

Rangeland and steer responses to grazing in the Southern Plains

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Abstract

This investigation was to determine the carrying capacity of the Southern Plains mixed-grass prairie by measuring vegetation and yearling steer gain responses to 2 replicates of 3 different grazing intensity treatments between 1941 and 1951. The light, moderate, and heavy grazing treatments, set at 41, 53, and 82 animal-unit-days ha^{-1} (AUD ha^{-1}), were grazed with straight-bred Hereford steers with an initial weight of 213 ± 11 (SD) kg from about 13 November to 29 September each year. Basal cover of the individual herbaceous species and the canopy cover of the shrubs were measured along 1,289, 10-m line-transects in the 6 pastures (about 215 per pasture). All treatments showed recovery from a long history of severe grazing and the drought of the 1930's. Vegetation change was largely attributed to favorable precipitation during the study. The basal cover of all perennial grasses was about 5% in 1941 and increased to between 8 and 15% by 1951. The increases were greater in the heavily stocked pastures compared with the light and moderate grazing intensity treatments. Steer gains averaged 168 kg per head. Of this total, 134 kg or 80% occurred in the summer period (April–September). Total live weight gain head $^{-1}$ decreased as stocking rate increased. Stocking rate affected gain head $^{-1}$ in both the winter and summer grazing periods. Live weight gain hectare $^{-1}$ increased as stocking rate increased. Apparently, the maximum gain hectare $^{-1}$ was not reached within the bounds of the experimental treatments. Net return hectare $^{-1}$ increased as stocking rate increased. Based on this initial study, carrying capacity of this prairie was greater than 53 AUD ha^{-1} . During extended periods of good rainfall, the carrying capacity of Southern Plains mixed-prairie may reach 82 AUD ha^{-1} .

Key Words: beef cattle, efficiency, mixed prairie, basal cover, gain per hectare, average daily gain, climate

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Resumen

El objetivo de esta investigación fue determinar la capacidad de carga de pastizales mixtos de las Planicies de Sudeste mediante la medición de la respuesta de la vegetación y la ganancia de novillos a 3 intensidades de apacentamiento con 2 repeticiones durante 1941 a 1951. Los tratamientos de apacentamiento fueron cargas animal ligera, moderada y alta que consistieron de 41, 53 y 82 unidades-animal-día ha^{-1} (UAD ha^{-1}), los animales utilizados fueron novillos Herford con un peso inicial promedio de 213 ± 11 (SD) kg y el período de apacentamiento fue del 13 de Noviembre al 29 de Septiembre de cada año. Se midió la cobertura basal individual de cada especie herbácea y la cobertura de copa de las arbustivas en 1,289 transectos de línea de 10 m localizados en 6 potreros (aproximadamente 215 por potrero). Todos los tratamientos mostraron una recuperación a un largo período de apacentamiento severo y la sequía de la década de lo 30's. El cambio de la vegetación se atribuyó principalmente a la precipitación favorable durante el período de estudio. En 1941 la cobertura basal de los zacates perennes fue aproximadamente 5%, para 1951 era entre el 8 y 15%. El incremento fue mayor en los potreros con cargas animal altas comparados con los que recibieron los tratamientos de apacentamiento ligero y moderado. El promedio de ganancia de los novillos fue 168 kg cabeza $^{-1}$. Del aumento total, 134 kg o el 80% se obtuvo en el verano (Abril a Septiembre). La ganancia total de peso vivo cabeza $^{-1}$ disminuyó al aumentar la carga animal. La carga animal afectó la ganancia cabeza $^{-1}$ tanto en el período de apacentamiento de invierno como en el de verano. La ganancia de peso vivo ha^{-1} incremento conforme la carga animal aumento. Aparentemente la máxima ganancia ha^{-1} no se alcanzó dentro de los límites de los tratamientos experimentales. El retorno neto ha^{-1} aumento al incrementar la carga animal. Basado en este estudio inicial, la capacidad de carga de estos pastizales fue mayor a 53 UAD ha^{-1} . Durante períodos prolongados de buena precipitación, la capacidad de carga de los pastizales mixtos de las Planicies del Sudeste puede llegar a 82 UAD ha^{-1} .

The Southern Plains Experimental Range (SPER) was established to conduct comprehensive grazing investigations to improve native rangeland management and develop more efficient beef production systems. Originally, this 1,746 ha unit was a single large, excessively grazed pasture owned by the Irish Syndicate Ranch for many years prior to being purchased by the U. S. Government on 13 December 1940. The native

sandhill rangeland was "observed to be in extremely poor condition as a result of severe drought, intense heat, and close grazing"¹ in 1936. Preliminary vegetation measurements began in 1940 and development of the SPER facilities began in 1941. Livestock water wells were drilled, boundary fences were established in cooperation with the Civilian Conservation Corp, and corrals, livestock weighing scales, and supplemental feed storage facilities were built.

Surveys of the topography, soil, and vegetation were completed in 1940 before the SPER was cross fenced in 1941. Some 3,729, 10-m transect lines were sampled across the SPER to determine the relationship of soil type, degree of slope, and slope direction on the composition, cover, and density of important species of grasses, forbs, and shrubs. Based on these surveys, the SPER was subdivided into pastures in 1941 to maximize the uniformity of vegetation, soil, and topography within each group of pastures assigned to the different grazing treatments. Grazing studies were formally initiated on 9 December 1941.

The purpose of the initial study was to determine profitable and sustainable stocking rates for the Southern Plains mixed-grass prairie by measuring vegetation and yearling steer gain responses to 3 different grazing intensities over the 10-year period of 1941 to 1951. These data were never fully published, although some mimeographed material, footnoted elsewhere in this paper, was distributed and some of the general results were briefly mentioned in previous publications (McIlvain and Savage 1951, and Shoop and McIlvain 1971a, 1971b).

Materials and Methods

The SPER is located in northwestern Oklahoma 10 km northwest of Woodward, and 2 km north of Ft. Supply, (99° 23' W, 36° 27' N, elevation 610–640 m). This research unit consists of gently rolling, stabilized sand dunes frequently interspersed with areas of heavier textured soils and has no well-defined drainage patterns. This sandhills

vegetation type dominates over 6 million ha along the major rivers that flow diagonally across the Southern Plains. The vegetation is dominated by a mixture of tall, mid, and short warm-season grasses and forbs, and sand sagebrush (*Artemisia filifolia* Torr.). The native vegetation of the Southern Plains mixed-grass prairie is within the sandsage-bluestem (*Artemisia-Andropogon*) prairie type of Küchler (1964, 1975). Pratt soils (sandy, mixed, mesic Psammentic Haplustalfs) are on lower slopes and more level areas, and Tivoli soils (mixed, thermic Typic Ustipsamments) occur on upper slopes (Berg 1994).

Experimental Animals

Male, straight-bred Hereford calves (approximately 220 days of age) were obtained each year from a single ranch. Calves were separated from their dams on their home ranch and shipped immediately to SPER in mid-October. At receiving, they were number-branded, vaccinated for blackleg (*Clostridium chauvoei*) and malignant edema (*Clostridium septicum*) (Manufactured by Fidelity Lab., Oklahoma City, Okla.), treated for ear ticks (*Otobius megnini* Dugés) and lice (*Linognathus vituli* L.), castrated, and dehorned. The calves then grazed standing sorghum (*Sorghum bicolor* (L.) Moench) for at least 2 weeks to recover from these operations.

After the receiving period, steers were weighed on 2 or 3 successive days and allotted to treatment groups blocked by weight and feeder grade. Initial steer weight after the receiving period averaged 213 ± 11 (SD) kg. Steers were weighed monthly through the grazing season, in early morning after being held off water (but not forage) for 12 hours.

Experimental pastures ranged in size from 43 to 86 ha. Steer numbers per pasture varied slightly over years because of weather conditions but averaged 16 head for the light and moderate stocking rates and 16.5 head for the heavy stocking rate. Average dates for the beginning and end of the grazing season were 13 November and 29 September.

During the winter period (November–March), steers were fed 41% crude protein cottonseed cake at a rate of 0.68–0.91 kg head⁻¹ day⁻¹. The steers had con-

tinuous access to block salt but no other minerals were fed. The steers were treated 3 times with Coral insecticide (Manufactured by Cutter Lab., Dallas, Tex.) for grub control in early winter and 4 times for horn fly (*Haematobia irritans* L.) control in summer.

Steers were grazed continuously throughout the 10.7-month grazing period each year. During the early years of the study, 1942–1945, the initial group of steers were grazed only through the winter period and were then sold. A second group of steers was then used for the summer period. This procedure maintained the prescribed stocking rates but negated analysis of livestock gains over the entire grazing period. The analysis was thus, restricted to steer gains from 1946 to 1951 when a single group of steers grazed from November to September.

Grazing Treatments

The grazing intensity treatments were selected to bracket what was hypothesized to be the sustainable level of utilization of the available forage resources. Two replicate pastures of each of 3 stocking rates were investigated in this study. Stocking rate was expressed as animal-unit-days (AUD) per hectare. The AUD were calculated separately for winter and summer periods and then combined into a total AUD. Animal units were calculated as average BW kg^{0.75}/454^{0.75} for each of the 2 gain periods. The stocking rates were about 41, 53, and 82 animal unit days ha⁻¹ (AUD ha⁻¹) for the light, moderate, and heavy grazing intensities, respectively. These stocking rates were approximately 2.6, 3.9, and 5.2 ha hd⁻¹ for an average 320-day or 10.7-month annual grazing period. Each steer was calculated as the equivalent of about 0.67 of an animal unit, based on average weights across a 10.7-month grazing season.

The moderate rate of grazing was designed for 'maximum use without injury to the vegetation'². It consisted of using 2/3 to 3/4's of the forage produced during the current year and leaving a 25-mm stubble on the shortgrasses and a

¹D.A. Savage, 1941 file report "Preliminary grazing treatments on the Southern Plains Experimental Range", U.S. Southern Great Plains Field Station, Woodward, Okla.

²Fourteen year summary of range improvement studies at the U.S. Southern Great Plains Field Station by E.H. McIlvain, D.A. Savage, E.A. Tucker and W.F. Lagrone. 1950. Miscellaneous Mimeographed Series. Woodward, Okla.

75- to 100-mm stubble on the tall grass species by late winter. Moderate grazing protected the ground surface with standing vegetation and litter and the pastures never had a closely grazed appearance. It was assumed that moderate grazing would allow the preferred tall and mid-grasses to increase in pastures that were in "poor condition" while those in "good condition" would maintain their stands of the preferred grasses. The heavy grazing treatment was designed to deliberately graze the rangeland to excess in comparison to the moderate and light grazing treatments. Land allowance per yearling was decreased about 1/3 in the heavy treatment and increased by about 1/3 in the lightly grazed pastures compared with those that were moderately grazed.

Vegetation Surveys

Vegetation measurements of the experimental pastures were conducted in 1940 before the grazing studies began and prior to finalization of purchase, and in 1942, 1949, and 1951 using the line-transect method (Parker and Savage 1944). Similar vegetation measurements were taken in 1949 and 1951 within 0.5 to 2 ha fenced exclosures established in many of the pastures at the beginning of the study. Sampling was restricted during World War II. The line-transect method used at SPER consisted of measuring the peripheral spread of the canopy cover of shrubs in a 10-cm band and the ground cover of all other species in a 1-cm wide band along a tightly stretched 10-m cable. The cable was first placed at the sand sagebrush canopy level and the shrub canopy cover was measured. Shrub branches equal to or less than 10 cm apart were considered as solid foliage cover. All branches of any one shrub measured in this manner were totaled. Branches separated more than 10 cm were measured independently. These procedures provided a tabulated record of shrub cover and density by species within a 10-cm band along the transect line.

After the shrubs were measured, the cable was lowered to ground level. The cover was measured at ground level of every herbaceous plant species that occurred within 0.5 cm of each side of the vertical plane projection of the cable. Again, the separate parts of a single plant were totaled and recorded as 1

Table 1. The number of strata, lines, and transects and the direction of the transect lines in each of the pastures used in the light, moderate, and heavy stocking rate study at the Southern Plains Experimental Range between 1940 and 1951.

Pasture	Treatment	Strata	Lines	Transects	Direction
17	Moderate	5	15	277	SE/NW
18	Light	5	15	306	E/W
19	Moderate	5	10	172	SE/NW
20	Light	5	10	224	NW/SE
21	Heavy	5	10	181	SW/NE
24	Heavy	5	10	129	W/E

figure for each plant along the transect. When parts of the same plant species were closer than 1 cm apart, they were considered to completely occupy the soil surface and represented solid ground cover. When the basal portions of any herbaceous plant were more than 1 cm apart, they were measured separately and the space between plants was considered open. This gave a record of basal cover and the total number of plants along each 10-m transect. Each pasture was subdivided into 5 strata with 10 or 15 transect lines per strata and an average of about 18 transects in each transect line (Table 1). On this semiarid mixed grass prairie, 4 trained technicians could read about 94 transects per day.

The basal cover of the 13 most important perennial grasses and the averages for annual grasses and perennial and annual forbs have been summarized. Canopy cover of sagebrush and other shrubs are also presented. Species composition was calculated for the herbaceous species by dividing the basal cover of each individual species by the total basal cover of all herbaceous species. Shrubs were not included in these calculations because canopy cover of shrubs was measured rather than basal cover.

Data Analyses

The basal cover and species composition data from the replicated pastures were subjected to analysis of variance by species or species group using the SAS procedures (SAS 1989). The data were analyzed using a model that tested effects of stocking rate, year and their interactions in a completely randomized design with repeated measures. The main treatment was stocking rate and the repeated factor was year. Response variables were basal cover and relative composition of the various plant species or groups of species. The protected LSD was used to

assess differences among treatment means ($\alpha = 0.05$). Pastures were the experimental unit for all analyses.

Each species or species group was analyzed separately. The species composition data were analyzed with and without arcsin transformation for percentages. No major differences were found in the results of the analyses. Thus, we have presented the untransformed data. To address the research objective, we emphasized interactions of stocking rate with year. A simple stocking rate effect indicates treatments were already different in 1940 before grazing began and the difference was consistent over years. Likewise, a simple year effect indicates the vegetation changed over time but the changes were similar at all stocking rates. Our main interest was in stocking rate by year interactions because such an effect indicates that the vegetation responded differently to different stocking rates over time. Significant effects of stocking rate were not considered especially important unless they changed over time.

Cattle weight data were analyzed by linear regression. The dependent variables were total live weight gain per head for the grazing season, gains in the winter period (November–March), and gains in the summer period (April–September). The independent variable was stocking rate.

Initially, regression models were developed for each year individually. The heterogeneity of intercepts and slopes for these regression models was tested using analyses of variance (Littell et al. 1991). The model included terms for stocking rate, year, and the interaction of stocking rate and year. Stocking rate was a quantitative variable and year was a qualitative variable. Intercepts and slopes differed between years for these models ($P < 0.01$). Differences between years were expected as many factors

affecting livestock performance vary over years. Some important factors included precipitation, temperature, forage production, forage nutritive value, and quality of livestock (Launchbaugh 1957). Because these year-to-year differences are difficult to predict (Ash and Stafford-Smith 1996) and our primary interest was in long-term relationships, we averaged live weight gains over years and developed a single regression model based on average gains. This model was used for subsequent analyses.

Gain ha^{-1} was calculated by multiplying the regression equation for gain head^{-1} by stocking rate. Net return ha^{-1} was calculated using methods of Hart et al. (1988). Variable costs for steer production were estimated at \$70 head^{-1} based on actual costs from yearling cattle enterprises in this region from 1990 to 1996. Variable costs were calculated assuming a 10% interest rate on operating capital, a 2% death loss, and a \$19.77 ha^{-1} land charge. Returns were calculated using prices of \$1.54, \$1.87, and \$2.20 kg^{-1} for purchase of a 213-kg steer calf. Prices for feeder cattle were then calculated using a constant value of gain of \$1.10 kg^{-1} . This resulted in prices of \$1.37, \$1.56, and \$1.76 kg^{-1} for 340-kg feeder steers. The effect of stocking rate on net returns was evaluated for each of these 3 price scenarios. Standard deviations and coefficients of variation were calculated for steer gain from 1946 to 1951. These variables were then compared to stocking rate using regression analysis. To compare variability of steer gain during the summer and winter periods we tested heterogeneity of intercepts and slopes for these regression models using analyses of variance (Littell et al. 1991).

Results and Discussion

Precipitation

Annual precipitation from 1940 through 1951 averaged 625 ± 129 (SE) mm and ranged from a low of 460 mm in 1940 to a high of 915 mm in 1941 (Fig. 1). The long-term average (1940–1996) annual precipitation at the SPER is 566 ± 159 (SE) mm, with about 70% of the rainfall occurring during the April through October growing season. Winter precipitation may often be quite limited, as in 1950, and rarely exceeds summer precipitation. The annual pre-

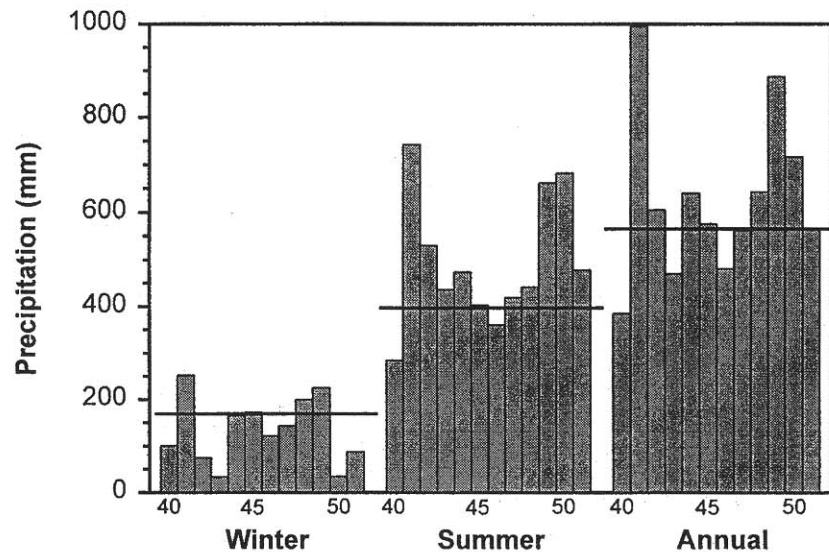


Fig. 1. Winter, summer, and annual precipitation (mm) for 1940 to 1952 period and the long-term (1940–1996) averages (straight lines) for each category at the Southern Plains Experimental Range, Fort Supply, Okla.

cipitation was either near or in excess of the long-term mean in all but 3 of the 10 years of the study (Fig. 1). Departures below the long-term average between 1940 and 1951 averaged about 8% of the long-term average, much less than the 30% deficit that defines drought conditions. Consequently, basal cover of most species of vegetation on all of the grazing treatments applied in this study generally increased during this period of investigation. Vegetation dynamics during more dynamic or below-normal precipitation periods might be somewhat different from those found in this study.

Basal Cover

Selecting a standard for comparing differences in vegetation responses to grazing is difficult. Hart and Ashby (1998) and Milchunas and Lauenroth (1993) concluded that ungrazed exclosures were often atypical of undisturbed plant communities. Sims et al. (1978) synthesized primary producer data from grazed and ungrazed desert, plains, and mountain grasslands and concluded that the grazed grasslands functioned as a more natural ecosystem than either the ungrazed grasslands or protected relics. In the present experiment, evaluation of vegetation and livestock responses to different levels of grazing intensity should provide some useful comparisons of the responses of the mixed-grass prairie vegetation to grazing by large ruminant animals.

Perennial grasses

The Southern Plains mixed-grass prairie showed remarkable recovery from the effects of a long history of close grazing and the drought of the 1930's during the 10-year period of this study. Generally, the basal cover of the vegetation increased under light, moderate, and heavy grazing with yearling steers between 1940 and 1951 (Fig. 2–4). A large portion of these changes in the vegetation was attributable to the favorable precipitation during this period (Fig. 1). In addition, vegetation changes from year to year are to be expected. Basal cover differed ($P < 0.05$) among the 4 sampling years for all species studied. Consequently, the following discussions emphasize differences in basal cover for different grazing intensities and the grazing intensity by year interaction.

Basal cover of perennial grasses was about 4% in all pastures at the beginning of the stocking rate study in 1941 (Fig. 2A). Basal cover of perennial grasses increased to between 5.5 and 7% by 1942 and to between 8.6 and 14.8% by 1951. The changes in basal cover were not uniform across years for all stocking rates (stocking rate by year interaction, $P < 0.01$). The increase in cover of perennial grasses was greater in the heavy stocking rate than in either the light or moderate rate.

Tall grasses generally increased in basal cover over the 10 years of this

Among the mid-grasses, only fall witchgrass (*Digitaria cognata* [J. A. Schultes] Pilger; (Table 2) and sand lovegrass (*Eragrostis trichodes* [Nutt.] Wood) (Fig 3D) showed year by stock-

Fig. 2. Basal cover of perennial and annual grasses and forbs and canopy cover of sand sagebrush and other shrubs at the light, moderate, and heavy grazing intensities in 1940, 1942, 1949, and 1951 at the Southern Plains Experimental Range, Fort Supply, Okla.

B Annual grasses

Fire Frequency (years)	Open Circles (kg/ha)	Solid Circles (kg/ha)	Open Triangles (kg/ha)
0.06	0.45	0.40	0.40
0.002	0.00	0.00	0.00
0.26	1.35	1.10	1.20
0.02	0.10	0.05	0.05

D Annual forbs

Fire Frequency (years)	Open Circles (kg/ha)	Solid Circles (kg/ha)	Open Triangles (kg/ha)
0.08	0.55	0.40	0.15
0.01	0.15	0.10	0.10
0.08	0.95	0.75	0.75
0.02	0.20	0.10	0.10

F Other shrubs

Fire Frequency (years)	Open Circles (kg/ha)	Solid Circles (kg/ha)	Open Triangles (kg/ha)
1.08	0.40	3.30	0.00
1.22	0.90	4.00	0.00
1.43	1.00	4.70	0.00
1.03	0.60	3.40	0.00

($P<0.05$) at increasing levels of stocking from light to heavy. Sand sedge (*Cyperus schweinitzii* Torr.), a grasslike species (Fig. 4F), also had a year \times stocking rate interaction ($P<0.05$). Sand

Species	Grazing Treatment													
	Light				Moderate				Heavy				Exlosures	
	1940	1942	1949	1951	1940	1942	1949	1951	1940	1942	1949	1951	1949	1951
	------(%)-----													
Little bluestem	3.1	2.5	3.3	17.5	3.4	3.6	4.3	20.9	3.9	3.7	2.9	14.1	12.7	8.0
Sand bluestem	3.2	5.2	2.2	3.6	5.0	6.7	2.2	2.7	5.1	6.2	1.8	1.9	3.8	6.4
Switchgrass	1.1	0.7	1.2	1.3	0.9	1.6	1.2	1.4	1.4	1.1	1.1	0.9	2.2	1.4
Fall witchgrass	0.0	0.0	0.0	5.5	0.0	0.0	0.0	7.5	0.0	0.0	0.0	7.6	1.0	3.1
Sand dropseed	28.9	22.8	13.2	7.7	43.9	34.3	18.3	7.8	28.7	20.6	18.3	9.5	18.5	15.8
Sideoats grama	0.7	0.4	0.5	0.4	1.0	0.9	1.5	1.1	0.9	1.7	1.2	1.0	0.5	3.8
Sand lovegrass	1.1	3.7	8.0	10.4	1.0	4.1	8.7	12.3	0.8	3.4	2.2	6.2	4.3	5.7
Sand paspalum	0.6	3.4	5.0	4.5	0.5	2.9	5.2	5.8	0.3	2.5	3.9	3.8	4.0	3.7
Sand sedge	0.1	0.7	1.2	2.3	0.1	0.7	1.4	2.2	0.3	1.0	1.9	2.0	0.8	2.4
Texas bluegrass	0.8	1.5	2.9	0.8	0.4	1.4	2.3	0.9	0.2	0.1	0.5	0.1	1.8	0.9
Other grasses	1.5	1.4	2.7	0.9	1.0	1.5	3.5	2.7	0.8	1.2	2.7	0.2	1.7	1.0
Blue grama	37.2	52.7	35.9	39.6	19.5	34.3	22.0	26.3	42.0	52.6	41.7	46.7	31.5	37.0
Buffalograss	1.2	2.0	0.0	0.4	1.4	3.0	1.6	2.3	0.2	1.9	2.3	3.2	0.5	0.9
Hairy grama	0.6	0.3	0.3	0.6	0.5	0.5	0.4	0.6	0.4	0.8	0.4	1.0	0.3	0.4
Perennial grasses	80.1	97.3	76.4	95.5	78.6	95.5	72.6	94.5	85.0	96.8	80.9	98.2	83.6	90.5
Annual grasses	10.1	0.0	13.4	1.3	8.6	0.0	15.0	1.3	9.5	0.1	12.0	0.5	9.1	3.5
Perennial forbs	1.6	0.8	1.4	1.5	2.1	1.4	1.7	1.7	1.3	0.7	0.6	0.3	1.5	2.9
Annual forbs	8.2	2.1	8.8	1.7	10.7	3.2	10.9	2.3	4.2	2.5	6.6	0.9	19.6	3.3

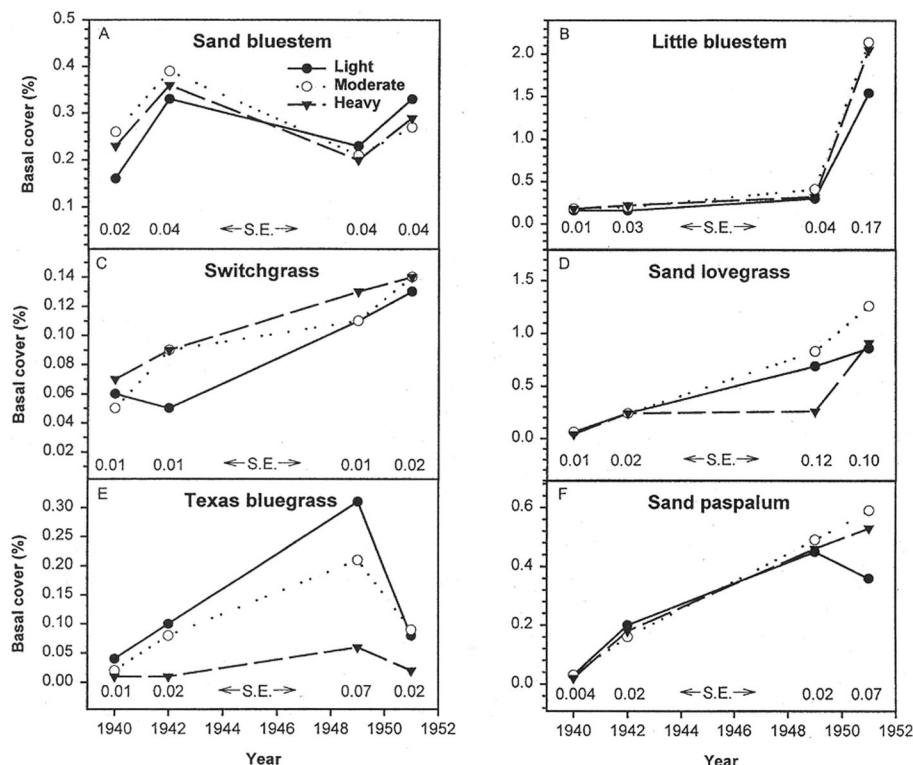


Fig. 3. Basal cover of sand bluestem, little bluestem, switchgrass, sand lovegrass, Texas bluegrass, and sand paspalum at the light, moderate, and heavy grazing intensities in 1940, 1942, 1949, and 1951 at the Southern Plains Experimental Range, Fort Supply, Okla.

paspalum (*Paspalum setaceum* Michx.; Fig. 3F) basal cover increased ($P < 0.01$) from 1940 to 1951 at all stocking rates. Although sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.; Fig. 4D) had numerically higher basal cover in the moderately and heavily stocked pastures than in the lightly grazed pastures, these differences were not statistically significant. The basal cover of cool-season Texas bluegrass (*Poa arachnifera* Torr.; Fig. 3E) was consistently, but not significantly, higher in the light and moderate stocking rates in comparison to the heavy rate. Basal cover of sand dropseed (*Sporobolus cryptandrus* [Torr.] Gray), an indicator of drought, declined in both the light and moderate treatments during this period of above-normal precipitation (Fig. 4E). In the heavily grazed pastures, sand dropseed continued to increase between 1940 and 1949 and then declined in basal cover by the 1951 sampling.

The short grasses (Fig. 4A and B) are also important components of this mixed-grass prairie. Blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths) basal cover was not

significantly affected by stocking rates, although the heavy treatment had more basal cover of blue grama after 10 years of grazing. Blue grama basal cover ranged from 1 to 2% in 1941 and increased to 3 to 4% by 1942. In the heavy stocking rate, blue grama basal cover increased from 1.96 in 1941 to 4.18, 5.16, and 7.26% in 1942, 1949, and 1951, respectively (Fig. 4A). Buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.; Fig. 4B) was dynamic ($P < 0.05$) across years but these increases were similar at all stocking rates. The basal cover of hairy grama (*Bouteloua hirsuta* Lag.; Fig. 4C) also differed ($P < 0.01$) across years, although the changes were less marked for the light stocking rate than those for moderate and heavy stocking rates.

In general, the basal cover of grasses, primarily perennial grasses, increased more than 3-fold under heavy use, and in excess of 2-fold under both the moderate and light use treatments. Increases in basal cover of blue grama accounted for 41, 30, and 49% of the increase in perennial grasses for the light, moderate, and heavy grazing intensities, respec-

tively. Blue grama cover increased between 1940 and 1942 and then stabilized in the light and moderate treatments while blue grama cover continued to increase between 1940 and 1951 at the heavy grazing intensity (Fig. 4A). Blue grama and sand dropseed tended to increase most under heavy grazing.

Annual grasses

Basal cover of annual grasses was more dynamic than that of perennial grasses and tended to follow levels of winter precipitation. Major annual grass species were downy brome (*Bromus tectorum* L.), six-weeks fescue (*Vulpia octoflora* (Walt.) Rydb.), and sandbur (*Cenchrus carolinianus* Walt.). Basal cover of annual grasses ranged from near 0 to 1.5% (Fig. 2B).

Forbs

Basal cover of forbs does not adequately reflect their impact and role in the plant community because their canopy cover, not basal cover, more nearly reflects water-use and energy capture by these mostly single-stemmed plants. Perennial forbs had greater ($P < 0.01$) basal cover in the light and moderate treatments compared with the heavier stocking rate (Fig. 2C and D). Basal cover of forbs ranged from a low of 0.18 to a high of 1.2%. Annual forbs tended to have 4 to 6 times more basal cover than perennial forbs in this mixed-grass prairie. Annual forbs were also more dynamic than the perennial forbs. The dynamics of different species of forbs follow precipitation patterns that correspond to their individual growth and development requirements. In general, annual and perennial forb populations and cover changes of annual grasses tended to be greater in wet years following years of lower rainfall. These plants respond more quickly to favorable rainfall conditions through seed germination and plant establishment. Perennial grasses respond more slowly through increased tillering (Briske and Stuth 1982).

Shrub canopy

Sand sagebrush canopy increased from an average of 27% in 1940 to about 37 to 57% in 1942 and 1949, respectively (Fig. 2E). Changes in sand sagebrush canopy cover were similar in all treatments during the grazing intensi-

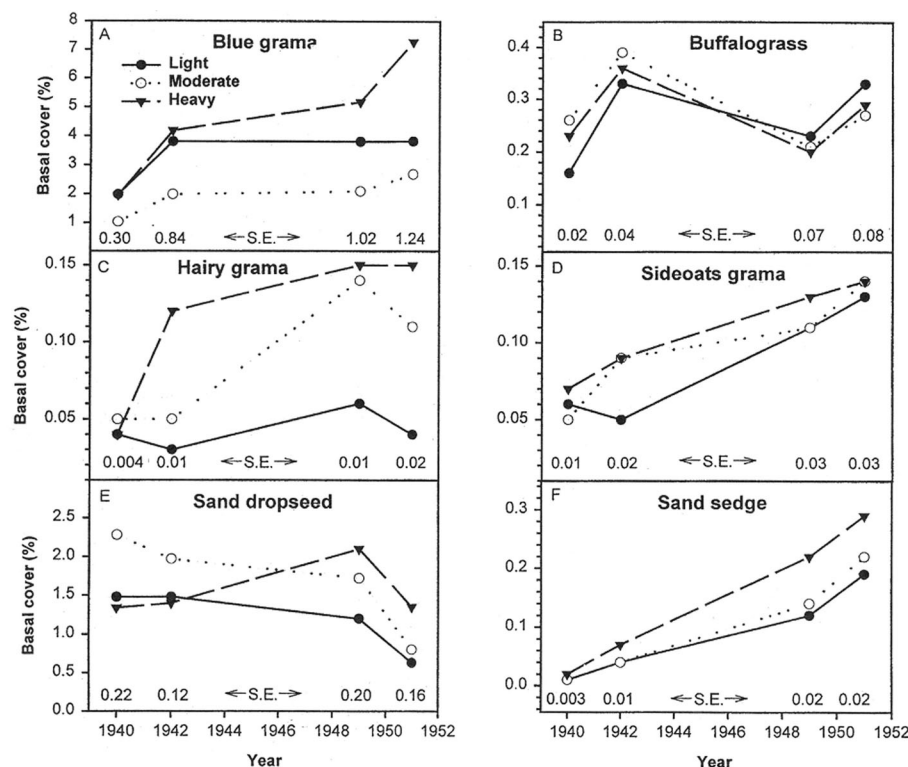


Fig. 4. Basal cover of blue grama, buffalograss, hairy grama, sideoats grama, sand dropseed, and sand sedge, a cool-season grasslike plant, at the light, moderate, and heavy grazing intensities in 1940, 1942, 1949, and 1951 at the Southern Plains Experimental Range, Fort Supply, Okla.

ty study. Sand sagebrush canopy cover declined to about 35% in all treatments between 1949 and 1951. In a similar study, Sims et al. (1976) found canopy cover of sand sagebrush was lower in the sandhills of northeastern Colorado than in the Oklahoma sandhills. Maximum canopy cover of sand sagebrush in Colorado was about 10% compared with more than 50% canopy cover in the Oklahoma study. In both cases, however, the least sand sagebrush cover was found at the light grazing intensity vs. greater cover in the moderate and heavily grazed pastures.

Species Composition

Changes in herbaceous species composition of basal cover are shown in Table 2. Also shown is the species composition of cover in exclosures, sampled in 1949 and 1951, where grazing was excluded since the study began. The total percentage composition of perennial grasses on the Southern Plains mixed prairie pastures averaged $97 \pm 2\%$ over the study period, only slightly more than the perennial grass composition in the

ungrazed exclosures. Forbs, principally annual forbs, made up the rest, $3 \pm 2\%$, of the herbaceous vegetation. It should be noted that basal cover measures underestimate the importance of single stem plants. Over the 10 years of this study, forb composition ranged from 1 to 12% in these study pastures. As with basal cover, species composition changes between years were generally significant. Our interest, again, was concentrated on effects of stocking rate and stocking rate by year interactions on species composition. Consequently, the discussion that follows largely deals with these interactions.

The statistical analyses were similar for species composition data whether or

not an arcsin transformation was used for the percentages. The same was true for all species composition data or for the data comparing the grazed pastures for all 4 sampling years or for the comparison of the grazing treatments with the exclosures in 1949 and 1951. In general, year differences in species composition were significant ($P < 0.01$), transformed or not, for all species except switchgrass, sideoats grama, hairy grama, and buffalograss. With data transformation, stocking rate \times year interaction was significant ($P < 0.05$) only for sand lovegrass and miscellaneous grasses and approached significance ($P < 0.10$) for switchgrass and annual and perennial forbs.

The composition of tall grasses increased from about $10 \pm 2\%$ (SE) of the composition in 1940 to over $21 \pm 2\%$ composition in 1951. Tall grass composition remained between 5.8 and 11.9% between 1940 and 1949. The tall grasses increased markedly by 1951, largely the result of increases in little bluestem which went from about 3 to almost 20%.

The species composition of mid-grasses ranged from about 30 to 48% during this study. There were similar amounts of mid-grasses, generally 30 to 34%, in the light and heavy treatments. The moderate treatment had substantially more mid-grasses than the other treatments. Sand dropseed was the dominant mid-grass in all 3 treatments with an average of $21 \pm 1\%$. As the sand dropseed composition declined across all treatments in the 10 years of this study, fall witchgrass, sand lovegrass, and sand paspalum tended to increase. Sand dropseed also tended to be the dominant mid-grass in the exclosures. Other important mid-grasses were sideoats grama and sand sedge.

Blue grama was, by far, the most important short grass species in terms of percentage composition. This was true on all treatments, but especially true in

Table 3. Coefficients and statistics of regression models describing gain per head (kg) over the entire grazing season, the winter period (Nov. to Mar.), and the summer period (Apr. to Sept.) for the 10-year grazing intensity study at 3 stocking rates (AUD ha^{-1}) between 1940 and 1951 at the Southern Plains Experimental Range, Fort Supply, Okla.

Period	N	Intercept	Stocking rate	R ²	C.V.	Root MSE
Total	6	197.6 ¹	-0.532	0.93	1.80	6.59
Winter	6	49.7	-0.270	0.93	4.39	3.28
Summer	6	147.9	-0.262	0.91	1.33	3.88

¹All coefficients significant, $P < 0.01$.

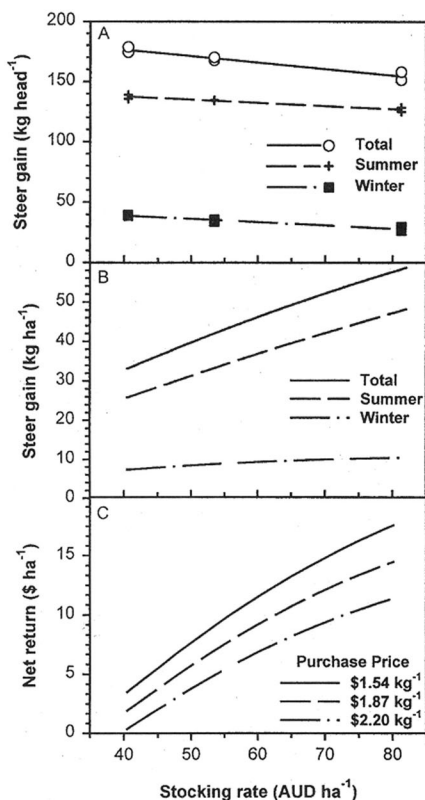


Fig. 5. Livestock gain as affected by stocking rate from 1946 to 1951 at the Southern Plains Experimental Range, Fort Supply, Okla. A) Regressions of steer gain per head. B) Livestock gain per hectare. C) Net return per hectare for 3 market scenarios.

the heavy and light grazing treatments. Blue grama tended to increase in the heavy treatment and its composition was more variable than in the light and moderate treatments (Table 2). The other short grasses, buffalograss and hairy grama, were important but minor compared with blue grama.

There were differences between stocking rates and exclosures for switchgrass ($P < 0.05$), Texas bluegrass ($P < 0.01$), hairy grama ($P < 0.01$), and buffalograss ($P < 0.01$). Switchgrass had $3.9 \pm 1.2\%$ composition in exclosures compared to $1.4 \pm .2$, $1.4 \pm .8$, and $0.9 \pm .3$ in the light, moderate, and heavy treatments, respectively. The other species ranged from $0.4 \pm .6$ to $3.2 \pm 0.4\%$ composition in the grazed treatment but were absent in the exclosures.

The southern mixed prairie has been cited as the most important western rangeland type for livestock production (Holochek et al. 1995). Holochek et al. (1995) also stated that stocking rate has more influence on vegetation dynamics

than any other grazing factor. Our study also confirms that rangeland sustainability is highly dependent on maintaining vegetation cover and productivity. Sims and Risser (1999) in a discussion of North American grasslands concluded that biological diversity is a fundamental aspect of sustainability. Proper stocking rate is a first step to maintaining species rich communities.

Livestock Response Gain per head

Steer gains averaged over all stocking rates were 168 kg per head for the November–September grazing period. Of this total, 134 kg or 80% occurred in the summer period (April–September).

Total live weight gain per head decreased as stocking rate increased (Fig. 5A). This is a classical response of individual animal performance to stocking rate (Harlan 1958, Hart 1978, Wilson and MacLeod 1991). These results are similar to those found in other studies in the central and southern plains (Launchbaugh 1957, Burzlaff and Harris 1969, Sims et al. 1976, and Kothmann et al. 1970; reviewed by Vallentine 1990) and Hart et al. 1988, Hart and Ashby (1998), and Manley et al. (1997). While there was a negative linear relationship between total gain per head and stocking rate, the slope coefficients were relatively small (Table 3). Comparing the highest and lowest stocking rates, gain per head decreased 22 kg (12%) as stocking rate increased 100%.

Stocking rate affected gain per head in both the winter and summer grazing periods (Table 3). The slope coefficient for stocking rate was equal for winter and summer gains. This was surprising considering the large difference in forage quality between winter and summer (Savage and Heller 1947). Hart (1978) suggested that the response of livestock gain to stocking rate is more pronounced as forage quality declines.

The variability of steer gains over years, expressed as the standard deviation of gains, was not related to stocking rate (Fig. 6). Relative variability, expressed as the coefficient of variation, increased as stocking rate increased for all gain periods (Fig. 6, $P < 0.05$). Since standard deviation did not change but mean gains declined, coefficient of variation increased.

It is a general tenet in grazing man-

agement that variability of livestock performance increases as stocking rate increases (Vallentine 1990). Higher stocking rates should increase production risk and result in greater variability in gains particularly in years with lower precipitation (Parsch et al. 1997). Although not usually stated specifically, the implication is that both absolute and relative variability increase. The lack of response for absolute variability in our study is likely the result of favorable weather conditions and a relatively short measurement period (6 years).

Averaged over stocking rates, the standard deviation of gain was not different for the summer compared to the winter period (7.1 versus 8.7 kg, $P > 0.05$). The coefficient of variation was lower for the summer period and the difference between summer and winter increased as stocking rate increased (Fig. 6, $P < 0.05$). The large difference in relative variability between summer and winter is a result of the fact that standard deviations of gain were not greatly different but winter gains were only 1/4 of summer gains. We suggest winter gains are more variable because cold stress from winter storms is more variable than heat stress in the summer period.

Gain per hectare

Live weight gain per hectare increased as stocking rate increased because the additional animals offset the reduction in gain per head (Fig. 5B). This occurred in both summer and winter. It appears that the maximum gain per hectare was not reached within the bounds of the experimental treatments and climate found in this study. As stocking rate doubled from the lowest to the highest stocking rate, live weight gain per hectare increased by 25.6 kg (77%).

Net return per hectare

Net return per hectare increased as stocking rate increased (Fig. 5C). Different price scenarios shifted the net return lines up or down but did not change the fundamental relationship.

The point of maximum net returns did not occur within the range of stocking rates used in the study (Fig. 5C). One significant reason for this is the relatively slight decline in per head gains as stocking rate increased. For a purchase price of \$1.87 kg⁻¹, our models project

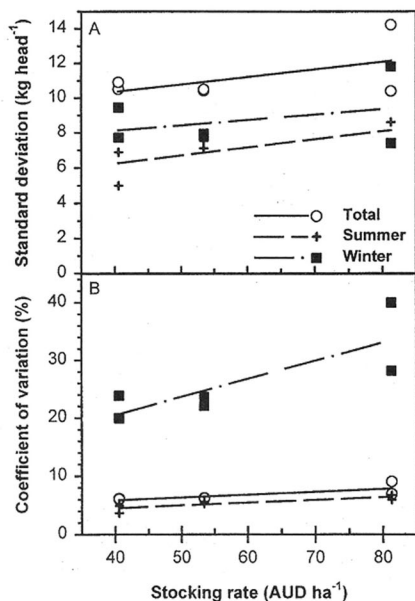


Fig. 6. Variability of steer gains as affected by stocking rate from 1946 to 1951 at the Southern Plains Experimental Range, Fort Supply, Okla. A) Standard deviation. All slope coefficients are nonsignificant ($P>0.05$). Standard deviation is similar for winter and summer periods ($P>0.05$). B) Coefficient of variation. Intercept and slope are significantly different ($P<0.01$ and $P<0.05$, respectively) between summer and winter periods.

that maximum net returns would occur at a stocking rate of 119 AUD ha⁻¹. This is a theoretical point only since it is outside the bounds of our experimental treatments. This stocking rate is 37 AUD ha⁻¹ above the highest stocking rate in the experiment. In contrast, the spread from the lowest to highest experimental stocking rates was 41 AUD ha⁻¹. Even if the gain relationship remained constant through 119 AUD ha⁻¹, it is unlikely that such a stocking rate would be sustainable from the vegetation standpoint.

An increase in variable costs per head or negative margin will lower the stocking rate that maximizes net return. At the purchase price of \$1.87 kg⁻¹, variable costs would have to increase by 57% to lower the optimum stocking rate to 82 AUD ha⁻¹, the highest rate in the experiment. Economic conditions fluctuate continually and it would not be unusual for economic conditions to favor stocking rates greater than those used in this experiment. Working on similar rangeland in eastern Colorado, Torell et al. (1991) agreed that economic conditions would occasionally promote heavy grazing.

However, if stocking rates were adjusted annually based only on projected economic conditions, average stocking rates would be moderate and sustainable.

Management Implications

Carrying capacity is a fundamental measure of the sustainability of a resource under grazing, and stocking rate studies are a primary research protocol to obtain such data. This study was designed to begin this process for the southern mixed-grass prairie rangeland. Coincidentally, gain responses of yearling steers at 3 grazing intensities was also measured to determine the productive potential for a use that is significant to this region's agriculture. Rainfall during the 1940–51 period was above normal. Precipitation was as significant as grazing to the vegetation and steer gain responses. Consequently, perennial grasses increased across light, moderate, and heavy grazing intensities. The history of intense overgrazing coupled with the 1930's drought may also have impacted vegetation responses. Although not documented, the heavy stocking rate applied in this study was probably significantly 'lighter' than the previous stocking rate imposed by the Irish Syndicate prior to establishment of the Southern Plains Experimental Range, particularly for the optimum precipitation conditions of the 1940's. The livestock response data from our study fit general gain per head and gain per area models. However, because of the favorable precipitation, gain ha⁻¹ was, apparently, still increasing at the highest stocking rate studied. During such favorable periods, vegetation and livestock responses are not tightly coupled. Consequently, to determine Southern Plains mixed-grass prairie carrying capacity, these studies must be of sufficient length to encompass both favorable and unfavorable climatic conditions. Anything shorter, as is the case with most grazing intensity studies including this one, will not adequately establish this vital management parameter and provide the guidance needed by conservationists and producers.

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