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Stocking Density Influences Predominantly Blue Grama Pasture Mass and Animal Performance

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Abstract: The optimum grazing management practices to sustain or increase grassland resilience must be determined. The effects of the current and previous year's stocking densities (light, medium, and heavy stocking densities of 0.53, 0.89, and 1.24 AU ha^{-1}, respectively) at the same stocking rate (35 AUD ha^{-1} yr^{-1}) of yearling heifers (*Bos taurus*) grazing predominately blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] pastures on animal gains and pasture mass during the growing season were evaluated at New Mexico State University's Rex E. Kirksey Agricultural Science Center at Tucumcari, NM USA, over three years. Previous grazing management had no influence on animal performance ($p > 0.14$) but seasonal average daily gains and total gains ha^{-1} were decreased from low- to high-density grazing ($p < 0.002$). Nevertheless, for grassland resilience, when low followed either high or medium, blue grama mass increased compared to low following low. Alternatively, when medium followed high, blue grama mass was reduced, but when high followed either low or medium, forage mass numerically increased ($p < 0.0117$ for the previous × current year's stocking density interaction). Consequently, short-duration, high stocking density may be best using multiple pastures, each with the same grazing period each year to allow for a long-duration rest. Otherwise, during persistent drought, a longer-duration, medium stocking density could be used to allow for recovery.

Keywords: blue grama; native grass; stocking density; pastures; previous stocking density

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1. Introduction

The demand for beef is increasing due to an increasing population, and forage-based beef production is one of the most productive agricultural enterprises in the US [1], including the US Great Plains [2] and the Southern High Plains (SHP), where standing forage is the main diet of beef cattle (*Bos taurus*) in the first two stages of production, cow–calf and backgrounding (the stocker phase) [1]. During backgrounding, small-to-medium-framed graze cattle on pastures to increase body size [3] before entering the feedlot [1,3] because a moderate weight gain during this period may allow for more economically effective gains at the feedlot [3].

Rangelands are important forage resources globally because they cover 25% of the earth's plant growth area [4,5], including the SHP, and support economically viable animal production during their period of active growth [6]. However, climate change and overgrazing have led to the degradation of native grasslands [7], including the native warm-season grasses typical of the SHP [8].

The frequency and intensity of defoliation have the greatest influence on individual plants, which determines stand productivity and persistence with tallgrasses more abundant at low stocking rates and shortgrasses, such as blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], more abundant at higher stocking rates [9]. A lack of localized precipitation may lead to grazing avoidance in a subsequent year as a built-in resting mechanism while new growth after precipitation influenced the migration of free-ranging herbivores [10].

Season-long grazing with animals moved once per year as a graze–rest rotation is the norm in the US [5]. Short annual grazing sessions followed by long rest periods lead to over-mature, low-quality grass in the next grazing session of that area [10]. That being said, seasonal exclusion and season-long rests allow for recovery after grazing and accumulation of energy reserves [7], as well as seed production to maintain a seed bank for recovery after periods of stand loss [7,10]. Time-controlled rotations without reducing stocking rates have been proposed globally as a means of mitigating degradation and sustaining forage quantity and quality, but beneficial results have been limited to high-precipitation environments [4]. Fynn (2012) [10] reviewed the literature and found that up to six grazing events in a year or season-long grazing can lead to increased grass productivity and quality following a season-long rest [10]. Focused grazing (confining animals to high-quality patches of forage) limits forage over-maturity and quality declines that lead to reduced animal productivity [10]. Summer rest and conservative grazing were favorable for blue grama [11]; however, fixed seasonal grazing periods may not maximize growth potential through nutrient recycling and availability for plant growth [10]. Consequently, ranchers should use flexible grazing management to maximize forage utilization and allow sufficient recovery after grazing, potentially even season-long grazing and season-long resting [10].

Native warm-season perennial grasses experience their peak growth from late April through September or October [9,12,13]. Spatial and temporal variability in forage mass quantity and the quality of rangelands can have a significant influence on livestock production [10], with forage mass production of shortgrasses, such as blue grama, being less variable than mid- and tallgrasses, and best predicted by current-year spring precipitation with no time lags [13]. Using yearling cattle instead of maintaining a cow–calf operation also lends flexibility to environmental fluctuations [2] The objectives of this study were to determine the effect of stocking density at the same stocking rate based on the number of animal unit days (AUD) ha^{-1} yr^{-1} of yearling beef heifers grazing blue grama on animal gains and pasture mass during the grazing season.

2. Materials and Methods

2.1. Site Description

The study was conducted in an 11.3 ha field at New Mexico State University's Rex E. Kirksey Agricultural Science Center at Tucumcari, NM, USA (35°12′0.5″ N, 103°41′12.0″ W; elev. 1247 masl). The soils were Canez (Fine-loamy, mixed, thermic Ustollic Haplargid), Quay (Fine-silty, mixed, superactive, thermic Ustic Haplocalcids), and Redona (Fine-loamy, mixed, superactive, thermic Ustic Calciargids) fine sandy loams that were arranged in such a way as to permit dividing the field into three blocks for replication. The climate in the region is Köppen–Geiger cold semiarid (http://www.cec.org/north-american-environmental-atlas/climate-zones-of-north-america/, accessed on 22 May 2023), characterized by cool, dry winters and warm, moist summers. Approximately 83% of the precipitation occurs as intermittent, relatively intense rainfall events from April through October [14]. Weather data were collected from a station within 1 km of the study field (Table 1).

Table 1. Temperature and precipitation from establishment through grazing of predominately blue grama pastures at Tucumcari, NM USA.

	Year					Long-Term Average
	1 (Seeding)	2 (Pre-Study)	3 (Study)	4 (Study)	5 (Study)	
			Temperature, C			
January	1.6	4.8	5.9	5.5	6.5	3.4
February	6.9	5.2	5.2	4.0	3.9	5.5
March	8.2	8.4	10.9	12.1	12.1	9.3
April	17.0	16.6	16.0	13.5	13.6	14.2
May	19.1	20.8	21.3	21.6	21.6	19.0
June	24.8	27.3	22.7	25.4	24.8	24.1
July	28.8	26.5	28.6	25.3	26.8	26.1
August	26.1	27.1	26.9	24.1	24.7	25.1
September	22.7	21.6	21.4	22.0	23.0	21.4
October	16.1	13.5	17.6	15.3	15.6	15.3
November	11.2	8.1	9.5	7.2	11.3	8.5
December	5.4	4.4	6.3	6.3	4.3	3.9
Mean Annual	15.7	15.3	16.1	15.6	15.7	14.6
			Precipitation, mm			
January	17	14	0	2	34	10
February	24	4	16	15	28	13
March	67	8	32	24	29	19
April	3	13	18	95	59	30
May	72	17	48	7	60	49
June	45	17	101	47	4	48
July	17	111	13	58	76	66
August	72	18	108	70	113	69
September	5	102	8	101	109	39
October	4	30	24	71	14	34
November	40	38	23	58	0	19
December	6	19	6	10	0	16
Total Annual	371	391	397	557	526	405

2.2. Pasture Development

For two years the previous crop had been winter cereal pasture from which the residual forage was swathed for baling in year 1, during which blue grama was established. On 22 May of year 1, the field was sprayed with 93.5 L ha^{-1} of 2.5% glyphosate [isopropylamine salt of N-(phosphonomethyl)glycine] to destroy existing vegetation. During June, it was conventionally tilled and formed into beds on 1 m centers for furrow irrigation. From 12 to 17 June, the field was pre-irrigated, after which the beds were reshaped. All irrigations were through siphon tubes. The irrigation set duration was sufficient to ensure that each bed was soaked to the center for its full length. From 20 to 22 June of year 1, the field was sown with 'Hachita' blue grama (5.6 kg PLS ha^{-1} [15]) using a conventional grain drill fitted with a native grass attachment without seed tubes. Additionally, during that period, 34 kg N ha^{-1} was uniformly broadcast over the field. The entire field was cultipacked immediately after seeding. Post-planting irrigations were applied from 22 to 27 June, and from 23 to 29 September, totaling approximately 1644.6 m^3 of water to promote establishment. On 24 July, the field was spot-sprayed with glyphosate to suppress bermudagrass (*Cynodon dactylon*) and kleingrass (*Panicum coloratum*) areas that were remnants of a grazing trial conducted for a decade prior to conversion to winter cereal pastures. Rotary mowing to control annual weeds occurred on 26 July, 27 August, and 13 November.

During the winter of years 1–2, the field was divided into nine pastures of equal size (1.22 ± 0.05 ha) to form three randomized complete blocks and fenced with high tensile electric fencing. An alley was installed across the irrigation ditch to the north of the field to facilitate penning and moving livestock as well as provision of water and ad libitum monensin mineral supplements (Hi-Pro Feeds, Friona, TX, USA) containing

1.89 kg monensin Mg^{-1}. Supplement consumption throughout the pre-study and study period (years 2 to 5) averaged 49.3 g hd^{-1} d^{-1}, which was within the labeled rate of 29-116 g hd^{-1} d^{-1}. No other supplements were provided.

All pastures were treated with gramoxone [Paraquat dichloride (1,1′-dimethyl-4, 4′-bipyridinium dichloride)] (0.95 L ha^{-1}) on 22 or 27 Feb of year 2, to control cool-season annual forbs. On 3 May, the pastures were treated with 3.79 L ha^{-1} Weedmaster [Dimethylamine salt of 2,4-Dichlorophenoxyacetic Acid + Dimethylamine salt of dicamba (3,6-dichloro-o-anisic Acid)] (1.89 L ha^{-1}) to control *Verbena* spp. All pastures received a second 3.79 L ha^{-1} treatment of Weedmaster between 12 and 18 June, to control *Amaranthus* spp. and other annual broadleaf weeds. Areas of bermudagrass and kleingrass within the pastures from the previous grazing trial were spot-treated with 2.5% glyphosate on 16 July, 16 Aug, and 16 October; however, some bermudagrass and kleingrass patches remained. It was concluded that since the focus of the study was the effect of stocking density on animal gains and subsequent feedlot performance, it would be better to accept the presence of 'other grasses' than to keep trying to remove them. In an attempt to improve stands of blue grama, all of the third replicate and a portion of the second replicate (the Redona soil area) were overseeded with 1.59 kg PLS ha^{-1} on 25 and 26 July of year 2 using seed from the same lot as the original planting. Pastures received a single, alternate-row irrigation from 22 to 25 May of year 2 and again from 6 to 13 June in year 5, calculated to be 822.3 m^3 of water (203 mm depth) to supplement low spring precipitation (Table 1) and to promote growth for earlier initiation of grazing (Table 2) based on depletion of the acclimation pasture containing a combination of dormant warm-season and actively growing cool-season grasses. Otherwise, no irrigations were applied in years 3 or 4.

Table 2. Grazing and forage mass sampling dates of blue grama pastures grazed at different stocking densities each year at Tucumcari, NM USA.

Year	Stocking Density	Grazing and Forage Mass Sampling Dates				
		Grazing Initiated	**Grazing Terminated**	**28-d**	**56-d**	**Dormant**
2 (pre-study; no forage sampling)	Low	21-May	19-June	-----	-----	-----
	Medium	21-May	29-June	-----	-----	-----
	High	21-May	26-July	-----	-----	-----
3 (study)	Low	9-July	7-August	4-September	2-October	2-December
	Medium	9-July	19-August	16-September	14-October	2-December
	High	9-July	16-September	14-October	11-November	2-December
4 (study)	Low	15-July	12-August	9-September	7-October	1-December
	Medium	15-July	23-August	20-September	18-October	1-December
	High	15-July	18-September	16-October	13-November	1-December
5 (study)	Low	18-May	14-June	12-July	9-August	2-December
	Medium	18-May	27-June	25-July	22-August	2-December
	High	18-May	25-July	22-August	19-September	2-December

Low, medium, and high stocking densities signify 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, at a consistent 35 AUD ha^{-1} yr^{-1} stocking rate for approximately 28, 40, and 67 d, respectively.

2.3. Cattle Management

Each May of years 2 to 5, crossbred beef cattle heifers were received from New Mexico State University's Clayton Livestock Research Center and placed on the acclimation pasture previously described. Immediately prior to grazing the predominately blue grama study pastures, the heifers were weighed and 45 of the most uniform animals were sorted into three replicates each of low, medium, and high stocking densities (approximately 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, representing 3, 5, or 7 hd $pasture^{-1}$ of small-to medium-framed animals (215 $\pm$ 9.5 kg hd^{-1}) and placed on the pastures to maintain a constant stocking rate of 35 animal unit days (AUD) ha^{-1} yr^{-1}. Each year, heifers in the medium and low stocking density treatments continued to graze until a comparable number of head days of grazing had been applied to each pasture as there had been for the high stocking density treatment. Stocking density treatments were randomly assigned to pastures within each of the three pasture replicates with three previous stocking densities and three current stocking densities accommodated by the randomization over a three-year period (years 3 to 5). Year 2 was used to establish the previous year's densities for year 3, after which years 3 and 4 served to establish the previous year's grazing effects for years 4 and 5, respectively. Each study year (years 3 to 5), animal live weights were recorded at the initiation of grazing, after 28 d of grazing, and on the date that each grazing treatment was terminated. All weights were recorded after an approximately 16 h fast without food or water. Average daily gain (ADG) was calculated for the first 28 d of grazing (ADG28) and the entire grazing season (ADGALL) for each treatment. Gain ha^{-1} during the first 28 d of grazing (GAINHA28) and total gain ha^{-1} for the grazing season (GAINHAALL) were also calculated for each pasture.

2.4. Forage Mass Measurements

Each study year, forage within a 0.31 m^2 quadrat was hand-clipped to ground level at three uniformly spaced locations in each pasture upon the initiation of grazing, by treatment when the animals were removed, 28 and 56 d after animals were removed, and after freeze-induced dormancy or occurrence of 5-day average soil temperatures of 2.2 °C. On each sampling date, samples were taken from the same general area of the pastures. The placement of the quadrat was such that a representative cross-section of the furrow-bed continuum was obtained. Each sample was separated and bagged as blue grama and other grass during clipping. Live and dead plant material were not separated. Each component was placed in a separate bag and dried for 48 h at 65 °C to determine the forage dry matter (DM) mass of each component within the sample. The total DM mass of each sample was calculated as the sum of the forage masses of grama and other grass. Pasture averages of the three subsamples were calculated. Forage mass sampling dates, including grazing beginning and ending dates, for each of years 2 (pre-study) to 5 are shown in Table 2.

2.5. Statistical Analysis

Two analyses were conducted for all data: one to evaluate the potential effects of the previous year's stocking-density treatment, with each combination replicated 2 to 4 times across the three years and three randomized complete blocks, and one to account for environmental effects of year and pasture management influences because the environmental and previous stocking density effects were confounded. For the first analysis, cattle gain data were subjected to the mixed procedure of SAS [16] to test the main effects of previous stocking density treatment and current stocking density, and their interaction and forage mass data were tested for the main effects of previous stocking density treatment, stocking density, and sampling period and all possible interactions. For the second analysis, cattle gain data were subjected to the mixed procedure of SAS [16] to test the main effects of year and current year stocking density and their interaction, and forage mass data were tested for the main effects of year, sampling period, and current year stocking density and all possible interactions. Replicate was considered random. All differences reported are significant at $p \leq 0.05$ and trends ($0.05 \leq p \leq 0.10$, [17] are discussed. When an interaction was significant, protected least significant differences were used to determine where differences occurred using the PDMIX800 macro [18].

3. Results and Discussion

3.1. Animal Performance

The month when grazing was initiated (May or July) had no apparent effect on animal performance when year 2 was included in the analysis evaluating the environmental influence of year, as years 2 and 4 were similar and years 3 and 5 were similar. The previous year's stocking density had no influence on any animal gain variable ($p < 0.14$). Otherwise, both of the main effects of year and present-year stocking density and their interaction were significant for all variables (Table 3). For the interactions, there was an increase across years within stocking density treatments and from the low- to high-stocking densities within each year that varied in magnitude. Consequently, the discussion of animal gain variables will concentrate on the main effects.

Table 3. Results of statistical analysis of gains by yearling beef heifers grazing predominantly blue grama pastures during the growing season under different stocking densities over four years at Tucumcari, NM USA. Values are the lsmeans of three replicates of the Year × Stocking density interaction.

Effect	ADG28		ADGALL		GAINHA28		GANHAALL	
				Year (Y)				
3	0.51	C	0.51	C	55	C	87	C
4	0.77	B	0.73	B	86	B	118	B
5	1.07	A	1.09	A	121	A	177	A
				Stocking Density (D)				
Low	0.90	A	0.92	A	67	C	152	A
Medium	0.76	AB	0.76	B	88	B	126	B
High	0.65	B	0.65	C	106	A	106	C
SEM	0.05		0.03		4		7	
				p-Values				
Y	<0.0001		<0.0001		0.0006		0.0006	
D	0.0274		0.0016		0.0015		0.0011	
Y × D	0.0419		0.0012		0.0016		0.0023	

ADG28, ADGALL, GAINHA28, AND GAINHAALL signify average daily gain (kg d^{-1}) during the first 28 d of grazing, ADG throughout the grazing period, gain (kg ha^{-1}) during the first 28 d of grazing, and total gain ha^{-1} during the grazing season, respectively. Years 1 and 2 were establishment and to set up the previous year's stocking-density effects, respectively. Low, medium, and high stocking densities signify 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, at a consistent 35 AUD ha^{-1} yr^{-1} stocking rate for approximately 28, 40, and 67 d, respectively. Means within a column and treatment effect followed by similar letters are not significantly different at $p < 0.05$. SEM signifies the standard error of the mean.

Stocker operations expect to attain an ADG of 0.91 kg d^{-1} [1]. The low stocking density approximated that level, for both ADG28 and ADGALL (Table 3). Despite being less than the low stocking density treatment, ADG28 and ADGALL of the medium and high densities were sufficient at >0.5 kg d^{-1} [19] to support moderate weight gain and allow for more economically effective gains at the feedlot [3]. Summer ADG on mixed native grass pastures in a previous study at this location was 1.21 and 0.63 kg d^{-1}, in years 1 and 2, respectively, which was no different than introduced pastures in the same study [3].

In his review paper, Allison (1985) [20] reported that ADG was greatest under continuous stocking and least under rotation or strip grazing of native grasses. The present study did not have a continuous stocking treatment; however, our differences in ADG28 and ADGALL among stocking density treatments being low > medium and high is consistent with ADG declining with increasing stocking densities (Table 3).

In previous research at this location, Capitan (2004) [3] reported summer-long total gains by yearlings grazing mixed native grasses of 44 and 21 kg ha^{-1} in years 1 and 2, respectively, which is considerably less than those measured in the present study for GAINHAALL (Table 3). The difference is likely due to stocking density. The stocking density for Capitan et al. (2004) [3] was 0.31 hd ha^{-1}, using 238 kg yearlings for an equivalent season-long (mid-May through mid-August or mid-September) stocking rate of about 8 AUD ha^{-1} yr^{-1}, compared to the 35 AUD ha^{-1} yr^{-1} used in the present study. Contrary to the results of the present study regarding GAINHA and GAINALL (Table 3), Allison (1985) [20] and others [2] reported that, as grazing intensity increased on blue grama pastures, gain ha^{-1} increased, but individual animal gains decreased. Crawford (2019) [4] reported work by others indicating that controlled-time grazing increased cattle weight gains using greater stocking densities and concluded from their [4] own research that continuously grazing cattle, at lower stocking densities, spent more time walking, thus burning more energy, and thereby reducing gains.

One limitation of this study is that it reports stocking density effects at the same stocking rate season-long for a single pasture. For the medium and high stocking density treatments, multiple pastures would be needed to equal the same grazing duration as the low-density treatment (i.e., 1.7 and 2.4 times the number of pastures for the medium and high stocking densities, respectively, to equal the length of the grazing season of the low-density treatment, calculated from Table 2). This being said, the GAINALL should also be multiplied by those factors to achieve an estimated 214 and 254 kg ha^{-1}, respectively, for the medium and high stocking densities for the same time frame compared to 152 kg ha^{-1} measured for the low stocking density (calculated from Table 3), which would be consistent with the findings of Crawford et al. (2019) [4].

The stocking density used by Venter et al. (2019) [5] was similar to that of the present study. There was no difference in animal gain from various grazing management treatments in that study [5], including season-long grazing, but they found that too frequent movements can lead to reduced animal performance due to a reduced ability to selectively graze more palatable plants, while season-long grazing allows for repeat visits to regrowth of previously grazed plants that are more palatable and have higher quality [4,5,7,20]. Perhaps, the low stocking density treatment in the present study and stocking rate combination allowed animals in that treatment to selectively graze in a small pasture similar to patch grazing of larger areas where previously grazed plants could be revisited for a higher plane of nutrition to attain greater ADG (Table 3). The effects of frequent moving were not evaluated in the present study; however, the influence of changing diet quality due to pasture rotations and changes in environment or pasture species has been reported at the location of this study [21–24].

3.2. Forage Mass

Soil type may have influenced the establishment of blue grama [9] in the present study, but that was overcome by reseeding with supplemental irrigation. The cause of poor establishment in the Redona soil is not well-understood, but it may well have been related to low precipitation in late summer and autumn of year 1 (Table 1) coupled with subtle soil-type differences in water holding capacity and plant-available water.

Results for blue grama and total forage mass were consistent because blue grama constituted >88, 98, and 95% of the total grass mass in years 3, 4, and 5, respectively (calculated from Table 4). Consequently, the discussion for all forage mass variables will concentrate on blue grama mass after year effects are discussed, which pertain equally to all grass variables. Hence, forage mass in the present study (Table 4) was similar to that measured previously at this location as well as elsewhere. Capitan et al. (2004) [3] reported available forage mass of mixed native grass of 0.79, 1.19, and 1.49 Mg ha^{-1} in May, July, and September, respectively, of year 1, and 1.51, 1.03, and 0.66 Mg ha^{-1} in May, July, and August, respectively, of year 2. Similarly, Smart et al. (2007) [13] reported that herbage production of shortgrasses averaged 1.3 Mg ha^{-1} yr^{-1}, while Gillen et al. (2000) [9] measured live standing forage mass in July and September and found it to vary from 0.63 to 1.41 Mg ha^{-1} annually in mixed-grass prairie in a higher precipitation zone (766 mm annually) [9] at the same latitude as the present study. In a review of the literature, Allison (1985) [20] reported that livestock production in native grasses is generally low due to low intake rates driven by animal body size and low forage availability, but intake was not limited when available forage mass exceeded 0.09 Mg ha^{-1}. Consequently, animal performance was likely never compromised by forage availability in the present study.

Table 4. Results of statistical analysis of forage mass (Mg ha^{-1}) in predominantly blue grama pastures grazed during the growing season under different stocking densities of yearling beef heifers over three years at Tucumcari, NM USA. Values are the lsmeans of three replicates of the Year × Sampling period × Stocking density interaction.

Treatment Effect	Blue Grama		Other Grass		Total Grass	
			Year			
3	2.25	A	0.34	A	2.57	A
4	1.22	B	0.02	B	1.22	B
5	2.30	A	0.13	AB	2.42	A
SEM	0.15		0.11		0.18	
			Sampling Period (*p*)			
Begin	2.01	A	0.16		2.15	A
End	1.61	B	0.05		1.65	B
28 d	1.81	AB	0.23		2.03	AB
56 d	2.06	A	0.24		2.29	A
Dormant	2.12	A	0.13		2.24	A
SEM	0.18		0.13		0.20	
			Stocking Density (D)			
Low	1.86		0.26		2.13	
Medium	2.00		0.10		2.08	
High	1.91		0.13		2.00	
SEM	0.22		0.16		0.25	
			p-Values			
Year	<0.0001		0.0174		<0.0001	
P	0.0556		0.6505		0.0325	
Year × P	<0.0001		0.8297		<0.0001	
D	0.9100		0.7528		0.9380	
Year × D	0.0897		0.7351		0.3302	
P × D	0.8509		0.9375		0.8156	
Year × P × D	0.8949		0.9697		0.9513	

Years 1 and 2 were establishment and to set up the previous year's stocking-density effects, respectively. Begin, end, 28 d, 56 d, and dormant sampling periods signify the initiation of grazing, by treatment when the animals were removed, 28 and 56 d after animals were removed, and after freeze-induced dormancy or occurrence of a 5-day average of 2.2 °C, respectively. Low, medium, and high stocking densities signify 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, at a consistent 35 AUD ha^{-1} yr^{-1} stocking rate for approximately 28, 40, and 67 d, respectively.

The year effect (Table 4) may have been caused by available soil moisture from the combination of precipitation (Table 1) and irrigation (applied only in year 5), which totaled 412, 243, and 492 (203 mm irrigation + 289 mm precipitation) and influenced both blue grama and other grass mass (Table 4). Pre-grazing precipitation for year 3 (August, year 2 through June, year 3) was similar to the long-term average for the same period (Table 1). As mentioned, growing season precipitation likely influenced results as did annual precipitation (Tables 1 and 3) [7].

The total grass value does not equal the sum of the blue grama and other grass due to rounding and the generation of lsmeans. Means within a column and treatment effect followed by similar letters are not significantly different at $p < 0.05$. SEM signifies the standard error of the mean.

The year × sampling period interaction for blue grama and total mass (Tables 1 and 5, for blue grama mass) likely occurred because, while there was no statistical difference in blue grama mass from the beginning of grazing until dormancy in year 3, blue grama mass did not recover after grazing in year 4; however, it did increase across the season in year 5 in similar proportions to that reported by Capitan et al. (2004) [3] for their year 1.

Table 5. The effect of year and sampling period on blue grama forage mass (Mg ha^{-1}) in predominantly blue grama pastures grazed by yearling beef heifers during the growing season (May through September) at Tucumcari, NM USA. Values are the lsmeans of three replicates and three stocking densities. Standard error of the mean = 0.27.

Sampling Period	Year					
	3		4		5	
Begin	2.54	ABC	1.98	CDE	1.49	EFG
end	2.06	CDE	0.95	G	1.82	DEF
28 d	2.13	CDE	0.99	G	2.33	BCD
56 d	2.39	BCD	0.98	G	2.82	AB
dormant	2.14	CDE	1.18	FG	3.05	A

Years 1 and 2 were establishment and to set up the previous year's stocking-density effects, respectively. Begin, end, 28 d, 56 d, and dormant sampling periods signify the initiation of grazing, by treatment when the animals were removed, 28 and 56 d after animals were removed, and after freeze-induced dormancy or occurrence of 5-day average 2.2 °C, respectively. Means within the interaction followed by similar letters are not significantly different at $p < 0.05$.

The greater blue grama mass at the beginning of grazing in year 3 was likely due to significant early spring/summer grazing in year 2 (Tables 2 and 5) that provided a sufficient period of regrowth prior to dormancy with precipitation in the months before dormancy in year 2 and in the spring months preceding the beginning of grazing (Table 1). The probable cause of the season-long lesser blue grama mass in year 4 was the lateness of grazing in year 3 (Table 2) that limited time for regrowth that year, coupled with less precipitation over winter and in the spring and early summer of year 4 prior to grazing (Tables 1 and 2). Bai et al. (2022) [7] reported that spring and summer grazing exclusion increased biomass production compared to autumn grazing. Lesser blue grama mass at the beginning of grazing in year 5 (Table 5) was also likely caused by the lateness of grazing in year 4 (Table 2). The productivity of perennial grasses can be greatly reduced by grazing in the previous season [10], coupled with less precipitation throughout winter and early spring (Tables 1 and 5). Changes in precipitation cause changes in the condition of rangeland [8]. The most stressful conditions for mixed-grass prairie occur when growing season precipitation was only 69% of the long-term average [9], which occurred after grazing in year 3 until grazing began in year 4 and after grazing in year 4 until grazing began in year 5. Regarding forage mass at the beginning of grazing (Table 5), cattle weight gains have been found to be reduced in years with greater grass production due to excessive precipitation [10]. That may have led to the lower ADG28 and ADGALL in year 3 and greater ADG28 and ADGALL in year 5, but the reduced values of those variables in year 4 are likely due to season-long forage mass availability (Table 3), although Allison (1985) [20] reported that intake was not limited when available forage mass exceeded 0.09 Mg ha^{-1} and Irisarri et al. (2019) [2] found that beef production was maximized at about 0.5 Mg ha^{-1} annual net primary production.

Blue grama was intensively grazed twice (early June and early July): (1) during a single year in which drought was imposed from May through October and in the year after that, (2) during the year that drought was imposed, but not in the year after that, or (3) not grazed at all [25]. Growth rates of blue grama grazed during and after drought were greater after the first grazing bout of the second year, but growth rates were not different among grazing treatments after the second grazing bout in early July [25]. Monthly temperature and total long-term precipitation averages during the April-through-September growing season at the 45th to 46th latitudes, where the Bai et al. [7] and Eneboe et al. [25] (https://www.usclimatedata.com/climate/miles-city/montana/united-states/usmt0229, accessed on 8 May 2023) took place, are roughly equal to April through November at the location of the present study (Table 1) and closely reflects the blue grama growing season for the present study. Nonetheless, blue grama has been observed to initiate growth earlier when temperatures and precipitation are conducive, which may have occurred in March of years 4 and 5. Blue grama aboveground net primary production (the sum of positive monthly changes in growth from April through November) did not differ due to imposed drought or grazing treatment in either of the two years of study [25].

Seasonal grazing, which was limited to spring or summer using the high stocking density treatment in the present study (Table 2), was beneficial compared to season-long grazing [7], which the low stocking density treatment most closely mimicked in the present study. Low grazing intensity had no effect on aboveground biomass, but under heavier grazing intensities, aboveground biomass was increased by exclusion in spring or summer compared to autumn [7]. This may be related to recovery time during the period of active growth caused by warmer temperatures and greater precipitation compared to recovery during cooler temperatures and less precipitation in the latter part of the native warm-season perennial grass growing season (late summer/early autumn [9,12] (Tables 1, 2 and 6). Aboveground biomass was greater under medium than low and high grazing densities for the same season of exclusion, indicating that grassland productivity is maximized by moderate grazing intensities [7].

Table 6. The effect of year and stocking density of yearling beef heifers grazing on blue grama forage mass (Mg ha^{-1}) in predominantly blue grama pastures during the growing season (May through September) at Tucumcari, NM USA. Values are the lsmeans of three replicates. Standard error of the mean = 0.27.

Stocking Density	Year					
	3		4		5	
Low	2.03	AB	1.09	C	2.48	A
Medium	2.53	A	1.11	C	2.35	A
High	2.20	A	1.45	BC	2.07	A

Years 1 and 2 were establishment and to set up the previous year's stocking-density effects, respectively. Low, medium, and high stocking densities signify 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, at a consistent 35 AUD ha^{-1} yr^{-1} stocking rate for approximately 28, 40, and 67 d, respectively. Means within the interaction followed by similar letters are not significantly different at $p < 0.05$.

While blue grama mass numerically increased after grazing ended in year 3 (Table 5), the significant increase in blue grama mass after grazing ended in year 5 was likely due to the timing of the irrigation and significant precipitation during the post-grazing period through dormancy (Tables 1 and 2). Favorable precipitation after grazing can delay the conversion of standing live crop to standing dead crop [9], allowing native warm-season grasses to restock root energy reserves [6] in autumn and provide greater forage in the following year prior to grazing, which may also have been the case after grazing in year 2 and prior to grazing in year 3 (Table 5). Current-year grassland productivity can be influenced by the climatic events of the previous four years [10] in addition to previous grazing management. In another study [25], the effects of a single year of drought on blue grama growth rates did not carry over into the subsequent year, likely due to above-average precipitation in mid-spring and that it was only after three years of persistent drought that the regrowth potential of grasses through axillary buds was reduced, indicating significant stand loss. Recovery from frequent or severe defoliation is an indication that growing conditions, including adequate moisture, were conducive to recovery [9]. Holochek et al. (2006) [8] reviewed grazing management research on rangeland and reported that low-to-moderately-grazed treatments had similar effects on native vegetation and that native vegetation utilization of up to 40% was sustainable because it maintained greater basal cover than either grazing exclusion or more intensive utilization by grazing. Without accounting for growth during the grazing season, <40% utilization occurred in year 3 and growth outpaced utilization in year 5, but utilization was >50% in year 4 (Table 5), indicating a high grazing intensity [8] that could have influenced initial forage mass in year 5. Eneboe et al. (2002) [25] reported that the negative influence of drought, which also was mildly the case between grazing in year 4 and year 5 (Table 1), was not as evident in stand loss until after three years.

This study was not designed to evaluate grazing initiation at different times of the year; however, the earliness of grazing in year 2 (Table 2) followed by precipitation near the long-term average (Table 1) may have led to greater blue grama mass in July of year 3 when grazing began. Conversely, the lateness of grazing in years 3 and 4 (Table 2) coupled with less precipitation between the end of grazing in those years and the beginning of grazing in the next year (243 and 289 mm from year 3 to year 4 and from year 4 to year 5, respectively) likely influenced available forage mass at the beginning of grazing in the subsequent year, especially when grazing began earlier in year 5. Holochek et al. (2006) [11] reported that perennial grass and blue grama mass measured in autumn were similar under a season-long rest after grazing from February through April or when grazing was excluded. Grazing during the growing season that removes photosynthetically active plant material likely has a greater influence on the spring growth of shortgrasses, such as blue grama, than removal of that same plant material after the onset of dormancy, but before the initiation of spring growth. Removing animals earlier in late winter could leave greater plant residues for soil cover and plant protection over late winter and spring when winds are greater [14]. As with animal performance, when year 2 was included in the analysis to evaluate for the environmental effects of year, years 2 and 4 had similar blue grama mass and years 3 and 5 had similar mass indicating that the month when grazing was initiated (May or July) had little influence on blue grama mass.

The trend ($0.05 < p < 0.10$ [19]) toward a year x stocking density interaction for blue grama mass (Tables 4 and 6) is due to differences in the magnitude of change over years within stocking densities and nonsignificant increases in blue grama mass from low to high stocking densities in years 3 and 4, followed by a numeric decrease in blue grama mass from low to high in year 5. Although not observed in the present study due to a lack of any year × stocking density interaction for GAINHAALL (Table 3), in light of the year × stocking density interaction for forage mass (Table 6) showing greater blue grama mass in years 3 and 5 when greater total moisture was available for growth (Table 1, with 203 mm supplemental irrigation applied in year 5), beef production on rangeland can be increased with grazing intensity in wet years, but not dry years [2]. Conversely, Gillen et al. (2000) [9] reported that stocking rate did not influence shortgrass forage production and there was no interaction with year, although, in the present study, stocking rate was held constant across treatments and years. Consequently, the trend ($0.05 < p < 0.10$ [17]) toward a year × stocking density interaction would be related to environmental influences and stocking density treatments in the present study (Table 6). Nonetheless, shortgrasses, such as blue grama, have greater grazing resistance than other native perennial grasses [12] because they maintain a greater proportion of photosynthetic material under grazing than taller grasses, which allows them to maintain a positive net aboveground primary productivity [25], potentially, even during low precipitation years.

As mentioned, recovery from frequent or severe defoliation is an indication that growing conditions, including adequate moisture, were conducive to recovery [12]. Consistent with forage mass measured 28 and 56 d after grazing indicating recovery each year (Tables 4 and 5), recovery periods of 30 and 60 d were also sufficient to overcome frequent or severe defoliation of sideoats grama (*B. curtipendula*) [12], which is less grazing-tolerant than blue grama as a midgrass species [11]. Defoliating sideoats more than once in a season significantly reduced biomass production with little difference in response when it was defoliated three (60 d intervals) or six times (30 d intervals) either moderately (10 cm stubble) or severely (5 cm stubble) when grown with a competing species [12]. It is likely that the blue grama in the present study was defoliated by grazing more than once in each treatment each year even within the 28-day high stocking density treatment because grazing animals tend to revisit previously grazed areas due to more palatable growth [4,5,7,20]. Drought in late summer and autumn limited forage production by native warm-season grasses to 50% of the production during that period in a high precipitation year in the study by Tilhou et al. (2019) [6], potentially also limiting the production of root energy reserves for spring growth. Under moisture-limited conditions, recovery may take longer; hence, rest periods should be longer [12]. Consequently, similarly to sideoats [12], it would be prudent under typical precipitation conditions to allow blue grama recovery periods of 50 or 90 d during fast and slow growth periods, respectively.

Under the analyses for the effects of the previous year's stocking density on the present year's blue grama mass, the effect of the previous year's stocking density was not significant ($p < 0.19$); however, the effect of the current year's stocking density was significant ($p < 0.0338$), as was the previous x current year's stocking densities interaction (Table 7, $p < 0.0117$). As previously stated, the results were similar for total grass mass as for blue grama mass; hence, only data for the blue grama mass will be discussed. When low-density, long-duration grazing (low) followed either high-density, short-duration grazing (high), or medium stocking density, blue grama mass increased compared to low following low (Table 7). Alternatively, when medium followed high, blue grama mass was reduced, but when high followed any previous stocking density treatment, forage mass increased, although not significantly.

Table 7. The influence of the previous year's stocking density on average blue grama mass (Mg ha^{-1}) under various stocking densities in the following year at Tucumcari, NM USA. Values are the lsmeans of 3 years and 3 replicates. Standard error of the mean = 0.31.

Previous Year Stocking Density	Current Year Stocking Density					
	Low		Medium		High	
Low	1.80	BC	2.46	AB	1.64	C
Medium	2.85	A	2.37	AB	1.76	BC
High	2.47	A	1.55	C	2.01	ABC

Low, medium, and high stocking densities signify 0.53, 0.89, and 1.24 AU ha^{-1}, respectively, at a consistent 35 AUD ha^{-1} yr^{-1} stocking rate for approximately 28, 40, and 67 d, respectively. Means within the interaction followed by similar letters are not significantly different at $p < 0.05$.

The effects of grazing exclusion can be positive or negative depending on the season and duration of the exclusion period and environmental conditions; hence, grazing management practices to increase grassland productivity must be determined on a regional scale [7], including the length of rest required for recovery after defoliation [12]. Bai et al. (2022) [7] found that spring grazing exclusion followed by moderate grazing intensity was the best option to preserve grasslands; however, animal feeding must continue somewhere year-round and grazing is the most cost-effective form of forage production. Consequently, based on the present study results (Table 7), high stocking density may be the best management for a short-duration grazing session at the same time of year using multiple pastures each with the same grazing period to allow for a long-duration rest in accordance with the carrying capacity of the ranch, even if fixed seasonal grazing periods may not maximize growth potential through nutrient recycling and availability for plant growth [10]. Additionally, because beef production on native grasses can be negligible after growth slows late in the growing season [2] and late summer/autumn is a period during which root energy is restocked for spring growth [10], rotating cattle to actively growing annual forages during that period may be advisable until dormancy is induced [24]. However, grazing the dormant native grass forage as soon as possible to minimize the cost of supplementation is advisable since the animals will be lighter at that time than during late winter [23]. Otherwise, during persistent drought, a longer-duration, medium stocking density could be used for less-intensive grazing to allow for as much recovery as possible, and avoid season-long low-density grazing, if possible (Table 7).

The stocking rate in the present study was intermediate to that used in the 7-year study by Gillen et al. [9], who considered their stocking rates to be high [2]. They attributed the lack of any effect on forage mass production was due to long-term (80-year) exposure of their pastures to high stocking rates leading the vegetation to an equilibrium of production under high stocking rates. In the present study, no long-term history was in place as the pastures were in their 3rd to 5th year after seeding. The present study was also not likely of sufficient duration to lead to potential stand degradation due to overgrazing that can occur from the low-density, long-term grazing described by Venter et al. (2019) [5]. Longer-term studies are necessary to evaluate the longer-term effects of grazing management [4].

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References

1. Kannan, N.; Osei, E.; Gallego, O.; Saleh, A. Estimation of green water footprint of animal feed for beef cattle production in Southern Great Plains. *Water Resour. Ind.* **2017**, *17*, 11–18. [CrossRef]
2. Irisarri, J.G.; Derner, J.D.; Ritten, J.P.; Peck, D.E. Beef production and net revenue variability from grazing systems on semiarid grasslands in North America. *Livest. Sci.* **2019**, *220*, 93–99. [CrossRef]
3. Capitan, B.M.; Krehbiel, C.R.; Kirksey, R.E.; Lauriault, L.M.; Duff, G.C.; Donart, G.B. Effect of winter and summer forage type on pasture and feedlot performance and carcass characteristics by beef steers. *Prof. Anim. Sci.* **2004**, *20*, 225–236. [CrossRef]
4. Crawford, C.L.; Volenec, Z.M.; Sisanya, M.; Kibet, R.; Rubenstein, D.I. Behavioral and ecological implications of bunched, rotational cattle grazing in east African savannah ecosystem. *Rangel. Ecol. Manag.* **2019**, *27*, 204–209. [CrossRef]
5. Venter, Z.S.; Hawkins, H.-J.; Cramer, M.D. Cattle don't care: Animal behavior is similar regardless of grazing management in grasslands. *Agric. Ecosyst. Environ.* **2019**, *272*, 175–187. [CrossRef]
6. Tilhou, N.W.; Nave, R.L.G.; Mulliniks, J.T.; McFarland, Z.D. Winter grazing stockpiled native warm-season grasses in the Southeastern United States. *Grass Forage Sci.* **2019**, *74*, 171–176. [CrossRef]
7. Bai, Z.; Jia, A.; Lie, D.; Zhand, C.; Wand, M. How seasonal grazing exclusion affects grassland productivity and plant community diversity. *Grasses* **2022**, *1*, 12–29. [CrossRef]
8. Holochek, J.L.; Baker, T.T.; Boren, J.C.; Galt, D. Grazing impacts on rangeland vegetation: What we have learned. *Rangelands* **2006**, *28*, 7–13. [CrossRef]
9. Gillen, R.L.; Eckroat, J.A.; McCollum, F.T. Vegetation response to stocking rate in southern mixed-grass prairie. *J. Range Manag.* **2000**, *53*, 471–478. [CrossRef]
10. Fynn, R.W.S. Functional resource heterogeneity increases livestock and rangeland productivity. *Rangel. Ecol. Manag.* **2012**, *65*, 319–329. [CrossRef]
11. Holechek, J.L.; Galt, D.; Khumalo, G. Grazing and grazing exclusion effects on New Mexico shortgrass prairie. *Rangel. Ecol. Manag.* **2006**, *59*, 655–659. [CrossRef]
12. Teague, W.R.; Sohower, S.L.; Baker, S.A. Competition between palatable and unpalatable prairie grass under selective and non-selective herbivory in semi-arid grassland. *Arid Land Res. Manag.* **2016**, *30*, 330–343. [CrossRef]

13. Smart, A.J.; Dunn, B.H.; Johnson, P.S.; Xu, L.; Gates, R.N. using weather data to explain herbage yield on three great plains plant communities. *Rangel. Ecol. Manag.* **2007**, *60*, 146–153. [CrossRef]
14. Kirksey, R.E.; Lauriault, L.M.; Cooksey, P.L. *Weather Observations at the Agricultural Science Center at Tucumcari—1905–2002*; Res. Rep. 751; New Mexico State University Agricultural Experiment Station: Las Cruces, NM, USA, 2003. Available online: https://studylib.net/doc/8404582/weather-observations-at-the-agricultural-science-center-at (accessed on 21 February 2022).
15. NRCS. *Conservation Release Brochure 'Hachita' Blue Grama (Bouteloua gracilis)*; USDA—Natural Resources Conservation Service Los Lunas Plant Materials Center: Los Lunas, NM, USA, 1982. Available online: https://www.nrcs.usda.gov/plantmaterials/nmpmcrb10444.pdf (accessed on 17 April 2023).
16. SAS Institute. *The SAS 9.4 for Windows*; SAS Institute Inc.: Cary, NC, USA, 2013.
17. Ramsey, F.L.; Schafer, D.W. *The Statistical Sleuth: A Course in Methods of Data Analysis*, 2nd ed.; Duxbury: Pacific Grove, CA, USA, 2002; p. 42.
18. Saxton, A.M. A macro for converting mean separation output to letter groupings in Proc Mixed. In Proceedings of the 23rd SAS Users Group International, Nashville, TN, USA, 22–25 March 1998; pp. 1243–1246.
19. Klopfenstein, T.; Roth, L.; Rivera, S.F.; Lewis, M. Corn residues in beef production systems. *J. Anim. Sci.* **1987**, *65*, 1139–1148. [CrossRef]
20. Allison, C.D. Factors affecting forage intake by range ruminants: A review. *Rangel. Ecol. Manag.* **1985**, *38*, 305. [CrossRef]
21. Lauriault, L.M.; Kirksey, R.E.; Donart, G.B.; Sawyer, J.E.; VanLeeuwen, D.M. Pasture and stocker cattle performance on furrow-irrigated alfalfa-tall wheatgrass pastures, Southern High Plains. *Crop Sci.* **2005**, *45*, 305–315. [CrossRef]
22. Lauriault, L.M.; Marsalis, M.A.; Cox, S.H.; Duff, G.C. Seasonal mass, performance under grazing, and animal preference for irrigated winter cereal forages under continuous stocking in a semiarid, subtropical region. *Grasses* **2022**, *1*, 1–11. [CrossRef]
23. Lauriault, L.M.; Schmitz, L.H.; Cox, S.H.; Duff, G.C.; Scholljegerdes, E.J. A comparison of native grass and triticale pastures during late winter for growing cattle in semiarid, subtropical regions. *Agronomy* **2022**, *12*, 545. [CrossRef]
24. Lauriault, L.M.; Schmitz, L.H.; Cox, S.H.; Scholljegerdes, E.J. A comparison of pearl millet and sorghum-sudangrass during the frost-prone autumn for growing beef cattle in semiarid region. *Agriculture* **2021**, *11*, 541. [CrossRef]
25. Eneboe, E.J.; Sowell, B.F.; Heitschmidt, R.K.; Karl, M.G.; Haferkamp, M.R. Drought and Grazing: IV. Blue grama and western wheatgrass. *Rangel. Ecol. Manag.* **2002**, *55*, 73. [CrossRef]