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Long-Term Forage and Cow-Calf Performance and Economic Considerations of Two Stocking Levels on Chihuahuan Desert Rangeland ☆

Milton G. Thomas [a], Ahmed H. Mohamed [b], Mohammed N. Sawalhah [c], Jerry L. Holechek [d,*], Derek W. Bailey [d], Jerry M. Hawkes [e], Pablo Luna-Nevarez [f], Francisco Molinar [g], Godfrey Khumalo [h]

[a] *Professor and John E. Rouse Chair of Beef Cattle Breeding and Genetics, Department of Animal Science, Colorado State University, Fort Collins, CO 80523*
[b] *Researcher at the Department of Plant Ecology and Range Management, Desert Research Center, Cairo, Egypt, 11753*
[c] *PhD candidate, Research Assistant, New Mexico State University, Las Cruces, New Mexico, 88003*
[d] *Professors in the Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM 88003*
[e] *Professor, Extension Animal Sciences and Natural Resources and Department of Agricultural Economics and Agricultural Business*
[f] *Professor Departamento de Ciencias Agronómicas y Veterinarias, Instituto Technologico De Sonora, Obregon, Son, MX, 85000*
[g] *El Paso Team Resources Leader, United States Department of Agriculture, Natural Resource Conservation Service, El Paso, TX, 79936*
[h] *Senior Lecturer of Animal Science, University of Swaziland, Luyengo, Swaziland, MR18*

A R T I C L E I N F O

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A B S T R A C T

Forage and cow-calf productivity on two lightly and two conservatively grazed pastures were evaluated over a 15-year period (1997–2011) in the Chihuahuan Desert of south-central New Mexico. Spring-calving Brangus cows were randomly assigned to pastures in January of each year. Pastures were similar in area (1 098 ± 69 ha, mean ± SE) with similar terrain and distance to water. Utilization of primary forage species averaged 27.1 ± 3.0% in lightly stocked pastures and 39.4 ± 4.0% on conservatively stocked pastures. No differences in perennial grass standing crop (163.5 ± 52.2 $kg \cdot ha^{-1}$) and calf weaning weights (286.1 ± 2.6 kg) were detected ($P > 0.10$) between light and conservative treatments. Lightly grazed pastures yielded greater ($P < 0.05$) kg of calf weaned $\cdot ha^{-1}$ and calf crop percent than conservatively grazed pastures in 1998 due to complete destocking of conservatively grazed pastures during that slight drought (i.e., rainfall was 75% of normal in 1998). After the initial 5 years of study (1997–2001), all pastures were destocked for 4 years (2002–2005) due to drought as rainfall was only 50% or less of normal. Pastures were then restocked for another 6 years (2006–2011). Postdrought, the percentage change in perennial grass standing forage crop ($kg \cdot ha^{-1}$) was -4.0 and -14.4 ± 2.5 % ($P < 0.09$) in the light and conservative grazed pastures across the 6 years, respectively. While conservative stocking rates may provide higher net financial returns than light stocking rates during nondrought years as there were more AU per pasture, potential losses from cattle liquidation during short-term (i.e., 1-year) droughts could nullify this advantage. Results suggest that light grazing use of forage is a practical approach for Chihuahuan Desert cow-calf operations to minimize risk of herd liquidation during short-term drought.

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Introduction

A major managerial challenge confronting ranchers on desert rangelands is that periodic droughts necessitate destocking to avoid harmful impacts on soils, vegetation, and livestock (Holechek et al., 2011). Global warming has the potential to exacerbate frequency and severity of drought, especially on desert rangelands (Brown and Thorpe, 2008; Polley et al., 2013). In the Chihuahuan Desert of New Mexico, 5 multiyear droughts have occurred in the 44-year period from 1969–2013 (Petrie et al., 2014). During these types of droughts, many ranchers were most likely forced to relocate or liquidate their livestock, creating challenges to finance herd rebuilding when the drought ends (Doye et al., 2013). These challenges are exacerbated on large-rangeland ranches because naïve cattle are not as adapted to desert environments and may select lower-quality diets and have less desirable grazing distribution patterns than cattle born, raised, and kept on the ranch (Bailey et al., 2010).

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* Correspondence: Jerry Holechek, Department of Animal and Range Sciences, 2980 South Espina Street, MSC 3I, New Mexico State University, Las Cruces, NM 88003.
E-mail address: holechek@nmsu.edu (J.L. Holechek).

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Conservative stocking targeting 31% to 40% use of primary forage species has become a well-accepted management practice in the Chihuahuan Desert because it reduces the need for stocking rate reductions in years of below-average precipitation, gives similar or higher net financial returns, improves livestock performance, lowers variable costs, and enhances forage productivity compared with moderate grazing (41% to 50% use of primary forage species; Paulsen and Ares, 1962; Winder et al., 2000; Holechek et al., 2003). Light grazing (20–30% use of primary forage species) can reduce the need for stocking rate adjustments in dry years and may better facilitate range recovery following drought compared with conservative grazing (Valentine, 1970; Khumalo et al., 2007).

A preliminary 5-year report of this study conducted at the Chihuahuan Desert Rangeland Research Center in south-central New Mexico showed little difference in forage or livestock productivity between light and conservative stocking (Thomas et al., 2007). However, light grazing did reduce the need to destock during short-term (1-year) drought. Our objectives herein are to describe 15 years of results from the study. This report includes the initial 5 years of data collection followed by 4 years of extended drought that required complete destocking of pastures, then a 6-year postdrought grazing period when pastures were restocked. These data permitted predrought and postdrought comparisons of forage and livestock productivity under light and conservative stocking. Comparative financial effectiveness of the two stocking treatments was also assessed, taking into consideration risk of drought-induced herd liquidation and subsequent herd rebuilding.

Materials and Methods

Study Site

Our study was located on the Chihuahuan Desert Rangeland Research Center (CDRRC) 37 km north of Las Cruces in south-central New Mexico. It is in the southern portion of the Jornada del Muerto Plains (lat 32°32′N; long 106°48′W) with level to gently rolling hills varying from 1 188 to 1 371 m in elevation. Soils of the CDRRC are mainly light sandy loams underlain by calcium carbonate hardpans at depths varying from a few centimeters to greater than 1 m (Valentine, 1970; Joseph et al., 2003). Soils are classified as fine loamy, mixed thermic, typic haplargids and are in Simona-Cruces associations (SCS, 1980).

Typical Chihuahuan Desert climatic conditions occurred across our CDRRC study site, which averages 200 frost-free days per year (Joseph et al., 2003). Wells and pipelines are the only permanent sources of water available for livestock on this research facility. In summer, temperatures are high with a mean maximum of 36°C during the month of June and a mean maximum of 13°C during January (Pieper and Herbel, 1982). Winds are often strong in the spring of the year (Joseph et al., 2003). Rain gauges are well distributed throughout the CDRRC. Historic mean annual precipitation (1930–2012) was 234 $\pm$ 20 mm, with 52% of the precipitation coming in the growing season of July to September. Average annual precipitation from 1997 through 2011 was 241 $\pm$ 20 mm.

Primary grasses on the CDRRC are black grama (*Bouteloua eriopoda* [Torr.] Torr.), dropseeds (*Sporobolus* spp.), and threeawns (*Aristida* spp.). Honey mesquite (*Prosopis glandulosa* Torr.) and broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton & Rusby) are the most commonly found shrubs.

Pasture and Forage Use Description

Four adjacent pastures with similar soils (sandy loams) and topography (flat) were delineated and fenced in 1991. Pasture 1 was 1 267 ha, pasture 2 was 932 ha, pasture 3 was 1 219 ha, and pasture 4 was 974 ha. Calculation of the grazable area of each pasture was based on distance from water and the procedures of Holechek (1988). Therefore, distance to water was not a concern for grazing distribution as stocking rates were based on the area defined as suitable for grazing.

Two treatments were randomly assigned to the four pastures in November of 1997. Pastures 1 and 3 were stocked to obtain 25% to 30% forage use (light), and pastures 2 and 4 were stocked to obtain 35% to 40% forage use (conservative). Stocking rates assigned to achieve these levels were based on the procedures of Holechek (1988). Perennial grass standing crop was estimated in November after the growing season, and stocking rates were determined using desired forage use levels and standing crop estimates. Pastures were stocked in January, which was the next time the cows were penned. Forage use was revaluated in June, and if critical stubble height levels were observed in a particular pasture, it was destocked. The following paragraph describes the stubble height measurement protocol. Pastures 1, 2, and 4 were in late-seral ecological condition, and pasture 3 was in midseral ecological condition at the start of the study based on the quantitative climax approach of Dyksterhuis (1949). Ecological condition scores for pastures 1, 2, 3, and 4 at the beginning of the study in 1997 were 65%, 60%, 46%, and 63%, respectively (Molinar, 1999). In 2010, ecological condition scores were 67%, 68%, 59%, and 58% for pastures 1 through 4, respectively (Mohamed, 2011).

Perennial grass standing crop was measured in autumn of 1993 through 2011 at 10 permanent sites (evenly spaced key areas) in each pasture (Joseph et al., 2003). Perennial grass standing crop and current year growth were determined by clipping twenty 0.5 m^2 quadrats at each site. Current year growth was separated from standing dead material. The reader is referred to Joseph et al. (2003), Khumalo (2006) and Mohamed (2011) for information on total herbaceous standing crop, herbaceous standing crop relative composition, and percent cover of plant species in the study pastures. Grazing intensity on the four pastures was evaluated in 1997 through 2011 using procedures of Holechek and Galt (2000). Grazing intensity (forage use) was measured in late June of each year because it is the end of the forage cycle before new growth of perennial grasses, which usually occurs in July. Percent use of the perennial grass standing crop was evaluated on 4 of the 10 previously described permanent sites (key areas) within each pasture that we considered a good representation of overall grazing intensity. Residual perennial grass biomass was determined by clipping twenty 0.5 m^2 quadrats at each of these key areas in late June. New systematically selected quadrat locations were clipped each year. Forage use was calculated by dividing the late June perennial grass standing crop by the perennial grass standing crop in the previous autumn. This number was then subtracted from 1 and multiplied by 100 to obtain forage use expressed as a percentage. Stubble heights of black grama, dropseeds, and threeawns were also evaluated in each key area. In drought years, black grama stubble heights were periodically checked during summer and autumn in all four pastures. If average stubble height fell below 7.6 cm, all cattle were removed from the pasture. A minimum stubble height of 7.6 cm has been recommended to avoid damage to black grama from excessive grazing (Paulsen and Ares, 1962; Valentine, 1970). When black grama stubble heights fall below 7.6 cm, damage to plant crowns and impaired soil health due to inadequate residual cover becomes probable. Both low-forage production and black grama stubble heights near or below 7.6 cm justified the decision to destock the conservatively grazed pastures in November of 1998 and all pastures in November of 2001 (i.e., no grazing was allowed 2002–2005).

Experimental Animals

Mature, pregnant, multiparous Brangus cows were randomly assigned by age and body condition score (BCS; scale 1 = emaciated to 9 = obese) to each pasture in January of each year. Cow age ranged from 5 to 10 years, which is the descriptor of a mature cow within the guideline of the Beef Improvement Federation (BIF, 1996). Cow age averaged 7.1 ± 1.5 years for 213 cows used in the 4 pastures across the 15 years of the study. These cattle were part of the Brangus breeding program for desert adaptability that was initiated in 1966 (Luna-Nevarez et al., 2010). Each pasture was assigned a single-sire mated herd. Cow weight and BCS were recorded each January, May, and October. Reproductive performance based on the number of cows exposed to breeding (i.e., pregnancy and calf crop percentages) and calf weaning weights were determined each October. To obtain these data, cows were gathered using horses and herded to a working facility central to the four pastures and this section of the CDRRC. Because of the extensive pasture system used in this study, weights were collected within 2 hours of penning the cattle and then animals were herded back to their assigned pasture (Luna-Nevarez et al., 2010). Body condition scores were collected using the system recommended for beef cows by Mathis et al. (2002) in which 1 is emaciated and 9 is obese.

Cattle were managed according to the procedures described by Obeidat et al. (2002) and Luna-Nevarez et al. (2010). Calving occurred February through May, breeding occurred from May 1 through August 1, and weaning occurred in mid-October. Birth and weaning weights were adjusted using BIF guidelines (1996). These weights were also adjusted for sex of the calf (i.e., steer equivalence procedure), as well as sire quality using expected progeny differences (EPD) provided by the International Brangus Breeders Association (2012). The mean EPD level for each trait was estimated for all the sires that produced progeny in the study. Each sire's deviation from this mean was also estimated. This deviation was then added or subtracted from the trait measure for each calf. This procedure was necessary as the pastures were single sire mated and there were differences in the qualities of the sires.

Protein supplement (i.e., range cubes with ~36% crude protein [CP] and 72% total digestible nutrient [TDN]; HiPro, Friona, TX) was fed on a per-cow basis from March 1 to May 2 at a rate of 1 $kg \cdot cow^{-1} \cdot day^{-1}$. An energy supplement from the same company (18% CP and 75% TDN) was fed at the same rate from May 2 until the onset of summer rains and forage growth, which was usually early July. Cows were palpated for pregnancy in autumn and nonpregnant cows were culled. These data were used to estimate pregnancy rate (%) for each pasture each year, and the number of calves born during the following spring was used to estimate calf crop percent. These estimates were based on the number of cows exposed to breeding the prior summer.

Statistical Analyses

Data were analyzed using the repeated measures procedures of PROC MIXED and GLIMMIX in SAS (2011). Numeric traits were analyzed with the mixed procedure, and the categorical reproductive traits were analyzed with the GLIMMIX procedure. Pasture served as the experimental unit and subject in the repeated measures analyses. Fixed effects were stocking level (light or conservative), year, and the interaction of stocking level and year. Covariance matrices were evaluated in these repeated measures analyses using the algorithms of compound symmetric, AR1, and unstructured. The most appropriate model was determined for each analysis using Akaike and Bayesian information criterion and null model likelihood ratio tests as described in Littell et al. (2006). Means were separated using preplanned pair-wise comparisons generated with the least significant difference procedure involving PDIFF. Data are presented as mean ± standard error (SE).

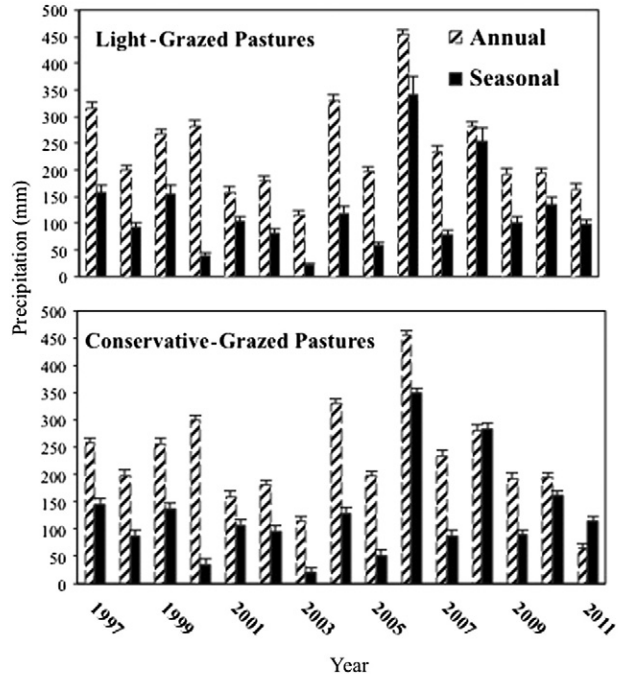

Fig. 1. Annual and growing season precipitation in lightly (upper panel) and conservatively (lower panel) grazed pastures on the Chihuahuan Desert Rangeland Research Center from 1997–2011.

In order to evaluate forage and cattle production differences between stocking treatments in the predrought and postdrought periods, data were pooled across the 1997–2001 (predrought) and 2006–2011 (postdrought) periods for each pasture. Holechek et al. (2003) found this approach to be meaningful for detecting long-term trends in forage production where experimental areas may not be equivalent in forage production at study initiation and precipitation varies greatly across landscapes and years. Specifically, data were normalized to the production levels of 1997–2001 (i.e., setting the predrought mean to 100%, then the postdrought response as a percent increase or decrease relative the mean for each pasture). Using pasture as the experimental unit, the post drought responses were compared among treatments with a one-way analysis of variance. Results of this analysis were confirmed with a Wilcoxon Mann-Whitney test as these data were converted to percentages and difficult to test normality with one degree of freedom.

Results and Discussion

Perennial Grass Production and Grazing Use

No differences ($P > 0.10$) in total annual (241.3 ± 20.0 mm, mean ± SE) or growing season (124.5 ± 25 mm) precipitation were detected between lightly and conservatively grazed pastures from 1997–2011 (Fig. 1). The grazing treatment × year interaction was not an important factor ($P > 0.10$) for precipitation. A slight drought occurred in 1998 ($P < 0.001$; 75% or less of average growing precipitation), and the years 2000, 2001, 2002, and 2003 were severe drought ($P < 0.001$; 50% or less of average growing precipitation). These rainfall patterns yielded grazing data for the initial 5 years of the study (1997–2001) and the last 6 years of the study (2006 to 2011). No cattle performance and grazing data were collected from 2002–2005 due to drought and complete destocking.

Grazable area$\cdot AU^{-1}$ varied across the 15 years of study (56.5 ± 8.5 ha vs. 72.9 ± 10.9 ha respectively; Fig. 2) in the conservatively

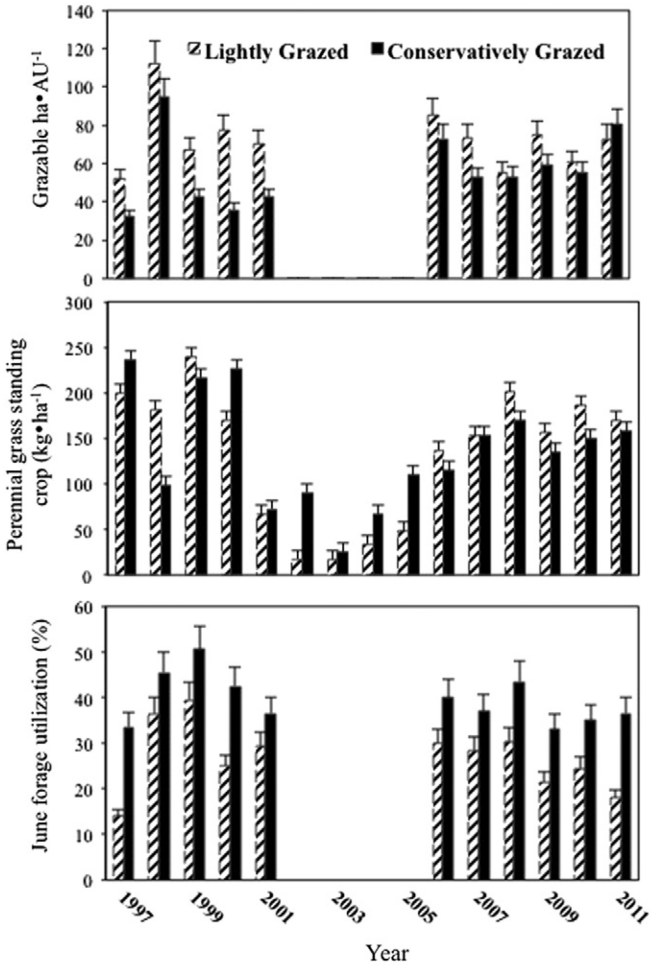

Fig. 2. Size of grazed area$\cdot$AU^{-1} (top panel), perennial grass standing crop (middle panel), and June forage utilization (bottom panel) in lightly and conservatively grazed pastures on the Chihuahuan Desert Rangeland Research Center from 1997–2011. NOTE: Pastures were not grazed years 2002–2005 as forage production was minimal due to severe drought.

and light grazed pastures, which was a measure of the differences in actual stocking rates as per the design of the study. More specifically, forage utilization (Fig. 2) was greater ($P < 0.001$) in the conservatively stocked pastures ($39.4 \pm 4.0\%$) relative to the lightly stocked pastures ($27.1 \pm 3.0\%$). These results validate the treatments and the accuracy of stocking rate calculations. The slight 1-year drought of 1998 resulted in excessive grazing use in June 1999. Even though stocking rate was reduced in the light pastures, and the conservative pastures were destocked based on grass stubble height, the June forage utilization measures were exacerbated due to lack of growth before rainfall in 1999. These values could have also been affected by grazing of other herbivores (*Lepus californicus* and *Antilocapra americana*).

Forage standing crop varied ($P < 0.001$) during the 15 years of the study. Growing season precipitation was 176% and 250% above average in 1999 and 2006, respectively (Fig. 1); thus, standing crop in these years was greater ($P < 0.05$) than in other years. There were several years of severe drought during the study and cattle were completely removed from the pastures for the years 2002–2005. Perennial grass standing crop during these years averaged 73.1 ± 15 kg$\cdot$ha^{-1} across the four pastures (Fig. 2), which was 45% of the 15-year average. The poorest year of forage growth was 2002 with the four pastures yielding on average only 37.8 kg$\cdot$ha^{-1} of grazable forage, which was 23% of long-term average. This extremely poor year of growth at the beginning of the 5-year drought forced complete destocking of the pastures in January 2002 based on reduced stubble heights measured in November of 2001. Pastures were restocked in 2006 after there was sufficient plant growth and stubble heights exceeded the 7.6 cm standard for black grama. Because no cattle grazing occurred in the four pastures from 2002–2005, these years are blank in the graphs of grazable ha$\cdot$AU^{-1} and June forage utilization.

Fig. 3 presents the forage standing crop levels of the two treatments predrought and postdrought. No differences were detected ($P > 0.10$) in comparisons of treatments and blocks of years 1997–2001 vs. 2006–2011. However, when the average standing crop of each pasture for 1997–2001 was used as a baseline, average standing crop for 2006–2011 declined less ($P < 0.09$) in the lightly grazed pastures ($-4.0 \pm 2.0\%$) than in the conservatively grazed pastures ($-14.4 \pm 2.5\%$). This is an important finding and suggests that forage production may have recovered from drought more quickly under light than conservative grazing. Valentine (1970) made a similar observation in a long-term study evaluating heavy, moderate, conservative and light grazing impacts on Chihuahuan Desert rangeland. In other previous reports from this project, rangeland ecological score increased from 56 to 63 in the 1997–2010 period on the light grazed treatment, but no change was observed in the conservative stocked treatment (62 in 1997 vs. 63 in 2010) (Molinar, 1999; Mohamed, 2011). This is most likely explained by better maintenance of perennial grass cover during drought in the light compared with conservative grazed pastures (Khumalo et al., 2007). In summary, the improved forage plant and soil health that resulted from light

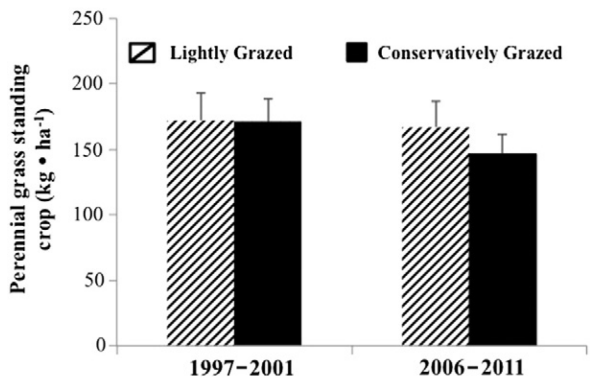

Fig. 3. Mean perennial grass standing crop for 1997–2001 and 2006–2011. NOTE: Pastures were not grazed years 2002–2005 as forage production was minimal due to severe drought.

Table 1
Mean ± standard error of Brangus cow-calf production measures from lightly and conservatively grazed pastures on the Chihuahuan Desert Rangeland Research Center from 1997 through 2011 ($n = 10.5 \pm 2.1$ AU$\cdot$grazing treatment pasture$^{-1}\cdot$year^{-1}).

Trait	Light Grazing	Conservative Grazing
Number of AU	289	338
Time of calving (Julian day)	87.3 ± 1.4	85.3 ± 1.3
Calf-adjusted birth weight (kg)	39.7 ± 0.4	39.8 ± 0.3
Calf-adjusted weaning weight (kg)	286.9 ± 2.5	285.2 ± 2.7
Total calf weaned (kg)	62 204	73 301
Kg calf weaned$\cdot$ ha$^{-1}\cdot$yr^{-1}	0.8 ± 0.5	1.2 ± 0.6
Cow winter weight (kg)	584.9 ± 5.4^{c}	594.6 ± 4.8^{d}
Cow winter BCS	5.2 ± 0.1	5.1 ± 0.1
Cow spring weight (kg)	523.9 ± 5.0	554.8 ± 24.1
Cow spring BCS	4.9 ± 0.1	4.7 ± 0.1
Cow autumn weight (kg)	550.0 ± 4.6	554.2 ± 4.0
Cow autumn BCS	5.2 ± 0.1	4.9 ± 0.1
Pregnancy rate (%)	85.8 ± 1.9	87.9 ± 1.7
Calf crop (%)	84.5 ± 1.9	86.6 ± 1.7

^{c,d}Means with different superscripts tend to differ ($P < 0.10$).

Table 2
Mean ± standard error of Brangus cow-calf production measures in lightly and conservatively grazed pastures on the Chihuahuan Desert Rangeland Research Center in two time blocks, before drought (1997–2001) and after drought (2006–2011).

	1997–2001		2006–2011	
Trait	Light Grazing	Conservative Grazing	Light Grazing	Conservative Grazing
Number of AU	143	151	162	171
Time of calving (Julian day)	83.5 ± 1.3	84.3 ± 1.2	86.7 ± 2.3	89.1 ± 3.4
Calf-adjusted birth weight (kg)	39.1 ± 0.7	40.2 ± 0.8	40.9 ± 0.9	38.2 ± 0.8
Calf-adjusted weaning weight (kg)	279.2 ± 6.9	278.2 ± 7.0	298.5 ± 14.8	297.3 ± 11.2
Total calf weaned (kg)	33 601	29 947	32 375	39 503
Kg calf weaned $ha^{-1} \cdot yr^{-1}$	0.6 ± 0.1	0.74 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Cow winter weight (kg)	546.5 ± 14	575.2 ± 14	601.1 ± 22	588.8 ± 29
Cow winter BCS	4.8 ± 0.1	5.0 ± 1.0	4.9 ± 0.1	5.1 ± 0.1
Cow spring weight (kg)	525.3 ± 9.1	502.4 ± 9.8	558.3 ± 26	560.5 ± 18
Cow spring BCS	4.9 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	4.8 ± 0.1
Cow autumn weight (kg)	528.6 ± 25	541.2 ± 30.5	565.1 ± 22	558.9 ± 19
Cow autumn BCS	5.1 ± 0.2	4.7 ± 0.2	5.0 ± 0.1	4.9 ± 0.2
Pregnancy rate (%)	92.8 ± 4.7	90.3 ± 4.3	85.0 ± 7.5	85.5 ± 8.5
Calf crop (%)	90.8 ± 4.5	85.1 ± 4.3	83.0 ± 7.5	85.4 ± 9.0

Means between columns and years 1997–2001 versus 2006–2011 did not differ ($P > 0.10$).
$n = 10.5 \pm 2$ AU • grazing treatment $pasture^{-1}$ • $year^{-1}$.

grazing appeared to cause more advancement toward climax vegetation.

Cow-Calf Production

The experimental protocol placed more AU in the conservative grazed pastures relative to the light grazed pastures during the 15 years of study (Table 1). However, no differences in any other measure of cow-calf production were detected ($P > 0.10$) between lightly and conservatively grazed treatments on these Chihuahuan Desert rangelands. A similar result was observed among treatments when cattle productivity was compared among the predrought and postdrought periods (Table 2). Cow winter weights were slightly heavier ($P < 0.10$) for conservative vs. light grazed pastures (Table 1), but we do not interpret this as an important difference between treatments. No differences in cow weights were detected ($P > 0.10$) in the spring or autumn (Table 1). There were also no differences detected ($P > 0.10$) in BCS between stocking levels. However, cow size in this Brangus herd has increased over time (Luna-Nevarez et al., 2010), which may have played a role in the results from this study. Increased cow size, which is due to genetic selection for growth rate, is a challenge for cow-calf production in the southwestern United States. Specifically, increased cow size without a reduction in stocking rate most likely increases cow-herd maintenance costs, grazing use, or both (Brown et al., 2005; Brown and Lalman, 2010; Lalman et al., 2013).

Results from the current study should have relevance to cow-calf production in states such as New Mexico, Texas, and Oklahoma. Specifically, weaning weights appeared similar to average weaning weights reported from standardized performance analysis (SPA) efforts in these states (286.1 ± 2.5 kg) during the same 15-year period (Bevers, 2012). However, the Chihuahuan Desert ecological zone is in the southern region of New Mexico and the extreme southwestern region of Texas. Hawkes and Libbin (2014) reported from surveys of New Mexico ranch budgets, which are most likely a better estimate of Chihuahuan Desert production relative to a three-state SPA summary, stating that weaning weights on medium-sized ranches were approximately 226 kg. This is substantially less than the weaning weights observed in the Brangus cattle used in this study. Therefore it should be noted that 45 years of genetic selection for desert adaptability in these Brangus cattle support the concepts reviewed by Rook et al. (2004) that there are rearing environment and genetic interactions influencing livestock grazing. It is also important to note that Brangus cattle used in this study are a two-breed composite of Angus and Brahman, which are known to maximize hybrid vigor in harsh environments (Thrift and Thrift, 2003; Brown and Lalman, 2010; Van Eenennaam, 2013).

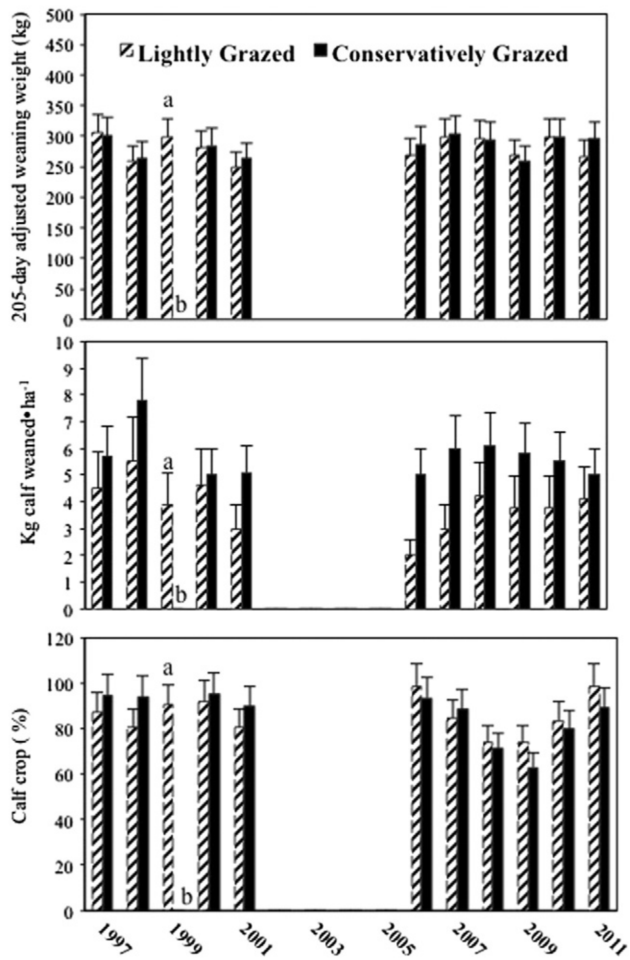

Fig. 4. 205-day adjusted weaning weight (top panel), kg of calf weaned $\cdot ha^{-1}$ (middle panel), and calf crop percent (bottom panel) in lightly and conservatively grazed pastures on the Chihuahuan Desert Rangeland Research Center. Means for a given year with different letters (*a* vs. *b*) are different ($P < 0.05$). NOTE: Pastures were not grazed from 2002–2005 as forage production was minimal due to severe drought.

On the basis of research by Luna-Nevarez et al. (2010), we expected year to be a significant source of variation in this cow herd for performance during 1997–2011. Specifically, year was (P < 0.05) important in the analyses of the calf and cow weight traits and BCS. This year effect is most likely a result of rainfall during the growing season and the subsequent forage availability and quality for grazing ruminants on these desert rangelands (Khumalo et al., 2007, 2008; Molinar et al., 2011).

Surprisingly, no differences were detected ($P = 0.16$) for the main effect of treatment in calf weight weaned $\cdot$ ha^{-1} between the conservatively and lightly stocked pastures, even though there were more AU placed in the pastures of conservative treatment (Table 1). However, a treatment × year interaction ($P < 0.05$) was observed for the traits of 205-day adjusted weaning weight, kg of calf weaned $\cdot$ ha^{-1}, and percent calf crop (Fig. 4). During the slight 1-year drought of 1998, the conservative-treated pastures had to be completely destocked on the basis of the stubble height criterion of the study, while the light-treated pastures sustained cattle grazing. This result suggests an advantage of lightly grazed pastures over that of conservatively grazed pastures during periods of slight (1-year) drought. However, neither grazing treatments can stockpile the forage needed to survive a multiyear drought as severe as the event from 2001–2005. These severe multiyear droughts have only been observed at the CDDRC three times in its history dating from 1927 (i.e., mid 1930s and 1950s; Molinar et al., 2011; Petrie et al., 2014).

In our first report of cattle productivity from this study (Thomas et al., 2007), we discussed the impacts of drought and reduced forage production and weaning weight. Pieper et al. (1991) and Winder et al. (2000) also discussed these relationships. All of these reports discussed the need for reduced stocking and/or complete destocking due to the depletion of forage reserves associated with drought. Determining a stocking level that will sustain a cow herd is an important management decision for beef producers utilizing arid and semiarid rangelands. For example, the Brangus cattle used in the current study have been selected for desert production since the late 1960s (Luna-Nevarez et al., 2010). Bailey et al. (2010) reported that the Brangus cattle that were raised and kept at this experiment station in the Chihuahuan Desert traveled farther from water and selected higher-quality diets than naïve Brangus cattle that originated from a subtropical environment (eastern Texas). Therefore, there is value in stocking a ranch with cattle adapted to the environment, even though the value of these cows may be difficult to estimate.

Cattle in this study received supplemental feed. This management strategy is viewed as necessary in most cow-calf operations to overcome nutritional deficits of the forage and maintain cow body condition when she is lactating (Lalman et al., 1997; Waterman and Butler, 2010; Mulliniks et al., 2012). Economic modeling of supplemented and nonsupplemented cows by Hawkes (2004) using data from the initial years of this study (1997–2001) suggested that protein supplementation in drought years increased net financial returns by \$1.00 to \$1.50 $\cdot$ ha^{-1} when pastures were lightly or conservatively stocked. In this modeling exercise, calf crops in dry years averaged 70% and calf weaning weights averaged 190 kg in nonsupplemented cattle compared with calf crops of 86% and 260 kg calf weaning weights in supplemented animals. Pregnancy rates and percent calf crop were reduced ($P < 0.001$) in the current study during years of limited rainfall and forage production (Fig. 3) even with supplemental feeding. The means from this study for these two traits are considered typical for most operations in the states of New Mexico, Oklahoma, and Texas (Bevers, 2012). As cost of supplemental feed and delivery continues to increase (Torell and Rimbey, 2010; CattleFax, 2013), light stocking levels may have an economic advantage over heavier stocking rates. The reason for this statement is that a greater forage standing crop will allow livestock more grazing selectivity and hence opportunity to consume a higher-quality diet. In practice, ranchers can improve protein supplementation decisions regarding timing and amount through use of the fecal sampling technique of Lyons and Stuth (1992).

The current study used mature cows from the New Mexico State University Brangus research breeding program that were adapted to these rangelands (Bailey et al., 2010; Luna-Nevarez et al., 2010). Thus, the pregnancy and calf crop percentages did not experience such severe drought reductions as in the study of Winder et al. (2000), which studied conservative and moderate stocking levels with heifers and young cows. Drought can be frequent and of extended time periods in the Chihuahuan Desert. Consistent use of light stocking levels is a practical approach for Chihuahuan Desert Brangus cow-calf operations to avoid herd liquidation during short-term (1-year) drought. Herd liquidation potentially forces ranchers to use unadapted or inexperienced cattle for restocking. Also, results of this study suggest that cows grazing conservative- and light-stocked pastures should have similar herd performance when the management includes some supplemental feeding; however, on the basis of our study of range condition (Khumalo et al., 2007, 2008; Mohamed, 2011), it appears light grazing on Chihuahuan Desert rangeland may facilitate improvement in rangeland condition. The light grazed treatment had improvement in rangeland condition score compared with no change for the conservative treatment during the period of study.

Experimental Limitations

Even though our total study area involved 4 392 ha, we consider the limited area and number of pastures as important experimental limitations. The average Chihuahuan Desert ranch supporting 250 cows is about 16 000 to 20 000 ha or roughly four times the size of our study area (Holechek, 1990, 1992). Large Chihuahuan Desert ranches typically involve areas of 50 000 ha or more. Precipitation is highly variable across landscapes and years in the Chihuahuan Desert. Even in the driest years, some parts (10–20%) of the landscape will likely receive enough rainfall for near-average forage production. Lightly stocked large ranches can typically carry more of their cow herd through extended drought periods because each year the probability is high that some areas will receive near-average or above-average precipitation and light stocking facilitates stockpiling of forage. On small ranches, the probability of receiving meaningful rainfall on some areas in drought years is greatly reduced. Lack of forage on our relatively small study area forced complete destocking during the 2002–2005 drought, whereas we may have been able to retain a portion of the herd without risk of heavy or severe grazing if we had access to the much bigger area of medium- or large-sized Chihuahuan Desert ranches.

On the basis of surveys by Hawkes and Libbin (2014), the average small, medium, and large size Chihuahuan Desert ranch retained about 36%, 36%, and 43% of their grazing capacities, respectively, in the 2002–2005 drought period (comparison involved 2004 vs. 2011 livestock inventories). The current study only involved four pastures on an extensive rangeland experiment station. Even though these pastures were completely destocked because of the study's protocol, the experiment station was able to retain approximately 30% of its livestock resources; therefore, this information supports our discussion that actual ranches retain a portion of their herd even under severe drought. In the severe 1950s drought, a conservatively stocked eastern New Mexico ranch was more profitable than three other ranches using higher stocking rates based on a report by Boykin et al. (1962). The most profitable rancher in this study considered conservative stocking the key to his survival. Boykin et al. (1962) found that all four ranchers studied decided to retain some portion of their livestock in the 1950s drought to avoid selling their well-adapted cattle at depressed prices.

Economic Considerations

Our data averaged over the two (1997–2001 and 2006–2011) grazing periods showed that conservative stocking yielded 18% more beef production than light stocking as there were more AU in the conservative pastures (Table 1). Hawkes (2004) conducted financial analyses of our predrought livestock production data (1997–2001) for each pasture. He reported that net financial returns from the light and conservative grazing treatments did not differ over the 5-year study period. Overall returns from pastures 1 (lightly stocked), 2 (conservatively stocked), and 4 (conservatively stocked) were \$2.31, \$2.20, and \$2.07$\cdot$ha^{-1}, respectively, but pasture 3 (lightly stocked) had depressed net returns (-\$0.12 per ha) due to consistently lower forage production than in the other pastures. Net returns varied greatly among years and appeared moderately associated ($r = 0.45$, $P < 0.10$) with previous year forage production. However, these analyses did not consider the costs associated with large changes in stocking rates and herd rebuilding that were required in current experiment. However, the Hawkes (2004) report did note the economic challenge of dynamic annual adjustments of the number of cows. Bailey et al. (2010) examined the effects of prior experiences on Brangus cow grazing behavior on this experiment station and documented the benefits of grazing adapted cows on distribution and diet selection. The value of grazing cows that are adapted to local forages, topography, and environmental conditions and the economics of buying and selling cattle to match forage conditions warrant further study.

Over the past 30 years, multiyear droughts (1994–1996, 2001–2005, 2011–2013) have occurred (Petrie et al., 2014; Sawalhah, 2014). On the basis of our assessment of cattle prices in annual ranch budgets compiled by New Mexico State University agricultural economists (Torell et al., 1998a,b, 2000; Hawkes and Libbin, 2014), cow-calf producers, depending on period, lost between \$250 and \$400$\cdot$AU^{-1} when they liquidated part of their cow-herd in response to drought and then were forced to purchase replacement females for restocking after the drought. This problem also occurred in the 1950s drought (Boykin et al., 1962). Generally under drought conditions, cows that must be sold are marketed as culls even though they may potentially have several remaining productive years in the breeding herd. Cull cows typically sell for only half or less of the price of replacement heifers. Following drought, prices of replacement heifers and functional mature cows are elevated as demand increases because most ranchers are attempting to restock. Correspondingly, the financial risk from forced destocking in a multiyear drought may negate any long-term financial advantage of light stocking over those higher stocking rates that supply more calves each year as the entire ranch faces the challenge of restocking postdrought. According to the report of Boykin et al. (1962) and our analyses of surveys by Hawkes and Libbin (2014), it appears most ranchers, even in severe drought, will make every effort to retain a portion of their cow herd. This is generally through mechanisms of purchased feeds, grazing leases, and/or perhaps overuse of their rangeland. Basing the size of a cow herd on forage availability in dry years and using yearling livestock to harvest surplus forage in wet years was identified as a financially sound drought management strategy by Boykin et al. (1962).

The yearling stocking approach for arid rangelands was evaluated in detail by Torell et al. (2010) and found to be financially advantageous over straight cow-calf operations. Adding flexible yearling enterprises on arid rangeland operations increased average net ranch returns by 14% with conservative stocking. A 50:50 forage allocation between cow-calf and yearling enterprises was found to be optimal, but optimal cow numbers decreased over time as dry conditions forced herd reductions (Torell et al., 2010). Gross sales and production costs increased by over 2.7 times for realization of the 14% net financial return increase. The authors commented that this increased expense and financial risk may not justify the added net returns for risk-averse producers. It was best to gradually switch to yearling production as drought forced herd liquidations, and for many price situations, the cow herd would not be rebuilt. Flexible stocking was also evaluated by Torell et al. (2010) but not recommended for arid rangelands. It was found that flexible stocking could potentially nearly double net returns relative to conservative stocking, but realizing this substantial gain depends on reliable climatic/forage forecasts that are not presently available and involve higher production costs.

A case study with application to the challenges of stocking rate reported that calf crops from naïve cattle under light/conservative stocking were initially 58% and calf weaning weights were 170 kg on a 1 400 AU ranch in western New Mexico (Holechek et al., 2011). Previous heavy grazing and severe drought had forced complete herd liquidation and later replacement with new naïve cattle. Over a 10-year period of careful livestock culling, replacement and adaptation, calf crops gradually rose to 91% and calf-weaning weights rose from 170 kg to 265 kg. Reproductive management and culling cows that failed to be pregnant each autumn helped keep grazing intensities light to conservative.

Management Implications

Conservative grazing has been the recommended grazing intensity for Chihuahuan Desert rangelands based on various studies of vegetation, livestock productivity, and financial returns. However, during periods of extended drought such as in 1944–1956 and, more recently, 1994 to present, ranchers using conservative grazing likely were forced to liquidate most or all of their herds due to lack of forage or the cost of purchased feeds. Light grazing of about 25% use of forage production reduces stocking level about one-third compared with conservative grazing (35% use). Light grazing also lowers the risk of destocking in a short-term (1-year drought). Very importantly, light grazing facilitates recovery of forage production and rangeland ecological condition following drought compared with conservative grazing. Also, drought cycles can be lengthy and U.S. cattle price cycles are now difficult to predict. Cow prices are invariably much higher when cattle are repurchased after drought and it may be difficult to purchase cows that are adapted to extensive rangelands. These realities and the excessive cost of supplemental feeds exacerbate management and financial risks associated with conservative, as well as higher, stocking levels in the Chihuahuan Desert; therefore rangeland management decisions must balance stocking rate with the potential for long-term drought.

Light grazing appears to be well suited to Chihuahuan Desert ranchers who prefer a passive, low-risk, low-input management approach. Light grazing is also suggested for pastures and ranches wherein improved range condition is a goal and there is concern a threshold will be crossed where rangeland recovery may not occur. Light grazing has been recommended for arid rangelands in other parts of the world. On semidesert and desert Australia rangelands, light grazing involving a 25% harvest coefficient is considered key to drought survival by some researchers (Johnston et al., 1996).

Conservative grazing may be best suited for ranchers who want to actively manage their rangelands, are willing to do intensive monitoring, and have a high proportion of land in late seral or climax condition. Ranchers using conservative grazing must be willing to quickly reduce livestock numbers in dry years. Under these conditions, there may be an economic advantage to conservative grazing.

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