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The Effects of Continuous and Rotational Livestock Grazing on Forb Quality and Quantity: Implications for Pronghorn Habitat Management

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ABSTRACT

Pronghorn (*Antilocapra americana*) evolved in grasslands with a diet composed of highly nutritious forbs. However, pronghorn habitat throughout North America has been lost to fragmentation and degradation. Additionally, the effects different cattle grazing regimes have on forb biomass, protein, and energy production for pronghorn are not well known in West Texas. We sampled forbs during the growing season in the months of September 2018 and 2019 to assess the effects of different cattle grazing regimes on forbs. We hypothesized rotational grazing would increase the nutritional quality of the forb community and overall forb production, compared to continuous grazing and no grazing. We randomly sampled pastures subject to continuous and rotational grazing, as well as ungrazed exclosures using 100, 96, and 64 1 m^2 plots, respectively. We collected all forbs in each plot and analyzed differences in nutritional composition and biomass production using redundancy analysis. We found that the effects of grazing varied by year. In wetter conditions, rotational grazing exhibited higher forb quality and biomass, while exclusion from grazing exhibited these results under drier conditions. The knowledge gained from this study helps resource professionals and landowners understand how cattle grazing affects forbs for pronghorn. This knowledge may be used to improve the suitability of pronghorn habitat through cattle grazing regimes.

Introduction

Pronghorn (*Antilocapra americana*) populations have declined throughout their range in New Mexico, Texas, Arizona, and Mexico (Bender et al., 2013; DeVos Jr. and Miller, 2005; Lucia, 2004). The declines in pronghorn numbers are generally attributed to habitat loss through degradation and fragmentation. Habitat loss due to brush encroachment is one of the main factors affecting struggling pronghorn populations in Texas, Arizona, and Mexico (DeVos Jr. and Miller, 2005; Schmidly, 2002). Pronghorn avoid brush-encroached areas in order to spot and evade predators (Goldsmith, 1990). Habitat degradation is a major past and present influencer in the decline of pronghorn populations in New Mexico and Arizona. In New Mexico, limited quantity and quality of forage have negatively affected pronghorn populations by reducing nutrient availability (Bender et al., 2013). Habitat degradation also results in low fawn recruitment. For example, low vegetation height produced insufficient fawning cover in Arizona, leading to reduced fawn survival (Neff et al., 1985; Neff and Woolsey, 1979). The interspersion of pronghorn habitat components on the landscape also influences the success of pronghorn populations (Gates et al., 2012). The high variation in precipitation suggests that pronghorn demographics are more susceptible to drought conditions than other populations of pronghorn (Simpson et al., 2007).This juxtaposition is particularly important with respect to quality forage and fawning cover (Loeser et al., 2005). Management efforts to restore pronghorn should focus on understanding the processes that affect the quality and quantity of pronghorn habitats.

Pronghorn life history is adapted to grassland habitats. They rely on their vision to detect predators and their speed to avoid them (Goldsmith, 1990). Because of this, they require open habitats with little woody vegetation (Goldsmith, 1988). Pronghorn exhibit a strong preference for high quality forbs, with secondary use of shrub species (Beale and Smith, 1970; Beasom et al., 1982; Buechner, 1950a; Koerth et al., 1984). These critical habitat factors are all shaped by the distribution and intensity of grazing by larger herbivores (Loeser et al., 2005). Thus, grazing was, and continues to be a dominant force shaping these aspects of pronghorn habitat.

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Pronghorn evolved sympatrically with American bison (*Bison bison*) on the grasslands of North America (Buechner, 1950b; McCullough, 1980; Seton, 1937). Bison grazed in large herds, moving between areas after short periods of time, while periodically resting the rangeland (Knapp et al., 1999). Bison grazing also increased forb production, and grazed less forbs leaving them available to pronghorn (Catchpole, 1996; Damhoureyeh and Hartnett, 1997; Fahnestock and Knapp, 1993). However, bison were nearly extirpated in the 1800s due to the combination of overhunting and habitat loss (Knapp et al., 1999). Following the decline of bison, cattle (*Bos taurus*) became the primary large grazer on North American rangelands (Allred et al., 2011; Yoakum, 1975).

The shift from bison to cattle as the dominant grazer on North American prairies altered the frequency and intensity of grazing (Plumb and Dodd, 1993). Fences associated with cattle grazing permit management of timing, frequency, and intensity (Mather and Hart, 1954), which led to various approaches to grazing management. Continuous grazing is the simplest and most common grazing method, requiring little labor, infrastructure, or maintenance (Gillespie et al., 2008; Holechek et al., 2004). This strategy applies grazing to a specific pasture year-round or while grazing is feasible (Driscoll, 1969). Rotational grazing, on the other hand, consists of moving cattle across different pastures throughout the year (Hart et al., 1988). Because this strategy requires regular movement of cattle and additional fencing, it is more labor intensive and costly than continuous grazing (Gillespie et al., 2008). However, rotational grazing allows rest for forage recovery, improves water infiltration into soils, and increases mineral cycling (Savory, 1999). Rotational grazing strategies emulate the historic relationship between pronghorn and bison in order to achieve similar benefits (Knapp et al., 1999; Krausman et al., 2009). How grazing affects forb abundance and quality may make it a valuable tool for improving pronghorn habitat.

We investigated the effect of grazing strategies on forb abundance and quality to determine the utility of alternative strategies for improving pronghorn habitat. Literature suggests the implications of different grazing systems for forb production may be complex. Moderate to heavy continuous grazing produces a higher quantity, but lower quality of forbs compared to rotational grazing (Heitschmidt et al., 1987; Pieper et al., 1991; White et al., 1991). However, rotational grazing could increase pronghorn forb utilization by restricting cattle's range during the growing season (Holechek et al., 2004). Grazing exclusion is unlikely to increase forb richness or cover due to the positive effects disturbance from grazing has on forb communities, suggesting some degree of grazing is important in maintaining pronghorn habitat (Loeser et al., 2005). We expect the effect of grazing systems on forb production to depend on annual conditions, due to the complicated nature of plant community responses to disturbance, and the influence of precipitation on those processes. We compared biomass, protein, and energy of forb communities under moderately stocked continuous and rotational grazing regimes to those in ungrazed exclosures, for two years that had variable precipitation levels.

Methods

Study area

This study took place in Presidio County on the 4,391-ha Mimms Ranch, north of Marfa, Texas (Fig. 1). The ranch is bounded by US Highway 90 to the south and State Highway 17 to the east, and is located within the Trans-Pecos ecological region (Gould, 1975). Temperatures of the Marfa grasslands range from an average high of 23° C in the summer to an average low of 5° C in the winter (National Oceanic and Atmospheric Administration (NOAA), 2018). The study area ranges between 1,371.61,981.2 m in elevation (Allcorn III, 2015) and receives 390.7 mm mean annual precipitation (National Oceanic and Atmospheric Administration (NOAA), 2018). Desert grasslands in Texas receive 75% of their total annual precipitation between the months of May and October (McClaran and Van Devender, 1997). The ranch is dominated by blue grama (*Bouteloua gracilis* (Willd. ex Kunth)), Halls panicum (*Panicum hallii* (Vasey)), black grama (*Bouteloua eriopoda* (Torr.)), and sideoats grama (*Bouteloua curtipendula* (Michx.); French, 2015). Common forbs include Greggs evening primrose (*Calylophus hartweggii* (Benth.)), dalea (*Dalea* spp.), shrubby milkwort (*Polygala lindheimeri* (A. Gray)), baby white aster (*Chaetopappa ericoides* (Torr.)), verbena (*Glandularia* spp.), broom snakeweed (*Gutierrezia sarothrea* (Pursh)), and Gordon bladderpod (*Lesquerella gordonii* (A. Gray); French, 2015). Prevalent shrubs include cacti (*Cylindropuntia* and *Opuntia* spp.), honey mesquite (*Prosopis glandulosa* (Torr.)), and vine ephedra (*Ephedra antisyphilitica* (Berl. ex C.A. Mey.); French, 2015).

The Mimms Ranch features 3 ecological sites, including igneous hills and mountain mixed prairie, loamy mixed prairie, and shallow mixed prairie (Natural Resource Conservation Service (NRCS), United States Department of Agriculture, 2011). The igneous hills and mountain mixed prairie ecological site soils are non-calcareous, shallow, rocky loams with depths of 10.250.8 cm. Vegetation on this site is limited, with many rock outcrops, and some mid-grasses and shrubs. This site is generally present on slopes of 2040% at elevations from 1,371.61,981.2 m. The loamy mixed prairie ecological site is found at average elevations from 1,371.61,706.9 m with slopes $\leq 2\%$. Vegetation on this site consists of grama grasses with approximately 1% shrub cover. The soils of this site consist of silt or clay loams developed from loamy and clayey alluvium with depths up to 177.8 cm. The shallow mixed prairie ecological site is dominated by grama grasses and mixed shrubs. Elevations of this site range from 1,371.61,828.8 m with slopes at 18%. This site is made up of shallow, loamy, and calcareous soils with depths of 17.850.8 cm.

The ranch practices both rotational (R) and continuous (C) grazing, with ungrazed (U) exclosures located throughout both treatments (Fig. 1). The rotationally grazed portion of the ranch is comprised of 34 paddocks, averaging 107.3 ha each ($SD = 29.1$). The paddocks are grazed for approximately two weeks each over the dormant season (October through May), with each paddock having approximately a 16 month rest period. The rotational system has a stocking rate of 3.25 ha/AUM (3648.2 ha/70 AU/16 months; Gammon, 1984). The continuously grazed pasture encompasses 858.3 ha of the ranch, and has a stocking rate of 2.4 ha/AUM (858.3 ha/30 AU/12 months; Gammon, 1984). The ranch installed 16, 0.4 ha exclosures randomly distributed throughout the property in 2008. The entire ranch burned in a wildfire in 2011, but was otherwise undisturbed from 2012 through the duration of this study, excepting cattle grazing (Allcorn III, 2015).

Field methods

We conducted vegetation sampling in September, during the peak of the warm-wet season, when we expected the largest amount of forb biomass to be present in the field, due to a strong relationship between the summer rainfall pattern and vegetation growth (Newhall and Berdanier, 1996; O'Gara and Yoakum, 2004; Sims and Singh, 1978; National Oceanic and Atmospheric Administration (NOAA) (2018); Natural Resources Conservation Service (NRCS), United States Department of Agriculture (2018)). We sampled forb biomass within a total of 260, 1 m^2 quadrats per year ($N = 520$) according to a stratified-random design, allocated proportionally to the area of each grazing system on the ranch ($N_C = 100$, $N_R = 96$, $N_U = 64$) using QGIS 3.2 (Cook and Stubbendieck, 1986; QGIS Development Team, 2018). We sampled 8 of the 34 paddocks

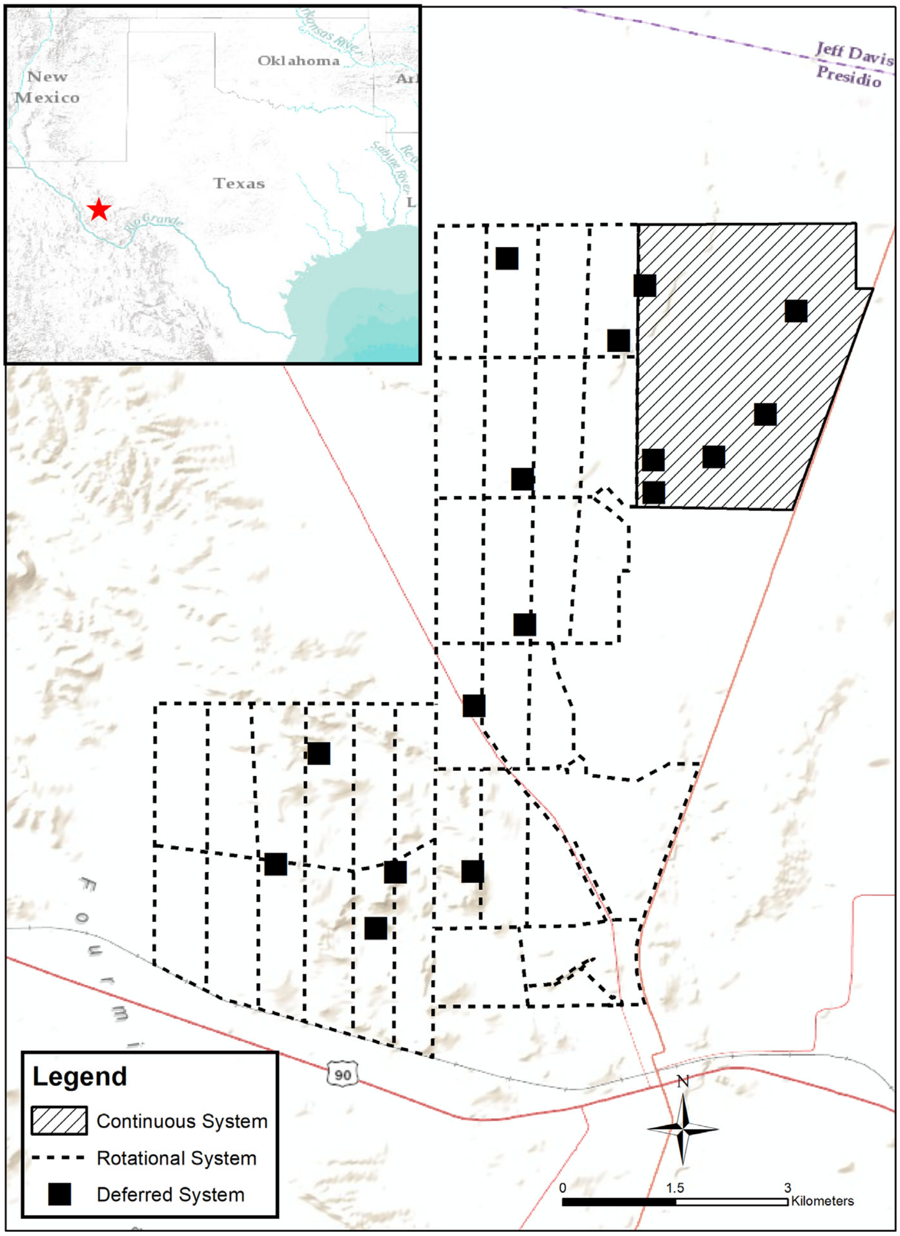

Fig. 1. This study took place on the Mimms Ranch in Marfa, Texas. This map displays the ranch boundaries and it's three grazing regimes: continuous, rotational, and ungrazed.

within the rotational system to represent the effect of grazing in each month cattle were present. Sub-sampling the rotational system also provided us equal sampling effort between the rotational (0.11 plots/ha) and continuous (0.11 plots/ha) systems by reducing both treatments to a comparable area (836 and 858.3 ha for the rotational and continuous systems, respectively). We identified all forbs within the plot to species, clipped and bagged them by species, and recorded the total wet weight of each species within each plot (Cook and Stubbendieck, 1986). Samples were placed in a 55° C Shel Lab SMO28-2 forced air oven until they reached a constant weight (Hobbs and Swift, 1985). The dried samples were then ground in a Wiley mill over a #40 mesh screen according to previous studies analyzing energy content of vegetation (Golley, 1961). We measured acid detergent fiber (ADF) content of each forb species with an ANKOM^{200} Fiber Analyzer (Macedon, New York). We then used ADF to estimate total digestible nutrients (TDN), according to $TDN_{xi} = 96.35 - (1.15 * ADF_{xi})$ where TDN_{xi} = the proportion TDN content by dry matter of species x in season i and, ADF_{xi} = the proportion ADF content by dry matter of species x in season i (Wertz-Lutz et al., 2010). We measured crude protein composition content of each forb species with a Kjeltec^{TM}8100 Tecator^{TM}Line Machine where CP_{xi} = the proportion crude protein by dry weight of species x in season i (Pond et al., 2005).

Analysis

We used redundancy analysis (RDA; Legendre and Legendre, 2012) to examine the relationships between grazing regime and forb biomass, protein, and energy content with R 3.6.2 (R Core Team, 2019) and the *vegan* package (v2.5-6; Oksanen et al., 2019). RDA can be considered a multivariate multiple regression that accounts for the covariance of response variables (forb biomass, protein, and energy, in our case; Wollenberg 1977). This can

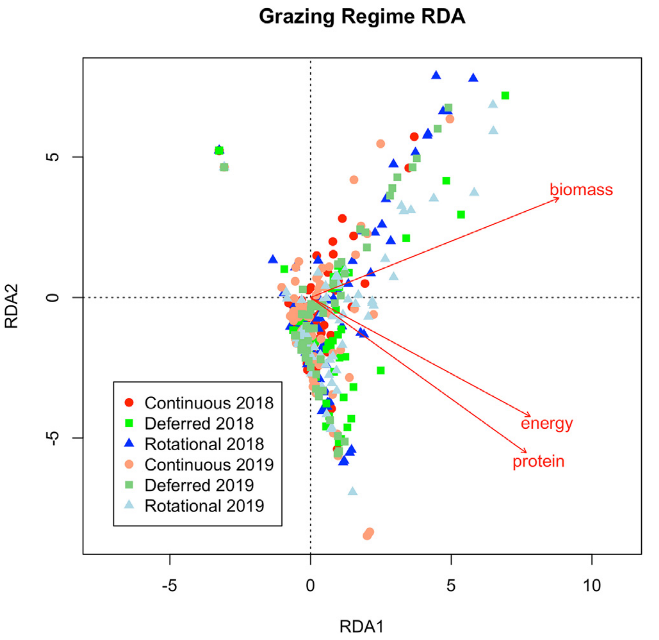

Fig. 2. This graph represents the final RDA bi-plot displaying the non-linear trade-off between the quality and quantity axes. It also reveals the 2018 ungrazed system and 2019 rotational system to have the highest frequency of plots falling in the tail of the joint distribution of quality and quantity.

Table 1
Mahalanobis distances showing all centroids were not far from the overall mean. This shows slight differences between the means across grazing regimes and years.

	2018	2019
Continuous	0.56	0.51
Rotational	0.36	0.40
Ungrazed	0.45	0.27

reduce the complexity of the response, facilitating interpretation. We included grazing system and year as dummy coded, discrete covariates of forb biomass and nutrient levels (Legendre and Legendre, 2012). Because annual conditions may impact forb response to grazing, we included an interaction between grazing system and year in our analysis. This allowed us to model the effect of grazing treatments on forb biomass, energy, and protein simultaneously, without assuming responses were independent. We quantified the multivariate distance between treatment means using Mahalanobis distance (McLachlan, 1999). This accounts for the differences in scale by reporting the differences in terms of standard deviations from the overall, multivariate mean.

Results

We found there is variability in biomass and nutritional values of forbs across grazing regimes (Appendix). Our biomass response variable was not linearly correlated with protein or TDN ($R = 0.16$, and 0.23, respectively), but the nutrition measures were strongly correlated ($R = 0.88$; Fig. 2). These correlations allow us to interpret the directions of the original nutrition variables as a single quality (nutrition) axes, which is approximately orthogonal to the original quantity (biomass) axes. The distribution of individual plots, relative to these axes, shows evidence of a nonlinear trade-off between forb quality and forb biomass within plots (Fig. 2). Grazing regime had an effect on the multivariate mean of grazing regimes ($P = 0.010$, $R^2 = 0.015$; Table 1), which varied by year ($P = 0.068$). However, the distribution of plots shows evidence that plots with both relatively high quality and biomass were more frequent under rotational than continuous or no grazing in 2019, while these plots were more frequent in the ungrazed exclosures in 2018 (Fig. 2). This suggests that grazing interacted with annual conditions to affect the shape of the distribution, as well as the mean.

In the year leading up to September 2018, the ranch received 260.12 mm of precipitation from October to September, with a majority occurring between May and September (Fig. 3a), while in the year leading up to September 2019 the ranch received 330.25 mm of precipitation more evenly throughout the year from October to September (Fig. 3b; PRISM Climate Group, 2020). Essentially, the study area received spring rains in 2019, but not in 2018.

Discussion

While we detected small differences in means between the two grazing systems and no grazing, observed differences in the tails of the distributions may be of more interest. Results suggest quality measures were strongly colinear, thus they reduce to a single axis. This reduces the distribution to two dimensions representing quality and quantity, respectively. We also found evidence of a nonlinear trade-off between these axes that shows a majority of the plots exhibited either high-quality or high-quantity forb production, but few exhibited both. This trade-off is consistent with the forage-maturation hypothesis where mature, high-biomass plants are nutritionally inferior to immature, low-biomass plants (Hobbs and Swift, 1988; McNaughton, 1984; 1986; Van Soest, 1982). Since all of our measures are bounded at zero, the tail of the resulting joint distribution is a fan that is longer along the margins than the center. The center of the tail contains plots with relatively high quality, given their high biomass, or relatively high production, given their high quality.

Increasing the frequency of plots in the tail region would provide more access to higher quantity and quality forage to wildlife, including pronghorn. Movements of large mammalian herbivores are linked to food productivity, quality, and particularly forage dispersion (Geist, 1978; Jarman, 1974; Owen-Smith, 1977; 1979). Increasing the frequency of plots in the desirable region of our ordination space would represent higher quantity and quality forage. This frequency of occurrence increase would require pronghorn to travel less to find resources, allow them to conserve more energy, and reduce physiological stress, ultimately reducing costly foraging efforts (Abrams, 1991). Grazing influenced the frequency of plots in this region, but the effect varied by year.

We suspect the annual differences in forb quality and quantity were driven by changes in timing and amount of precipitation. Based on our 2-year study, this suggests in areas with late and limited rainfall, exclusion from grazing facilitates the highest frequency of desired pronghorn forage production in late summer. However, in years that experience spring rainfall, rotational grazing may facilitate this response. It should be noted that the year effect completely encapsulates differences in moisture, temperature, or any other factors between years. Consequently, we cannot definitely conclude that precipitation drives these differences. Long-term data are needed to understand how forb communities respond to annual precipitation in combination with grazing systems. Such data will allow future pronghorn habitat management and restoration efforts to better adapt to annual environmental conditions.

A common overarching theme in our results is the importance exclusion periods from grazing had on facilitating a higher frequency of forb production. Despite grazing management requires proper stocking rates for animal and forage production, grazing exclusion could be critical to prevent overgrazing. This is especially true when forage is actively growing, not during dormancy. The length of time for plants to recover following grazing depends on

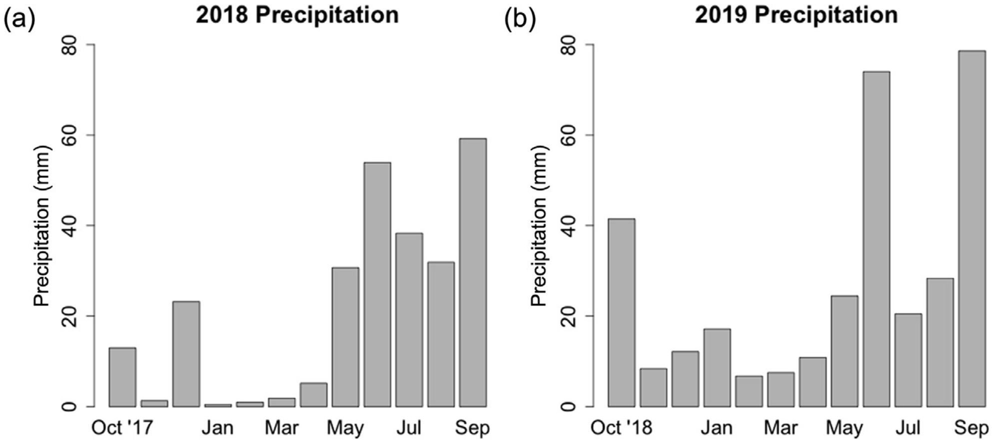

Fig. 3. In the year leading up to September 2018 (a), the study area received 260.12 mm of precipitation with a majority occurring later in the year. In the year leading up to September 2019 (b), the study area received 330.25 mm of precipitation occurring well distributed throughout the year.

several factors, including the type of forage species, plant vigor, and the level of utilization. Recovery time also depends on the season or time of year, specifically day length and temperature conditions. While literature is by no means definitive on the value of grazing exclusion, as often the periods of grazing removal may not be long enough to provide any change in defoliation patterns compared to continuous grazing, our findings are supported by studies that suggest periods of exclusion improve forage production compared to continuous grazing systems (McDonald et al., 2019). However, explicit grazing exclusion may not be an option and rotational grazing provides periods of exclusion needed to facilitate a higher frequency of desired pronghorn forage production, while still providing economic income through livestock grazing (McDonald et al., 2019; Souther et al., 2020). Rotational grazing also maintains or improves ecological and animal productivity (McDonald et al., 2019; Norton, 1998; Teague et al., 2008; 2011). Properly managed grazing is not detrimental to pronghorn habitat and can help maintain and increase habitat for wildlife (Krausman et al., 2009). However, periods of exclusion incorporated into grazing systems may be instrumental in increasing pronghorn habitat quality by facilitating production of higher quality pronghorn forage (Krausman et al., 2009; McDonald et al., 2019). Our study exposed the importance of grazing and how rest from grazing can affect pronghorn forage production, but we only analyzed indefinite exclusion versus one discrete rotational grazing exclusion pattern. Future research should examine the influence of exclusion duration along a continuum, rather than only discrete categories.

Although grazing strategies incorporating exclusion facilitated the highest frequency of desired pronghorn forage production under the conditions of our 2-year study in the month of September, continuous grazing is still one of the most common grazing techniques used today (Holechek et al., 2004). Therefore, implications of continuous grazing on desired pronghorn forage production should be considered. Under the light to moderate stocking rates used in our study, continuous grazing produced a higher frequency of plots near the center of the distribution and a lower frequency in the tails compared to rotational grazing and exclosures. Although continuous grazing did not produce the highest frequency of pronghorn forage production in either year of this study, it was not detrimental to the overall forb community as results showed only small differences were detected at the tails of the distributions(Briske et al., 2008; Hart et al., 1988; Holechek et al., 1987). This study only analyzed forage production in the warm-wet season. Therefore, continuous grazing could have different effects on desired pronghorn forage production in other times of the year.

Effect of stocking intensity on forage production should also be considered in addition to grazing technique and annual conditions. Stocking rates can have a greater potential for altering the botanical composition of range plant communities than grazing systems (Hart et al., 1993; Jakoby et al., 2015). This study analyzed similar stocking rates between grazing systems to detect effects of grazing regimes on pronghorn forage production. Similar stocking rates provided us a fair comparison between the results of continuous and rotational grazing on forage production. Future studies should analyze different stocking rate consequences on pronghorn forage production since grazing regime effects are now better understood. Overall, grazing management must be responsive and adaptive to changing annual conditions regardless of grazing technique and stocking intensity (Jakoby et al., 2015).

Finally, pronghorn are highly selective foragers, consuming only the highest quality of the available forb species (Koerth et al., 1984). We conducted our analysis including all forb species. Future research should identify factors driving forb preference of pronghorn. Results from this study could become more precise by understanding the driving factors behind specific forb preference of pronghorn. Our study examined pronghorn forage production within the warm-wet season. We selected the peak of the growing season in September to provide the best comparison of forage production between grazing regimes. Future research should look into grazing effects on pronghorn forage production throughout different times of the year to gain a better understanding of the year-long forb production system. Sampling needs to be focused on the peaks of the cool-dry and warm-dry seasons as these are the most limiting times of the year for pronghorn forage (French, 2015; Simpson et al., 2007; Yoakum and O'Gara, 2000).

Implications

Our results suggest rotational grazing facilitates a higher frequency of high-quality forb production for pronghorn in years of adequate rainfall. However, exclusion from grazing likely produces similar outcomes in drier years with late rains. While continuous grazing did show a slight lower frequency of plots with higher quantity and quality of forbs. It should be considered when managing for late summer pronghorn forage production as we found it to provide equivalent results to systems incorporating periods of exclusion. We recommend incorporating resting periods into grazing plans to increase forage quality and abundance. Cattle managers striving to cope for both cattle and pronghorn should consider flexibility in grazing systems and adjust stocking rates according to weather conditions as a positive tool for increasing forb production. Our research lays a foundational understanding of forb response to grazing to maximize forb production for pronghorn and increase pronghorn habitat quality through the use of livestock grazing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2021.03.006.

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