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Understanding producers' perspectives on rotational grazing benefits across US Great Plains

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Abstract

Experimental findings on rotational grazing (RG) trials have generally differed from producer observations of RG outcomes on commercial scale ranches. Factors such as small plot size, short duration trials and relatively rigid grazing management that lacks responsiveness to the dynamic and complex social-ecological systems in grazing trials could all contribute to this disparity in outcomes. These differences call for a better understanding of producer perceptions of RG benefits. To fill this knowledge gap, we surveyed 4500 producers from the Northern and Southern Great Plains of the USA. Among the 875 respondents, 40.5% reported that they used continuous grazing (CG), 52.7% implemented RG management in an extensive manner, while 6.8% adopted management intensive grazing. Compared with CG users, adopters of RG in its extensive and intensive form reported an average annual increase of grazing season by 7.6 and 39.3 days, respectively. When controlling for producer demographics, ranch management goals and other rancher characteristics, we found soil and climate heterogeneity significantly affected the perceived relative benefits of RG *vs* CG strategies. Therefore, instead of focusing on whether RG outperforms CG *per se*, future research could focus on comparison of RG benefits under different management intensity levels and identifying soil and climate conditions where RG benefits are more noticeable.

Introduction

As one of the earth's major land cover types, rangelands play a critical role in sustaining human livelihoods and wellbeing through the production of grazing livestock and the provision of a wide range of ecosystem services, including carbon sequestration (Schuman *et al.*, 2002; Garnett *et al.*, 2017) and biodiversity maintenance (Fuhlendorf and Engle, 2001; Sugita *et al.*, 2007; Godde *et al.*, 2020). In the past several decades, rangeland degradation, mainly attributable to overstocking, improper grazing management, diminished nutrient cycling and changing climate, has become a worldwide concern (Archer and Stokes, 2000; Vetter *et al.*, 2006; Harris, 2010; di Virgilio *et al.*, 2019). To help improve long-term ecological and economic sustainability of rangelands, rangeland research during the past century has primarily focused on identifying proper stocking rate and developing sustainable grazing management strategies (Wang *et al.*, 2018; di Virgilio *et al.*, 2019).

While stocking rate can affect soil health, plant and livestock productivity, maintaining proper stocking rate alone is insufficient to avoid overgrazing and prevent rangeland degradation (Teague *et al.*, 2004, 2013; Barnes *et al.*, 2008; Provenza *et al.*, 2013). In large pastures, livestock demonstrate heterogeneous grazing behavior with preferred areas that have better soils or are close to water and shade being heavily grazed, while other areas are underutilized (Wallis DeVries *et al.*, 1999; Witten *et al.*, 2005; Teague *et al.*, 2011). To minimize overgrazing and reverse rangeland degradation in preferred areas, managing livestock distribution and providing adequate recovery time from grazing are deemed critical (Barnes *et al.*, 2008; Norton *et al.*, 2013; Teague *et al.*, 2013).

Rotational grazing (RG) facilitates the attainment of such management objectives by dividing the grazed area into a number of paddocks with one paddock being grazed while the other paddocks are recovering from prior grazing (Teague *et al.*, 2013). In practice, RG spans a continuum of management intensity levels with greater management intensity typically being associated with more paddocks, shorter grazing period per paddock and longer post-herbivory recovery periods in each paddock (Hanson *et al.*, 1998; Undersander *et al.*, 2002; Foltz and Lang, 2005; Heiberg and Syse, 2020; Wang *et al.*, 2020).

There is evidence that RG with few paddocks per herd, longer grazing periods and shorter recovery periods can result in limited plant and animal production advantages compared to continuous set-stocking at low stocking rates (Briske *et al.*, 2008, Teague *et al.*, 2013). Low stocking rate as well as improperly applied RG strategies do not facilitate degraded resource recovery or provide adequate economic returns over time (Jakoby *et al.*, 2014, 2015; Teague and Kreuter, 2020). Therefore, some grazing research has concluded that there were no improvements in ecological and livestock indicators in RG compared to continuous grazing (CG) and recommended stocking rate adjustment as the primary tool for preventing overgrazing (e.g., Briske *et al.*, 2008). However, grazing management success stories reported at the whole ranch scale are often underpinned by the implementation of adaptive RG strategies (Gerrish, 2004; Provenza *et al.*, 2013; Savory and Butterfield, 2016; Teague and Barnes, 2017; Teague and Kreuter, 2020).

The contextual differences between scientific research and rancher experiences may help explain the apparent conflicts in outcomes. Spatial and temporal scales are frequently noted as important factors in research outcomes. While commercial ranches generally exceed 100 hectares and sometimes cover several thousand hectares, most scientific research is carried out in small field plots, averaging less than 30 hectare with only 14% comparable in size with commercial ranches (Teague *et al.*, 2013; Wolf and Horney, 2016). Compared to controlled experiments in small paddocks, livestock behavior and grazing distribution differ in larger paddocks, thereby affecting plant composition differently (Earl and Jones, 1996; Teague and Barnes, 2017). Due to treatment response time lags, study duration is another factor that likely affects research outcomes. Compared to ranchers' long-term experiences with conservation practices, the duration of most research projects is generally too short to capture the improvement in grass composition and soil health resulting from the improved grazing management (Pinchak *et al.*, 2010; Teague *et al.*, 2011).

Inconsistent use of terminology can also contribute to the result disparities. Some studies simply refer to all practices that involve moving animals as RG. While some studies have used terms such as adaptive multiple paddock grazing, holistic planned grazing and management intensive RG to distinguish the adaptive management emphasis relative to conventional RG, which tends to follow a rigid predetermined rotation schedule, the definition of such terms are often inconsistent among different studies. In most experimental trials, a fixed grazing schedule and set stocking rates are applied without accounting for changing weather conditions and social variables, such as ranchers' goals, knowledge and experience. At the ranch scale, however, holistic or integrative management approaches respond more adaptively to the dynamics of complex social-ecological systems (Roche *et al.*, 2015; Teague and Barnes, 2017; Gosnell, *et al.*, 2020).

Ranchers and researchers often have divergent perspectives, which could also lead to their different perceptions on grazing management practices. Barton *et al.* (2020) found that ranchers prioritized the planning benefits of RG, such as drought planning and increased confidence about uncertainty and risks, rather than the grazing benefits as emphasized by researchers. Roche *et al.* (2015) also pointed out that ranchers adapt grazing management to pursue multiple outcomes, while researchers primarily emphasize only biophysical outcomes in terms of forage production and livestock weight gains at the scale of experimental plots.

To help reconcile the discrepancies between scientific findings and rancher perceptions, it is necessary to reduce their contextual differences. In this regard, studies have utilized producer interviews and surveys to identify their adoption decisions and the benefits and challenges perceived by ranchers regarding RG practices (Stinner *et al.*, 1997; Roche *et al.*, 2015; Becker *et al.*, 2017; Sitienei *et al.*, 2019; Venter *et al.*, 2019; Barton *et al.*, 2020; Heiberg and Syse, 2020; Wang *et al.*, 2020). Among these, Roche *et al.* (2015) inferred that ranchers perceive tangible benefits from RG as indicated by its widespread adoption in California and Wyoming. Additionally, Becker *et al.* (2017) found that North Central Texas ranchers using eight or more paddocks perceived an improvement in the ecological status of their land compared with those using CG. By contrast, Wang *et al.* (2020) identified labor time and water source constraints followed by high installation costs as the main barriers to the adopting RG.

The analyses of producers' perspectives of RG benefits and the challenges they have to overcome to apply RG provide helpful insights. However, very few studies have investigated whether the relative benefits of alternative RG strategies vary under different scenarios (di Virgilio *et al.*, 2019). For example, climate factors potentially influence RG benefits (Teague *et al.*, 2013; Wolf and Horney, 2016; Gosnell *et al.*, 2020). As droughts often exacerbate the disproportionate grazing impacts on palatable and unpalatable grass species (McIvor, 2007), RG benefits may be magnified in lower precipitation areas since it allows post-herbivory recovery of palatable grasses, and can improve underlying soil and ecological functions (Teague *et al.*, 2013). In addition, soil conditions also affect RG benefits and failing to consider soil and slope differences can lead to erroneous conclusions from field experiments (Teague and Foy, 2004).

In this study, we add to the grazing management literature by analyzing climate and soil effects on producers' perceptions regarding RG benefits. Using the experiences from RG ranchers spanning the Northern and Southern extremities of the Great Plains, we examine the effects of soil and climate heterogeneity on producer perceptions of three categories of potential RG benefits: (1) plants—such as increased percentage of desirable grass, length of grazing season and faster drought recovery; (2) livestock—such as increased stocking capacity and improved livestock health; and (3) environmental—such as decreased runoff and soil erosion.

To understand producers' perceptions about the benefits of varying levels of management sophistication with RG, we define extensive RG as systems with 4–15 paddocks per herd with livestock grazing each paddock for weeks to months before being moved to the next paddock. On the opposite end of the continuum, we define management intensive grazing (MIG) as a more sophisticated and management intensive form of RG that incorporates at least 16 paddocks per herd and variable 1–7 days grazing periods followed by variable 20–100 days post-grazing recovery periods depending on management goals and extant weather conditions (Teague *et al.*, 2013). We also analyze how factors such as demographics, ranch management goals and ranch characteristics may affect producers' perceptions of RG benefit.

Methods

Survey description

In 2018, we conducted a mail survey among 4500 producers in North Dakota, South Dakota and Texas. The survey sample was purchased from Survey Sampling International. We used the selection criterion that the selected cattle operations had at least 100 non-feedlot cattle. We selected 1500 producers in each state using this minimum operation size criterion along with proportional sampling to ensure that the number of producers selected per county was proportional to the number of qualified ranching operations in each county.

In North and South Dakota, we included most counties but excluded those toward the west that consist primarily of public lands and forest. In Texas, we included counties from four districts that are primarily occupied by rangeland, including the

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Panhandle, Rolling Plains, Central and West Central districts (agecoext.tamu.edu). Our study areas are located on the northern and southern extremities of the US portion of the Great Plains, which exhibits a distinct north-south increasing temperature gradient and an east-west declining precipitation gradient. Our two study areas encompass these gradients, enabling us to examine differences in potential RG benefit perceptions across varying temperature and precipitation levels.

The mail survey was conducted using a questionnaire that incorporated areas of inquiry such as ranch management practices, perceived benefits and adoption status of extensive RG and MIG, basic ranch information and producer demographics. The survey was administered during late January to early April 2018 using five mailings. These included a pre-survey announcement letter, the survey questionnaire with a cover letter and a reminder/thank you card to all selected landowners, and for those producers who did not return the first survey questionnaire, we sent a replacement questionnaire with another cover letter and a final reminder card (Dillman, 1978). To help boost the response rate, we also mailed a third survey questionnaire to non-respondents in June 2018. We received 875 completed questionnaires from the three states, which represents an overall response rate of 20.6% based on an effective sample size of 4250 producers that excluded 250 ineligible samples (Wang *et al.*, 2020).

Data description

In the survey questionnaire, we asked producers about the plant, livestock and environmental benefits of RG and MIG that they observed on or expected on their own or neighboring ranches. We directed the set of benefit questions to all producers, regardless of their adoption status, so that we not only gather opinions from RG or MIG adopters, based on their observations on their own ranches, but also understand non-adopters' expectations of the benefits, potentially based on their observations from neighborhood ranches. Producers were asked to indicate the benefits by using a four-point rating scale: 1 = None; 2 = Slight; 3 = Medium; and 4 = Significant. Besides the ordinal benefit variables, we also included a continuous dependent variable, i.e., grazing season length, whereby we asked producers to provide the length of their grazing season in a typical year.

RG intensity level adopted by the producers was included as an explanatory variable to control for the influence of adoption decisions. We also included types of cattle operation as explanatory variables because the composition of grass species can vary between cow-calf plus stocker operations and cow-calf only operations (Wilmer *et al.*, 2018). Compared to cow-calf only operations, cow-calf plus stocker operations can adapt more quickly to drought due to their greater capacity to adjust stocking rates by selling stockers.

According to Roche *et al.* (2015), ranchers' goal prioritization affects their perceptions on grazing management successes and failures. Therefore, we asked producers to use a five-point scale to indicate the importance of the goal to improve soil and grassland quality on their land: 1 = Not important; 2 = Slightly important; 3 = Somewhat important; 4 = Quite important; and 5 = Very important.

Given that level of education might also affect the likelihood of adoption of conservation practices, such as RG, we also asked producers to indicate their highest level of education. Choice options ranged from 1 = less than high school to 5 = advanced degree. Non-formal education provided by Extension agencies can also facilitate producers' understanding of the benefits of conservation practices and government agencies, such as the Natural Resources Conservation Service (NRCS), can play an important role in producers' adoption decisions (Kim *et al.*, 2008; Bates and Arbuckle, 2017; Wang, 2019). Producers were therefore asked to use a five-point scale to rate the importance of Extension and government agencies in their decision making: 1 = Not important; 2 = Slightly important; 3 = Somewhat important; 4 = Quite important; and 5 = Very important.

Several operation characteristics were also included as explanatory variables. Leased grassland, which generally associated with no tenure security and limited investment in infrastructure, often does not benefit from RG (Whitson *et al.*, 1982; Wang *et al.*, 2018). Accordingly, we asked producers what proportion of their livestock operation was based on owned and leased land. Additionally, given that RG benefits may depend on operation scale (Wang *et al.*, 2016), we also asked producers to select one of five choice options to indicate their approximate gross sales from cattle enterprises in a typical year: 1 = <\$50,000; 2 = 50,000–99,999; 3 = \$100,000–249,999; 4 = 250,000–499,999; 5 = 500,000–999,999; 6 = \$1 million or more.

We also supplemented producer survey data with land capability class (LCC) and land slope data, obtained for each ranch location from the NRCS's SSURGO database, to capture the potential land quality effect on perceived RG benefits. LCC I refers to land that is highly suitable for crop cultivation, LCC II is land generally suitable for most cultivated crops but may require moderate conservation practices, LCC III and IV is land that requires careful conservation practices such as no-till and cover crops and proper management, and LCC V and above is land that is not suitable for cropping (Klingebiel, 1961). In addition, land with steeper slopes is more susceptible to soil erosion and, therefore, is suited mainly for livestock grazing.

To capture the potential climate effect on producers' perceptions of RG benefits, we also obtained the county level 30-year (1988–2017) average annual precipitation and growing season minimum temperature from the National Oceanic and Atmospheric Administration (NOAA). Finally, to capture regional differences in producers' perceptions of RG benefits, we included a bivariate respondent location variable in which 0 = the Dakotas and 1 = Texas.

Empirical model

Multivariate probit model

We developed an empirical model to understand how producers' perception on RG benefits varies across the US Southern and Northern Plains. To achieve this, we asked producers to indicate their perceptions of RG benefits on their own or neighboring ranches. Producers' responses toward potential benefits of RG take four discrete values with intrinsic order. Since producers' perceptions of RG-related plant, livestock and environmental benefits are likely correlated, we used a multivariate probit model to jointly analyze producers' perceptions of RG benefits in the five different aspects as listed in Table 1.

Following Roodman (2011), the multivariate probit model is defined as:

$$Y_i = \begin{cases} 1, & \text{if} \quad \alpha_{i,0} < Y_i^* \leq \alpha_{i,1} \\ 2, & \text{if} \quad \alpha_{i,1} < Y_i^* \leq \alpha_{i,2} \\ \vdots & \qquad \vdots \\ J & \text{if} \quad \alpha_{i,J-1} < Y_i^* \leq \alpha_{i,J} \end{cases},$$

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Table 1. Description and mean values for the benefit variables, overall and grouped by different grazing strategies

Variable	Description	Mean value			
		Overall	CG	Extensive RG	MIG
Grass	Increased percentage of desirable grass†	3.031	2.672[a]	3.253[b]	3.288[b]
Drought	Increased drought resilience/faster drought recovery†	3.037	2.625[a]	3.273[b]	3.465[b]
Stocking	Increased stocking rate capacity†	2.883	2.643[a]	3.022[b]	3.119[b]
Health	Improved livestock health†	2.703	2.349[a]	2.905[b]	3.085[b]
Erosion	Decreased runoff and erosion†	2.868	2.426[a]	3.121[b]	3.339[b]
Grazing Season	Length of grazing season (days)	218.7	220.1[a]	214.6[a]	242.8[b]

Note: †Producers rated benefits by on a four-point scale: 1 = none; 2 = slight; 3 = medium; 4 = significant. Superscripts are used to denote Duncan's multiple range test results, where the numbers with same letters imply no statistically significant difference exist between the average values in different groups.

where Y_i and Y_i^* represent the observed and latent variables, with $i \in \{1, 2, 3, 4, 5\}$ denotes the five potential benefits associated with RG. Among them, Y_1 and Y_2 are grass-related benefits, denoting increased percentage of desirable grass and increased drought resilience, respectively. Variables Y_3 and Y_4 relate to RG-associated livestock benefits, with Y_3 representing increased stocking rate capacity and Y_4 representing improved livestock health. The environmental benefit is denoted by Y_5, which refers to decreased runoff and erosion. Each of the observed benefit variables Y_i can take J potential values. In our case, $J = 4$, meaning that producers have four different levels of perceived benefits to select from, which are 1 = None, 2 = Slight, 3 = Medium and 4 = Significant.

The latent variable Y_i^* corresponds to the observed variable Y_i through an ascending sequence of cut-points $\alpha_{i,0}, \alpha_{i,1}, \alpha_{i,2}, \cdots, \alpha_{i,J-1}, \alpha_J$ with $\alpha_{i,0} = -\infty$ and $\alpha_J = +\infty$. Note that $Y_i^* = X\beta_i + \varepsilon_i$, where$X$ denotes the vector of explanatory variables, which are the same across all five equations and capture farm-level variances regarding grazing management intensity, cattle enterprise types, producer goal and demographics, farm characteristics, land quality and climate variables (Table 2). The vector of coefficient estimates is denoted by β_i, which measures the effect of the explanatory variable on the expected values of the latent variables, $E(Y_i^*)$. The coefficient is scaled by density function to compute the marginal effect of explanatory variables on the observed variable, $E(Y_i)$ (Greene, 2012).

The error terms ε_i follow standardized normally distributions that are independent on X, i.e., $\varepsilon_i|X \sim N(0, 1)$, but are correlated across equations with correlation coefficient matrix $[\rho_{ik}]_{3\times3}$, where ρ_{ik} denotes the tetrachoric correlation between two latent variables Y_i^* and Y_k^* ($i, k \in \{1, 2, 3, 4, 5\}$). A ρ_{ik} that is significantly different from 0 means that producer perceptions on different benefits Y_i and$Y_k$are correlated.

Ordinary least square model

In addition to the perceived RG benefits, we also asked producers about the length of their grazing season in a typical year, denoted by Y, which is a continuous variable that reflects the length of grazing period for different producers. To estimate the effect of grazing management intensity on Y, we use ordinary least square (OLS) regression, specified as $Y = X\beta + \varepsilon$. Note that X denotes the same vector of explanatory variables as used in the multivariate probit model, as detailed in Table 2, ε is the error term that follows standardized normal distribution that are independent of X and β is the vector of estimated coefficients that measure the effect of the explanatory variables on the expected value of Y.

Results

General statistics description

Table 1 provides the description and mean values for the variables related to RG benefits. Based on the overall mean values, it is apparent that producers perceived higher grass-related than livestock-related and environmental-related benefits associated with RG. The length of the grazing season for all respondents averaged 219 days. To understand differences in producer perceptions according to their grazing strategies, we conducted Duncan's multiple range test for all the benefit variables included in the empirical models. Compared to CG users, both extensive and intensive RG adopters perceived significantly higher benefits in all five benefit categories. On average, RG adopters observed medium to significant benefits in each category except for the livestock health, which averaged just less than medium benefit. Additionally, MIG adopters indicating a significantly longer grazing season than extensive RG and CG adopters.

Figure 1 further shows these differences in perspectives, with RG and MIG adopters grouped into the adopter category and the CG users into the non-adopter category. Compared to adopters, a much higher proportion of non-adopters perceived there is no benefit of RG in all of the listed categories. This lack of benefit perception ranged from 15.2% for grass-quality to 26.8% for livestock health, while over one-fifth of non-adopters perceived significant benefits of RG for drought-resilience (22.9%), grass-quality (23.2%) and stocking capacity (25.2%) but less significant benefits for livestock health (17.8%) and soil erosion reduction (17.1%). In comparison, minimal RG adopters perceived no drought resilience (3.3%) and grass-quality benefits (1.8%), and over 80% of adopters perceived medium to significant grass-quality-related benefits. With respect to livestock, far fewer adopters perceived there to be no or slight benefits for increased stocking capacity (26.9%) and improved livestock health (30.4%), whereas 37 and 31.5% perceived significant benefits regarding stocking rate and livestock health, respectively. With respect to environmental benefits, i.e., decreased runoff and erosion, nearly 80% of the adopters perceived medium or significant benefits, compared to less than 50% of non-adopters.

Table 2 provides the description and summary statistics for all explanatory variables included in the multivariate ordered probit model and OLS model. Of the respondents, 40.5% used CG, 52.7% were extensive RG adopters and 6.8% were MIG adopters. Among them, 20.9% own a cow-calf plus stocker operation, only 2.6% have a grass-finishing operation, while the remainder have

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Table 2. Description and summary statistics for the explanatory variables in the multivariate ordered probit model

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
Extensive RG	1 = extensive RG user; 0 = non-user	874	0.527	0.500	0	1
MIG	1 = MIG user; 0 = non-user	874	0.068	0.251	0	1
Cow-calf and stocker	1 = have cow-calf stocker operation; 0 = do not have it	874	0.209	0.407	0	1
Grass-finishing	1 = have grass-finishing operation; 0 = do not have it	874	0.026	0.160	0	1
Soil/grassland goal	Soil/grassland quality improvement goal (1 = not important; 2 = slightly important; 3 = somewhat important; 4 = quite important; and 5 = very important)	852	4.117	0.797	1	5
Education	Highest level of education (1 = less than high school; 2 = high school; 3 = some college; 4 = 4-year college degree; 5 = advanced degree)	850	3.238	0.966	1	5
Ext. and gov. agency	Importance of Extension and gov. agency in decision making (1 = not important; 2 = slightly important; 3 = somewhat important; 4 = quite important; 5 = very important)	830	2.804	1.130	1	5
Rental ratio	Share of rented grassland	819	0.327	0.344	0	1
Gross sales	Level of your beef cattle enterprise gross sales in a typical year (1 = <$50,000; 2 = 50,000–99,999; 3 = $100,000–249,999; 4 = 250,000–499,999; 5 = 500,000–999,999; 6 = $1 million or more)	833	3.067	1.298	1	6
LCC I and II	Share of land with LCC equal to I and II	867	0.438	0.408	0	1
Slope less than 3%	Share of land slope less than or equal to 3%	867	0.431	0.383	0	1
Temperature	30-year county average growing season minimum temperature (°C)	874	14.64	3.906	8.981	23.67
Precipitation	30-year county average annual precipitation amount (10^3 mm)	874	0.626	0.199	0.137	1.192
Texas	Producer location: 1 = Texas producers	874	0.372	0.484	0	1

cow-calf only operations. Regarding the importance of the goal to improve soil and grassland quality on their land, the average value of 4.117 indicates that most producers rated soil and grassland quality improvement as 'quite important' (Table 2). With respect to the importance of Extension and government agencies, the average rating was 2.804, which indicates that producers generally viewed Extension and government agencies as 'somewhat important' in their decision-making. The mean value of 3.238 for education indicates that most producers have some college/technical school education. On average, about one-third (32.7%) of the rangeland and pasture used for livestock production was leased (Table 2). Annual gross sales of the beef cattle enterprise took six possible values, with the mean value of 3.067 indicating median gross sales of '$100,000–$249,999' (Table 2).

With respect to land quality and slope within 1-mile radius of the location of respondents' farm or ranch, 43.8% of the land was categorized as LCC I to II and the slope of 43.1% of the land is less than 3 degrees. The average annual precipitation across all of the counties included in the study ranged from 137 to 1192 mm with an overall average of 626 mm, while the average growing season minimum temperature ranges from 9 to 24 degrees with an average minimum temperature of 15 degrees. For the Texas variable, the average value of 0.372 indicates that 37.2% of respondents are from Texas and 62.8% are from the North and South Dakota.

Model estimation results

Table 3 presents the coefficient and standard error (SE) estimation results for the multivariate probit model. All of the correlation coefficients, ρ_{ik} (i, k = 1, 2, 3, 4, 5)[1], differ significantly from zero at $P < 0.01$ (bottom of Table 3). This indicates that ranchers' perceived RG benefits in the grass, livestock and environmental categories are significantly correlated with each other, which justifies our use of the multivariate probit model. The marginal effects of explanatory variables on grass, livestock and environmental-related benefits are presented in Tables 4–6. Table 7 presents the results from OLS model. The R^2 value of 0.356 indicates that 35.6% of variability in the length of grazing season can be explained by the included explanatory variables.

As indicated in Table 4, extensive RG and MIG adopters are 20.4 and 20.7%, respectively, more likely to rate significant benefit from increased proportion of desirable grass. Compared to CG users, RG adopters, especially MIG adopters, also perceived significantly greater benefits for drought recovery (Table 4). Specifically, 22.2% of extensive RG adopters and 34.0% of MIG adopters perceived significant greater drought recovery benefits than CG users. Compared with CG users, both extensive and intensive RG adopters are more likely to perceive significantly greater livestock health and stocking capacity benefits (Table 5). Additionally, extensive RG and MIG adoption significantly affects producers' perception on environmental benefits, with extensive RG and MIG adopters being 22.4 and 28.1%, respectively, more likely than CG grazers to perceive significant benefits in decreased runoff and erosion.

The types of operations also affect producers' perceptions about RG-related livestock benefits (Table 5). Compared with

[1]Note that ρ_{ik} stands for the correlation coefficients between benefit i and k, with the benefit numbered Table 3.

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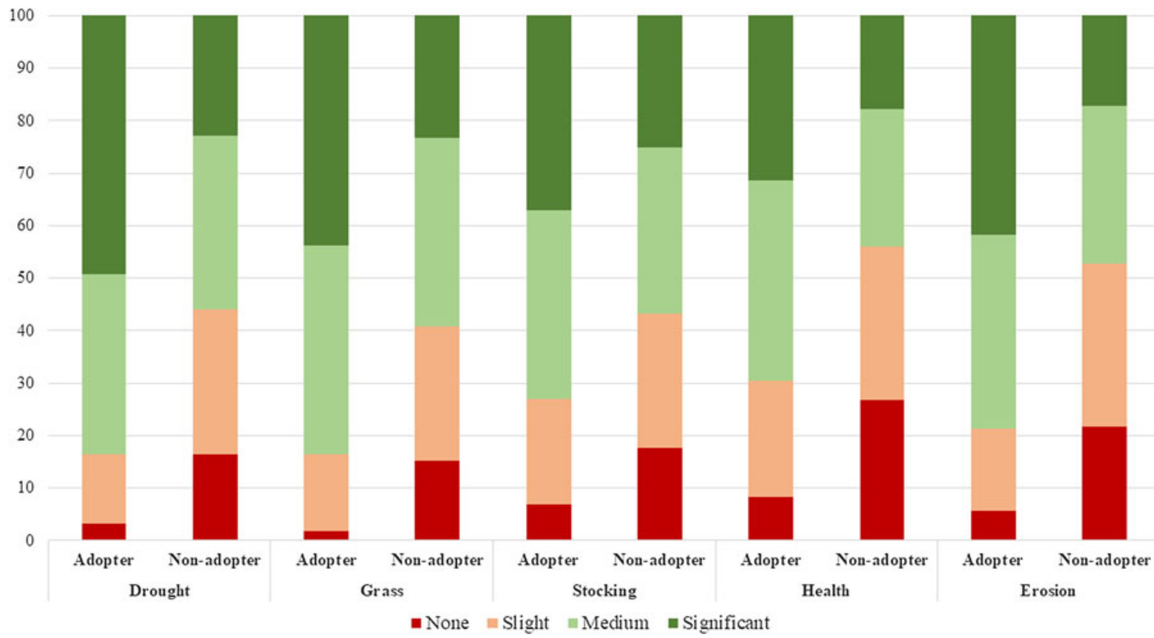

Fig. 1. Percentage of adopters and non-adopters of RG with perceived RG benefits ranging from 'none' to 'significant'. (Note that drought = faster drought recovery; grass = increased percentage of desirable grass; stocking = increased stocking capacity; health = improved livestock health; and erosion = decreased runoff and soil erosion)

cow-calf only producers, integrated cow-calf and stocker producers were 1.0 and 6.4% less likely to perceive medium or significant livestock health benefits, respectively. In contrast, compared to cow-calf only producers, grass-finishing cattle producers were 26.8 and 23.9% more likely to perceive significant RG-related benefits with respect to stocking capacity and livestock health, respectively.

Our research indicated that producers who prioritized soil/grassland quality improvement as a management goal are more likely to perceive significant benefits in all five RG-related benefit aspects (Table 4–6). One unit increase in the importance of the soil/grassland improvement goal led to a 9.7% increase in perceived benefit regarding runoff and erosion reduction (Table 6).

Education is positively related to perceived grass-related and runoff and erosion minimization benefits (Table 3). Specifically, an increase in education by one unit was found to lead to a 2.8% greater likelihood that producers perceive a significant increase in the benefit of desirable grass, and a 3.5% greater likelihood that they perceive a significant benefit in decreased soil runoff and erosion. Compared to formal education, informal education appears to play a more critical role in producers' perceived benefits of RG practices. Specifically, those who view Extension and government agency as important in their decision-making are more likely to perceive significant RG benefits in all benefit categories (Tables 4–6). This implies that by providing educational and technical support, Extension and government agencies may help producers improve their understanding of the RG benefits.

The ratio of leased to owned land is negatively related to producers' perceptions of RG-related benefits; specifically, operators on rented land were 7.4 and 7.1% less likely to perceive significant benefits regarding increased drought resilience and decreased runoff and erosion, respectively (Tables 4 and 6). We also found cattle gross sales, an indicator of herd size, was negatively associated with producers' perceived livestock health benefits of RG (Table 5).

The proportion of land under LCC I and II, which can sustain greater stocking capacity, negatively affects producer perceived RG-associated benefits (Table 3). Specifically, when the proportion of LCC I and II increases from 0 to 100%, producers were 7.4, 6.2 and 7.2% less likely to perceive increased percentage of desirable grass, improved livestock health and decreased runoff and erosion as significant benefits, respectively (Table 4). These findings indicate that producers with poorer quality land are more likely to perceive RG to be beneficial. Flatter land, with a slope of less than 3%, has a positive effect on perceived grass benefit. That is, when the percentage of land with flatter slope increases from 0 to 100%, producers were 8.3% more likely to perceive significant benefit toward increased percentage of desirable grass.

In addition to land attributes, climate and regional factors are also associated with producers' perceived RG benefits. Growing season minimum temperature and precipitation are positively correlated with producers' perceived RG-related grass, drought and environmental benefits. Specifically, as average growing season minimum temperature increases by 1 degree, producers were 3.8, 3.1 and 3.7% more likely to perceive significant increases in desirable grass and drought resilience and decreased runoff and erosion, respectively. Conversely, as average annual precipitation amount decreases, producers were more likely to perceive significant increased RG benefits associated with respect to increased desirable grass, increased drought resilience and decreased runoff and erosion, respectively. Finally, Texas producers were 18.4% less likely than Dakota producers to perceive significant benefits in terms of increased percentage of desirable grass (Table 4), but not with the other four categories of benefits.

We also modeled factors that affect producers' length of grazing season in a typical year. After controlling for the climate and study region, adoption of extensive RG and MIG were found to be associated with 7.6 and 39.3 days of longer grazing seasons per year, respectively, when compared with CG (Table 7). The other factors that were found to be associated with the length of grazing days included land quality, climate and location of the producers.

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Table 3. Estimated explanatory variable coefficients and standard errors for the multivariate ordered probit model

	Grass (1)	Drought (2)	Stocking (3)	Health (4)	Erosion (5)
Extensive RG	0.626***	0.655***	0.299***	0.653***	0.729***
	(0.090)	(0.089)	(0.088)	(0.088)	(0.090)
MIG	0.636***	1.002***	0.351**	0.783***	0.915***
	(0.183)	(0.190)	(0.178)	(0.178)	(0.185)
Cow-calf and stocker	−0.013	−0.132	−0.016	−0.217**	−0.002
	(0.105)	(0.104)	(0.103)	(0.102)	(0.104)
Grass-finishing	0.086	0.417	0.796***	0.810***	0.394
	(0.274)	(0.290)	(0.297)	(0.283)	(0.285)
Soil/grassland goal	0.319***	0.226***	0.121**	0.264***	0.315***
	(0.054)	(0.054)	(0.053)	(0.054)	(0.054)
Education	0.085*	0.027	0.065	0.054	0.115**
	(0.047)	(0.047)	(0.046)	(0.046)	(0.047)
Ext. and gov. agency	0.224***	0.221***	0.246***	0.151***	0.235***
	(0.040)	(0.040)	(0.039)	(0.039)	(0.039)
Rental ratio	−0.056	−0.220*	−0.117	−0.050	−0.232*
	(0.123)	(0.123)	(0.121)	(0.121)	(0.122)
Gross sales	0.032	0.028	0.044	−0.130***	−0.022
	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)
LCC I and II	−0.227*	−0.154	−0.038	−0.209*	−0.234**
	(0.118)	(0.118)	(0.116)	(0.116)	(0.117)
Slope less than 3%	0.253**	−0.012	0.117	0.179	−0.088
	(0.121)	(0.121)	(0.119)	(0.119)	(0.120)
Temperature	0.116***	0.091**	−0.025	0.051	0.121***
	(0.042)	(0.042)	(0.041)	(0.041)	(0.042)
Precipitation	−1.055**	−1.123**	0.114	−0.525	−1.262***
	(0.479)	(0.481)	(0.474)	(0.472)	(0.479)
Texas	−0.565**	−0.304	0.153	−0.372	−0.355
	(0.254)	(0.255)	(0.251)	(0.251)	(0.253)
$\rho_{12>}$	0.691***				
ρ_{13}	0.588***	ρ_{23}	0.593***	ρ_{34}	0.575***
ρ_{14}	0.564***	ρ_{24}	0.614***	ρ_{35}	0.477***
ρ_{15}	0.647***	ρ_{25}	0.733***	ρ_{45}	0.567***
Observations	741			$\chi^2(70)$ = 379.15	
Log-likelihood	−3695.83	_	_	Prob. > $\chi^2(70)$ <0.001	

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

When controlling for other factors, we counterintuitively found that an increase in the share of LCC I and II land from 0 to 100% was associated with a 20-day decrease in annual grazing season. This is probably because higher quality lands, as indicated by higher share of LCC I and II, are likely preferred for cropping than grazing, and producers are likely to use smaller portions of their arable land for shorter periods of grazing with livestock feeding on crop residues, cover crops or winter crops (Kumar *et al.*, 2019). Our study also found that every 1 degree increase in minimum temperature led to a 7.45-day increase in the grazing season. Similarly, grazing season was found to be 11.9 days longer for every 100 mm increase in average annual precipitation. Finally, after controlling for the temperature and precipitation effects, Texas producers reported an average of 54-day longer grazing seasons than Dakota producers did.

Discussion

Overall, the proportion of livestock producers in our study who used RG to manage their forage resources (59.5%) is very similar to that of Pruitt *et al.* (2012), who found that, in 2008, 60.2% of

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Table 4. Marginal effects on grass-related benefits

	Increased percentage of desirable grass				Increased drought resilience			
Potential benefit	None	Slight	Medium	Significant	None	Slight	Medium	Significant
Extensive RG	−0.065***	−0.112***	−0.027***	0.204***	−0.088***	−0.101***	−0.034***	0.222***
MIG	−0.066***	−0.114***	−0.027***	0.207***	−0.134***	−0.154***	−0.052***	0.340***
Cow-calf and stocker	0.001	0.002	0.001	−0.004	0.018	0.020	0.007	−0.045
Grass-finishing	−0.009	−0.015	−0.004	0.028	−0.056	−0.064	−0.022	0.141
Soil/grassland goal	−0.033***	−0.057***	−0.014***	0.104***	−0.030***	−0.035***	−0.012***	0.077***
Education	−0.009*	−0.015*	−0.004*	0.028*	−0.004	−0.004	−0.001	0.009
Ext. and gov. agency	−0.023***	−0.040***	−0.010***	0.073***	−0.030***	−0.034***	−0.011***	0.075***
Rental ratio	0.006	0.010	0.002	−0.018	0.029*	0.034*	0.011*	−0.074*
Gross sales	−0.003	−0.006	−0.001	0.010	−0.004	−0.004	−0.001	0.009
LCC I and II	0.023*	0.041*	0.010*	−0.074*	0.021	0.024	0.008	−0.052
Slope less than 3%	−0.026**	−0.045**	−0.011*	0.083**	0.002	0.002	0.001	−0.004
Temperature	−0.012***	−0.021***	−0.005***	0.038***	−0.012**	−0.014**	−0.005**	0.031**
Precipitation	0.109**	0.189**	0.046**	−0.344**	0.150**	0.173**	0.058**	−0.381**
Texas	0.058**	0.101**	0.024**	−0.184**	0.041	0.047	0.016	−0.103

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

Table 5. Marginal effects on livestock-related benefits

	Increased stocking rate capacity				Improved livestock health			
Potential benefit	None	Slight	Medium	Significant	None	Slight	Medium	Significant
Extensive RG	−0.050***	−0.050***	−0.001	0.101***	−0.137***	−0.087***	0.031***	0.192***
MIG	−0.059**	−0.058**	−0.001	0.118**	−0.164***	−0.104***	0.037***	0.231***
Cow-calf and stocker	0.003	0.003	0.000	−0.006	0.045**	0.029**	−0.010**	−0.064**
Grass-finishing	−0.133***	−0.132***	−0.003	0.268***	−0.170***	−0.108***	0.039**	0.239***
Soil/grassland goal	−0.020**	−0.020**	0.000	0.041**	−0.055***	−0.035***	0.013***	0.078***
Education	−0.011	−0.011	0.000	0.022	−0.011	−0.007	0.003	0.016
Ext. and gov. agency	−0.041***	−0.041***	−0.001	0.083***	−0.032***	−0.020***	0.007***	0.045***
Rental ratio	0.020	0.019	0.000	−0.039	0.010	0.007	−0.002	−0.015
Gross sales	−0.007	−0.007	0.000	0.015	0.027***	0.017***	−0.006***	−0.038***
LCC I and II	0.006	0.006	0.000	−0.013	0.044*	0.028*	−0.010*	−0.062*
Slope less than 3%	−0.020	−0.019	0.000	0.039	−0.037	−0.024	0.009	0.053
Temperature	0.004	0.004	0.000	−0.008	−0.011	−0.007	0.002	0.015
Precipitation	−0.019	−0.019	0.000	0.038	0.110	0.070	−0.025	−0.155
Texas	−0.026	−0.025	−0.001	0.051	0.078	0.050	−0.018	−0.110

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

US beef cow-calf producers reported using some type of RG. Windh *et al.* (2019) pointed out that RG adopters should perceive RG to be economically superior to CG in order to compensate the RG-related capital expenses, opportunity costs and maintenance costs. Like Roche *et al.* (2015), we found that a large majority of RG adopters implemented extensive rather than intensive RG practices. However, unlike the survey region of Roche *et al.* (2015), where Mediterranean climate annual grasslands dominate, our results are based on the experiences of producers' grazing perennial grasslands in the Great Plains and do not support the contention of the Californian researchers that MIG is less beneficial than extensive RG. The MIG producers in our study indicated multiple benefits including high-cost savings through prolonged grazing seasons. Therefore, it is more likely that the low MIG adoption rate is due to the labor and water resource concerns related to intensive grazing management (Wang *et al.*, 2020).

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Table 6. Marginal effects on environmental benefits

	Decreased runoff and erosion			
Potential benefit	None	Slight	Medium	Significant
Extensive RG	−0.123***	−0.098***	−0.003	0.224***
MIG	−0.154***	−0.123***	−0.004	0.281***
Cow-calf and stocker	0.000	0.000	0.000	−0.001
Grass-finishing	−0.066	−0.053	−0.002	0.121
Soil/grassland goal	−0.053***	−0.042***	−0.001	0.097***
Education	−0.019**	−0.015**	−0.001	0.035**
Ext. and gov. agency	−0.040***	−0.031***	−0.001	0.072***
Rental ratio	0.039*	0.031*	0.001	−0.071*
Gross sales	0.004	0.003	0.000	−0.007
LCC I and II	0.039**	0.031**	0.001	−0.072**
Slope less than 3%	0.015	0.012	0.000	−0.027
Temperature	−0.020***	−0.016***	−0.001	0.037***
Precipitation	0.213***	0.169***	0.006	−0.387***
Texas	0.060	0.048	0.002	−0.109

Table 7. Estimate of the effects on length of grazing season

Variables	Coefficient	Std. Error
Extensive RG	7.596*	4.394
MIG	39.27***	8.871
Cow-calf and stocker	−2.478	5.154
Grass-finishing	−9.322	13.21
Soil/grassland goal	2.111	2.667
Education	−3.111	2.301
Ext. and gov. agency	−2.587	1.941
Rental ratio	−2.821	6.094
Gross sales	0.589	1.728
LCC I and II	−20.45***	5.821
Slope less than 3%	−8.486	5.961
Temperature	7.540***	2.066
Precipitation (10^3 mm)	−119.4***	23.65
Texas	53.55***	12.65
Observations = 740	$R^2 = 0.356$; Adj. $R^2 = 0.344$	

Note: ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

Among all the benefits addressed, increased drought resilience is perceived as the most beneficial feature of RG. This finding is consistent with Savory's (1983) description about the particular suitability of holistic management for ecosystems with prolonged dry periods. Given that adjusting stocking rates in a timely manner is essential when coping with drought (Teague *et al.*, 2013), an important benefit of RG, specifically MIG, is that the forage in the smaller paddocks will be depleted more rapidly and noticeably under dry conditions, thereby allowing managers to proactively reduce stock numbers if dry conditions persist (Diaz-Solis *et al.*, 2009). Similarly, we found producers located in drought-prone areas, i.e., those with higher temperature and lower precipitation are more likely to perceive RG-related benefits. In this regard, simulation results also indicated that RG benefits are more apparent under drier weather conditions (Wang *et al.*, 2018), while others also highlight the importance of RG to minimize the negative impacts of droughts (Teague *et al.*, 2013; Jakoby *et al.*, 2014, 2015).

Our finding that RG adopters, especially MIG practitioners, experienced significantly longer grazing season in a typical year is consistent with Undersander *et al.* (2002), who pointed out that, compared to CG, RG relieves grazing pressure during the post-grazing recovery period, which can boost forage yield through rapid regrowth and therefore extend the grazing season. Additionally, Ball *et al.* (2008) noted that longer grazing season is associated with improved livestock performance due to the better forage quality in properly managed pastures than hay that is required when pasture forage is depleted. Longer grazing season implies less hay feeding days, which provides substantial economic benefits as feeding hay is two or three times costlier than grazing livestock on grassland (Julien and Tess, 2002).

Another highly rated benefit perceived by both extensive RG and MIG adopters is increased proportion of desirable grass. This finding is consistent with Lawrence *et al.* (2019), who found that, compared with CG, short-duration RG increased foliar cover of perennial herbaceous species by 19%, and reduced foliar cover of introduced annual plants by 14%, both of which are positive outcomes. Both extensive RG and MIG adopters are more likely to perceive livestock-related benefits, i.e., stocking capacity and livestock health improvement. This result is consistent with findings by Heiberg and Syse (2020) who interviewed beef producers and indicated that MIG improves the land and carrying capacity, which allows more livestock production with less land. Meanwhile, Undersander *et al.* (2002) attributed the enhanced physical fitness of livestock under RG strategy to more frequent herd movement.

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It is noteworthy that nearly 60% of non-adopters in our survey sample perceived medium or significant benefits of RG *vs* CG regarding desirable grass percentage and stocking capacity. This contrasts with the conclusions of some researchers regarding RG benefits for vegetation and livestock production (Briske *et al.*, 2008). Among other factors, climate heterogeneity could affect the relative benefits of RG *vs* CG. For example, Hawkins (2017) found that most studies in areas with less than 400 mm precipitation showed negative or no significant RG benefits on plant basal cover and they concluded that RG is more suitable in areas with moderate or high precipitation. Given that the average annual precipitation in our study area is 626 mm with only 4.23% of the respondents having less than 400 mm rainfall, most of our survey respondents are located in moderate precipitation areas. This could explain the widespread favorable perception of RG on vegetation and livestock-related benefits. The relationship between perceived RG benefits and precipitation level has also been discussed in the context of equilibrium and non-equilibrium models of vegetation change. Sub-humid grasslands, where weather is relatively predictable, are often characterized as equilibrium systems in which herbivory represents a primary driver of these ecosystems (Woodis and Jackson, 2009). In contrast, arid and semiarid grasslands are considered by many researchers to be non-equilibrium systems, the dynamics of which are primarily influenced by highly variable precipitation and frequent droughts, and grazing effects are regarded as less important (Illius and O'Connor, 1999; Oates *et al.*, 2011).

We also found that factors such as operation type, land lease status, herd size and regional factors could affect producers' perceptions and understanding about RG and MIG benefits. Among all operation types, the percentage of grass-finishing livestock producers is low (2.6%), which is consistent with Riely (2011)'s observation that grass-finished beef remains a niche market. As demand for grass-finished beef continues to increase (Acharya *et al.*, 2020), little growth in the supply chain suggests that some underlying barriers, such as lack of policy support, could hinder the expansion of the grass-finished beef sector (DeLonge, 2017). Furthermore, finishing livestock on grass may require producers to acquire additional pastures and skills and to adopt new grazing management strategies including RG or MIG. Our finding that grass-finishing producers perceive greater livestock-related benefits of RG is consistent with Sitienei *et al.* (2019), who found that 97% of the grass-finishing producers they surveyed used RG and 91% indicated that RG is more profitable than CG.

Our findings that leased land negatively affected perceived benefits of RG is possibly because lessees are unlikely to adopt intensified grazing management practices especially if the lease agreement does not encourage them to do so (DALC, 2012), or it could be because the lease agreement is too short for them to benefit from the lagged benefits of RG. Additionally, producers who lease land are not ultimately responsible for the land sustainability (Cox, 2010), and, therefore, might not pay much attention to RG-related benefits such as drought recovery and reduced soil erosion. Our respondents' perception that large herd size is negatively associated with RG-related livestock health benefits may be partially explained by the fact that larger herds are more susceptible to respiratory and gastrointestinal diseases (Hill *et al.*, 2009). Furthermore, larger herd size generally requires more hired labor and poses greater challenges for livestock health inspection (Stahl *et al.*, 1999). Therefore, while RG is often associated with livestock health improvement, this perceived benefit may diminish with herd size.

We also observed regional differences in producers' benefit perceptions, which is consistent with previous studies that found producer willingness to adopt RG, level of RG intensity and perceived RG profitability varied by region (Kim *et al.*, 2005; Pruitt *et al.*, 2012; Jensen *et al.*, 2015; Sitienei *et al.*, 2019). For example, differences in soil quality can affect the advantage of RG relative to CG. Our findings indicate that producers with poorer quality land are more likely to perceive RG-related benefits. Similar to our findings, Sherren and Kent (2019) indicated that MIG is more advantageous in areas with poorer soils that exhibit less soil biota and slower nutrient cycling.

While our study enhanced the understanding of livestock producers' perspectives about RG benefits, it had some limitations and indicated some areas for future research. RG practices span a continuum of intensities; in our study, we include only two categories, extensive RG and MIG. Differentiation of RG into more explicit categories of grazing management intensity and adaptation capacity is important if the benefits and limitations of various types of RG are to be properly understood. Future studies could benefit by incorporating a wider range of RG strategies. Additionally, inclusion of a greater number of MIG adopters and grass-finished beef producers could fill knowledge gaps about the advantages of investing in grazing management intensification. Finally, research about effective information exchange platforms to help non-adopters make more informed decisions and to adopt more intensive grazing management strategies could facilitate improved management of grasslands more broadly.

Conclusion

We surveyed producers from the Northern and Southern Great Plains to understand their perceptions about the benefits of RG and MIG. Among the RG adopters, the majority (89%) implemented the practice in an extensive manner and only 11% adopted MIG. We found that producers who had adopted MIG generally provided higher ratings for RG benefits, but this practice has a low adoption rate indicating that it is underutilized. We also found that producers who prioritized grassland and soil improvement, those with more owned land and those with more formal education perceived significantly greater benefits from RG.

Our results demonstrated that while RG and MIG adopters in our study area perceive greater benefits than do CG producers, a high proportion (nearly 60%) of CG producers also perceived medium or significant benefits of RG in terms of providing faster drought recovery, increasing percentage of desirable grass and increasing stocking capacity. We found that the relative benefits perceived by RG adopters vary across heterogeneous geographic conditions. Specifically, perceived RG benefits were more pronounced in warmer, drier and more drought-prone areas within our survey region, which spanned mostly moderate precipitation areas. These perceived benefits are also more pronounced on poorer quality land that is not suitable for crop cultivation.

Grazing management terminology has generally conflated different grazing management approaches and needs to be refined to compare outcomes of studies that include different RG approaches. Our findings that MIG producers perceive more benefits than extensive RG suggest that lumping studies with low- and high-intensity RG management strategies, as has been done in some review articles, could lead to misleading conclusions about the benefits of RG. Careful definition and differentiation of the RG into more explicit categories of grazing management

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intensity and adaptation capacity is imperative if the benefits and limitations of various types of RG are to be properly understood.

The finding that a high proportion of CG producers also perceived medium or significant benefits related to RG suggests that the primary factors that hinder producers from adopting RG might not be lack of perceived benefits, but rather unresolved resource constraints, including labor and water. Therefore, to overcome potential barriers to RG adoption, technical and financial support and farm demonstrations may be critical. Finally, varying RG benefits across heterogeneous regions suggest that besides addressing the contextual differences between scientific studies and commercial ranching experiences, future research should emphasize the role of soil and climate disparities on the relative benefits of RG grazing strategies, especially MIG. Ultimately, it could be more cost-effective to promote intensified grazing management in regions where its benefits are most pronounced and salient.

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