Adaptive, Multi-Paddock, Rotational Grazing Management: An Experimental, Ranch-Scale Assessment of Effects on Multiple Ecosystem Services

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Abstract

Decisions on how to move livestock in space and time are central to rangeland management. Despite decades of small-scale research, substantial uncertainty exists regarding the relative importance of cattle stocking rates *per se*, versus the movement of cattle in both space and time, in achieving desired vegetation and livestock outcomes at scales relevant to livestock producers. We report on a ranch-scale experiment comparing effects of collaborative, adaptive, multi-paddock, rotational management (CARM) versus more traditional, season-long, continuous rangeland management (TRM) on perennial grass density and production, cattle performance, and wildlife habitat, while holding the annual stocking rate the same in both systems. We collaborated with stakeholders to develop an adaptive grazing management plan, collected pre-treatment data in 2013, and implemented treatments during 2014 – 2020. Results for 2014 – 2018 were reported by Augustine et al. (2020); here we report on two additional years of results, covering a 7-year period of treatments from 2014 – 2020. With two additional years of measurements, we found no significant difference in total forage production in CARM vs. TRM treatments, averaged across all soil types in the experiment. In one year, we found that CARM increased forage production on loamy soils and decreased forage production on alkaline soils, but these differences were minor and in opposite directions, resulting in no net overall effect. Furthermore, we found that adaptive, rotational grazing management substantially reduced livestock weight gains in each of the first 6 years of the experiment, when cattle were managed as a single, large herd occupying each paddock sequentially. Across the 6 years, cattle weight gain averaged 15% lower in CARM vs. TRM. In the 7th year, stocking density in CARM was reduced 50% by giving cattle access to two paddocks at a time. This year also coincided with a drought. Under these conditions, cattle weight gains were identical in both treatments. Results emphasize the importance of replicated controls in assessing grazing management effects. Even in heterogeneous landscapes where livestock are moved adaptively among paddocks to match seasonal patterns of forage growth, such management may not lead to desired outcomes for vegetation and livestock.

Introduction

Few studies have examined the effects of adaptively managed rotational grazing systems in heterogeneous and spatially extensive landscapes (Briske et al., 2008; Hawkins et al., 2017; Teague and Barnes, 2017). Livestock distribution on the landscape is typically managed via fencing and water infrastructure, which can be costly, yet experimental studies addressing the ecological and economic benefits of such management remain rare. A South African study did not find any benefits to vegetation or livestock production arising from rotational versus season-long grazing regimes (Venter 2019). In North America, Teague et al., (2011) found that adaptive, multi-paddock grazing at ranch scales enhanced soil organic matter and vegetation composition relative to long-term continuous grazing, but did not evaluate livestock production. A synthesis of research in Australian rangelands concluded that complex, multi-paddock, rotational grazing systems were not appropriate for the region, but that moderate stocking rates and provision of periodic growing-season rest from grazing were essential to maintaining rangeland condition (O'Reagain et al. 2014).

Here, we report on a grazing management experiment that incorporates study design recommendations discussed by Teague and Barnes, (2017) to examine the effects of adaptive, multi-paddock, rotational grazing management on vegetation and livestock production in a semi-arid rangeland. Results of the first five years of the experiment were recently reported by Augustine et al. (2020); here we report on two additional years of results, covering a 7-year period of treatments from 2014 – 2020. Decisions regarding annual stocking rate and the sequence and timing of cattle movements among paddocks for the adaptive, multi-paddock grazing were made by an 11-member stakeholder group seeking to achieve a suite of vegetation, livestock, and wildlife and objectives (see Wilmer et al., 2018); this experimental treatment is hereafter referred to as Collaborative

Adaptive Rangeland Management (CARM). For CARM, the 10, 130-ha paddocks were grazed by a single, herd of steers managed using adaptive, rotational grazing which incorporated planned year-long rest in 20% of the paddocks. For TRM, 10 paired, 130-ha paddocks experienced season-long, continuous grazing by herds of yearling steers at one-tenth the stocking density of the single CARM herd. Overall stocking rates for both treatments were identical. We hypothesized that periodic, year-long rest from grazing in the CARM treatment would increase forage production, and that the adaptive nature of the rotational management system would compensate for negative effects of high stock densities to yield similar livestock performance as in TRM.

Methods and Study Site

Research was conducted at the Central Plains Experimental Range (CPER) in northeast Colorado, USA (40°50′N, 104°43’W). Long-term mean annual precipitation on the CPER is 340 mm. Topography is flat to gently rolling; soils range from fine sandy loams on upland plains to alkaline salt flats bordering drainages. Two C4 shortgrass species comprise over 70% of aboveground net primary productivity (Lauenroth and Sala, 1992). Twenty 130-ha paddocks were paired into ten blocks where each block contained two paddocks similar in terms of soil and plant characteristics, topographic patterns, and prior management history. One paddock in each pair was randomly assigned to the TRM treatment. Each TRM paddock was grazed throughout the growing season (mid-May to early October) by a single herd of yearling steers. The other was assigned to the CARM treatment (Fernandez-Giménez et al. 2019). Each TRM paddock was grazed (i.e., none were rested) by a herd of yearling steers that occupied each paddock separately, whereas the CARM paddocks were grazed by a single 10-fold larger herd of steers managed with an adaptive, rotational grazing system, with 20% of the paddocks planned for year-long rest each year (Fernández-Giménez et al., 2019). Details of the cattle management strategy applied to the CARM paddocks were developed by the 11-member stakeholder group who used stocking rate adjustments, grazing rotations, and season-long rest to help achieve specific goals and objectives (Wilmer et al., 2018).

Paddocks were stratified by ecological site and topography. We established four pairs of plots in the seven experimental blocks containing loamy and/or sandy plains ecological sites, and six pairs of plots in three blocks that additionally contained the salt flat ecological site. We measured aboveground net primary production (ANPP) of plant functional groups (C4 perennial grasses, C3 perennial graminoids, annual grasses, forbs, and subshrubs) at peak biomass in August, with harvests occurring in a 0.18 m^2 rectangular quadrats within four 1 x 1 m moveable grazing cages per plot. For analyses of forage production, we treated both 2013 and 2014 as pretreatment years because the vegetation measurements occurred in grazing cages moved annually, and hence measurements of forage in 2014 could not yet have been affected by the treatment. Forage measurements from 2013 and 214 were averaged at the plot scale and included as a covariate in the linear mixed model to account for pre-treatment variation among plots and paddocks.

The stocking rate was initially 0.61 animal unit months (AUM) ha-1 in 2014. and was adjusted to 0.64, 0.67, 0.70, 0.81, 0.70, and 0.70 AUM ha^{-1} during 2015 – 2020 respectively. Which CARM paddocks experienced pulse grazing and which were rested from grazing varied across years and depended on an adaptive grazing management plan developed by stakeholders as well as on-the-ground, weather-dependent conditions (i.e., forage biomass and cattle behavior) measured weekly during the grazing season. In response to results from 2014 – 2019, the grazing strategy for CARM was changed for the 2020 grazing season by dividing the CARM cattle into two separate herds, where each was planned to have access to 4paddocks during the growing season, with the remaining two paddocks rested. This was done to reduce the stock density at any given point time in the CARM treatment to half of the level used in the prior six years. Because 2020 was a drought year, actual grazing implementation required the cattle to graze all 10 paddocks, and then to regraze several paddocks in order to have sufficient forage for the full extent of the grazing season.

Table 1. Results of a linear mixed model for annual herbaceous forage production in response to CARM vs. traditional grazing management, year, and ecological site in the shortgrass steppe of northeastern CO.

Effect	Num DF	Den DF	F Value	*Pr > F*
Treatment	1	117	5.35	0.0225
Year	5	22.7	68.58	<.0001
Treatment*Year	5	311	1.19	0.3124
Ecosite	2	50.8	16.72	<.0001
Ecosite*Treatment	2	119	8.22	0.0005
Ecosite*Year	10	227	1.08	0.3779
Ecosite*Treatme*Year	10	336	1.01	0.4314

Each year, we weighed steers individually at the beginning of the grazing season (mid-May), stratified steers by weight, and randomly assigned them to TRM and CARM treatments. We individually weighed steers again at the end (early October) of each grazing season. We used shrunk weights (Derner et al., 2016) to determine seasonal gains (kg steer^{-1}) and average daily gain (kg steer-1 day-1), calculated as seasonal gain divided by number of grazing days.

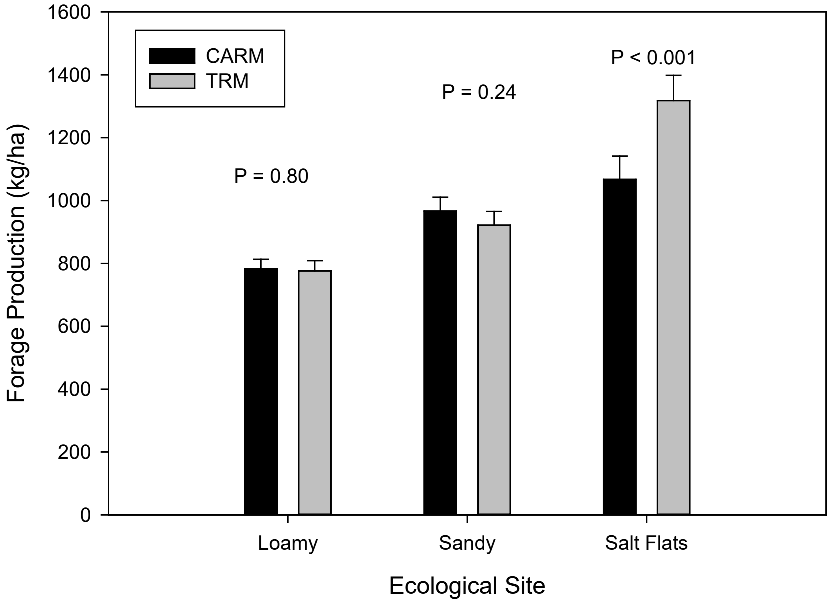
Results

Total production of herbaceous forage (C_3 and C_4 perennial graminoids plus forbs) increased substantially during the wet years of 2014 and 2015, was below average during dry years in 2016 and 2018, and declined to approximately 50% of average production during a drought in 2020. A linear mixed model of annual herbaceous forage production showed no significant 3-way interaction between treatment, ecological site and year ($P = 0.43$; Table 1), a significant treatment x ecosite interaction ($P = 0.0005$), and no treatment x year interaction ($P = 0.31$; Table 1). The only significant contrasts between treatments arose because forage production averaged 19% lower on the salt flat ecosite in CARM compared to TRM, whereas grazing treatment had no effect on the Loamy Plains or Sandy Plains ecosites (Figure 1).

Cattle weight gains

Cattle weight gains in the two grazing treatments were nearly identical in the pretreatment year of 2013. Cattle weight gains were reduced by 13 – 19% in CARM vs. TRM in all of the first 6 years of treatments (2014 – 2019), Averaged across these 6 years, daily weight gains for cattle in CARM were 15% lower than those of TRM (Fig. 2). In the 7th year of the experiment, which coincided with a drought, weight gains were nearly identical in the two treatments (Figure 2).

Figure 1. Comparison of total forage production in CARM and TRM treatments during 2015 – 2020 in shortgrass steppe of northeastern Colorado.



Discussion

Whether adaptive, multi-paddock rotational grazing management strategies can achieve multiple desired ecosystem services on rangelands has proven difficult to evaluate due to the long-term and large-scale dynamics involved (Hawkins et al., 2017; Teague and Barnes, 2017). Recent assessments of the long-term consequences of rotational grazing systems in Australia and Africa found neutral or negative effects on vegetation and livestock production (Badgery et al., 2017; Venter et al., 2018). We similarly found that 7 years of implementation of adaptive, rotational grazing management by decision-makers provided with detailed vegetation and animal monitoring data did not enhance forage production, and resulted in a substantial loss in season-long weight gain of cattle in 6 of 7 years. During the first 6 years, reduced cattle weight gain in CARM was likely the result of cattle grazing at such a high stock density that they foraged less selectively and acquired lower-quality diets. Ongoing analyses of grazing behavior and diet are evaluating these mechanisms. In the 7th year of study, the stock density in the CARM treatment was reduced 50%, by allowing cattle access to two paddocks at any given point in time rather than one. Weight gains were nearly identical between CARM and TRM cattle at the lower stock density (Figure 2). A drought occurred in the 7th year so we are uncertain whether the reduced stock density (which was still 5 times greater than in TRM) was sufficient to eliminate the difference in weight gain, or if the drought led to such poor forage quality across both treatments that no difference in weight gain could arise due to the stock density difference. Future years of study are needed to disentangle these factors.

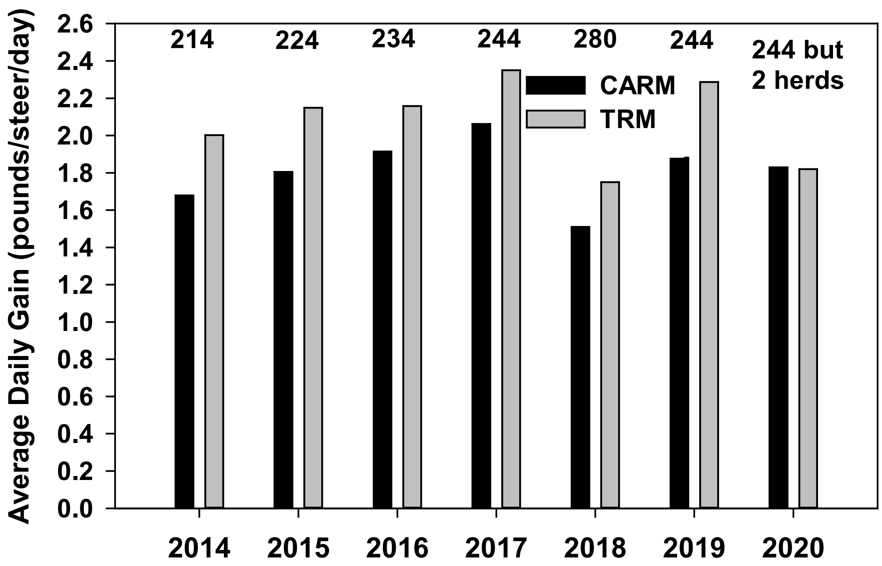


Figure 9. Effect of grazing management treatments on average daily weight gains (kg $steer^{-1}$ day^{-1}) of yearling steers.

The outcomes of CARM appeared to be positive in the absence of direct comparisons to paired TRM paddocks. Forage production increased during the first two years following CARM implementation, the plant community persisted in a desired condition, and stakeholders were able to increase stocking rate during the first four years. These results identify one potential reason multi-paddock rotational grazing may be perceived to benefit rangeland condition. However, when these outcomes were directly compared to those of TRM in an experimental framework, we see that similar forage production was also achieved but with greater cattle weight gains in TRM than with CARM. Our results suggest that rangeland managers seeking to implement adaptive, prescribed grazing to achieve multiple ecosystem services should seek to identify sufficiently low stocking densities to sustain desired livestock weight gains and economic returns.

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