate (MC) continuous grazing treatments. Treatment effects were significant (P<0.10) in analyses of grass % CP (Q_2 = 1.2). Date effects were significant (P<0.05) in all analyses (Q_8= 1.1, 5.9 and 12.4 for % CP, % OMD and % live respectively). Treatment by date interaction was not significant in either analyses.*

coefficients were 0.53, 0.41, and 0.54 (n = 478, P<0.001) between percentage CP and OMD, percentage CP and live standing crop, and between percentage OMD and live standing crop, respectively. This was as expected because previous research at the ranch has shown %CP and %OMD are greater for live than dead grass tissue (Heitschmidt et a. 1981, 1987).

Discussion and Conclusions

We conclude from the results of this study that: (1) standing crop in the HC pastures was characteristically dominated by warm-season shortgrasses and Texas wintergrass whereas standing crop in the MC pastures was characteristically dominated by Texas wintergrass and a mixture of warm-season short- and midgrasses (Table 1); (2) aboveground standing crop dynamics were similar in both treatments (Fig. 3); (3) quantity of available forage was greater in the MC than HC treatment (Fig. 3, Table 3); and (4) forage quality was greater generally in the HC than MC treatment (Fig. 4, Table 4).

Although species composition was not measured directly in this study, we believe the greater abundance of shortgrasses in the HC treatment was the result of a general shift in species composition from a Texas wintergrass/warm-season midgrass complex (good range condition) to a Texas wintergrass/warm-season shortgrass complex (fair range condition). Previous research in these same pastures (Heitschmidt et al. 1985) supports this conclusion in that it showed frequency of buffalograss and end-of-season standing crop of warm-season shortgrasses inside temporary exclosures was substantially greater in the HC than MC pastures on most range sites. Standing crop dynamics were similar between treatments because species composition by functional group (cool-season vs. warm-season species) was similar. Quantity of available forage was greater in the MC than HC treatment, probably because of the combined effects of both reduced forage demand (stocking rate) and greater aboveground net primary production (ANPP). Although the vegetation sampling scheme utilized in this study was not conducive for estimating ANPP, previous research in these same study pastures (Heitschmidt et al. 1985) has shown single year (1982) ANPP estimates of 3,285, 2,640, and 1,850 kg/ha in the HC treatment and 3,110, and 2,940, and 2,505 kg/ha in the MC treatment for Loamy Bottomland, Clay Loam, and Rocky Hills sites, respectively. Quality of forage was greater generally in the HC than MC treatment because the proportional amount of low quality (senesced) forage was greater in the MC (63%) than in the HC treatment (58%).

The results of this study also provide strong evidence as to why cow-calf production is more variable across years in the HC treatment than in the MC treatment (Heitschmidt et al. 1988). For example, during the period from 1982 through 1987 production/cow in the HC treatment averaged 211 kg and production/ha averaged 44 kg as compared to production estimates of 215 kg/cow and 34 kg/ha in the MC treatment (Heitschmidt et al. 1988). These averages were attained at average stocking rates of 4.9 and 6.4 ha/cow/yr, respectively, and the feeding of an average of 112 and 24 kg/cow/year of a 20% CP range cube during winter in the HC and MC treatments, respectively. However, production/cow, production/ha, stocking rate, and amount of winter supplement fed in the HC treatment ranged from 169 to 248 kg/cow, 29 to 51 kg/ha, 4.6 to 5.9 ha/cow and 67 to 186 kg/cow, respectively, as compared to respective ranges of 182 to 237 kg/cow, 29 to 38 kg/ha, 6.2 to 6.4 ha/cow and 0 to 87 kg/cow, in the MC treatment. These data in combination with the results from this study indicate the variation results because quantity of available forage limits nutrient intake more frequently in the HC than MC treatment. This occurs because periodic drought often limits the accumulation of an adequate forage reserve in the HC treatment. As a result, livestock production among years is more variable in the HC than MC treatment.

Lastly, we believe the results of this study provide a classic example of how grass-dominated ecosystems generally respond to continuing high levels of herbivory. Because capture of solar energy is the first step required to maintain the integrity of an ecosystem, and because high levels of herbivory (grazing) often limit an ecosystem's ability to capture solar energy, either a shift in plant species composition or a reduction in herbivore density (forage demand) should be anticipated over time. But because our management strategy in these treatments is focused on maintaining a constant herbivore density over time, ecosystem response has been limited primarily to a shift in plant species composition. In this instance, the shift is towards a species complex that is generally less palatable (i.e., annual broomweed), less productive (i.e., short-grasses) and more grazing tolerant (i.e., short-grasses).

Literature Cited

Assoc. Off. Anal. Chem. 1975. Official methods of analysis (11th ed.). Assoc. Off. Anal. Chem., Washington, DC.

Bartolome, J.W. 1984. Impacts of grazing intensity and grazing systems on vegetation composition and production. p. 917-215. *In:* Developing strategies for rangeland management. Westview Press, Boulder, Colo.

Danckwerts, J.E., and A.J. Aucamp. 1986. The effect of range condition on the grazing capacity of semi-arid South African savanna. p. 229-230. *In:* Proc. 2nd Int. Rangeland Congress, (eds. P.J. Joss, P.W. Lynch and O.B. Williams), Aust. Acad. of Sci., Canberra, Australia.

Ellison, Lincoln. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26:1-78.

Heitschmidt, R.K., R.A. Gordon, and J.S. Bluntzer. 1982. Short duration grazing at the Texas Experimental Ranch: Effects on forage quality. J. Range Manage. 35:372-374.

Heitschmidt, R.K., S.L. Dowhower, R.A. Gordon, and D.L. Price. 1985. Response of vegetation to livestock grazing at the Texas Experimental Ranch. Texas Agr. Exp. Sta. Bull. 1515.

Heitschmidt, R.K., S.L. Dowhower, and J.W. Walker. 1987. 14-vs. 42-paddock rotational grazing: Forage quality. J. Range Manage. 40:315-317.

Heitschmidt, R.K., S.K. Canon, W.E. Pinchak, and S.L. Dowhower. 1989. Effects of yearlong continuous, deferred rotation, and short duration grazing treatments on cow/calf production at the Texas Experimental Ranch. J. Prod Agr. (In press).

Lauenroth, W.K. 1979. Grassland primary production: North American grasslands in perspective. p. 3-24. *In:* Norman R. French (ed.) Perspectives in grassland ecology. Springer-Verlag, New York.

Little, T.M., and F.J. Hills. 1978. Agricultural experimentation: Design and analysis. John Wiley and Sons, New York.

Malechek, J.C. 1984. Impacts of grazing intensity and specialized grazing systems on livestock response. p. 1129-1158. *In:* Developing strategies for rangeland management. Westview Press, Boulder, Colo.

Sims, P.L., J.S. Singh, and W.K. Lauenroth. 1978. The structure and function of ten western North American grasslands. I. Abiotic and vegetational characteristics. J. Ecol. 66:251-285.

Snedecor, G.W., and W.C. Cochran. 1967. Statistical methods (6th ed.). Iowa St. Univ. Press, Ames.

Soil Conservation Service. 1984. Field office technical guide. USDA. Abilene, Texas.

Stoddard, L.A., A.D. Smith, and T.W. Box. 1975. Range management. McGraw-Hill Book Co., New York.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Brit. Grassland Soc. 18:104-111.

Van Soest. P.J., and R.H. Wine. 1967. Use of detergents in the analyses of fibrous feeds. IV. The determination of plant cell wall constituents. Assoc. Off. Anal. Chem. 50:50.