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RESEARCH ARTICLE

Landowner Perceptions toward Adopting Patch-Burn and Mixed-Species Grazing for Rangelands in the U.S. Southern Great Plains

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Abstract
The sustainability of grazed rangelands can be improved by adopting innovative management practices that enhance the ecological resilience, productivity, and long-term viability of rangeland ecosystems. This study applied a bivariate Multiple Indicator–Multiple Causation model to examine how landowner characteristics are associated with their perceptions concerning patch-burn grazing (PBG) and mixed-species grazing (MSG). Data were collected through a mail survey of landowners in the Southern Great Plains who own at least 100 acres. The significant and positive correlation between PBG and MSG suggests that their relative preference tends to change together, potentially allowing them to complement when implemented together.

Keywords: Bivariate Multiple Indicator–Multiple Causation; diffusion; innovation; mixed-species grazing; patch-burn grazing

Introduction

Rangelands around the world, which include grasslands, savannas, and shrublands, have historically evolved with strong interactions between fire and animal grazing (Bond and Keeley, 2005; Scasta et al., 2016) influencing both livestock productivity and rangeland ecosystems. Traditionally, management strategies for rangelands, which account for about 55% of the U.S. land surface area (Weltz et al., 2003), emphasize optimum livestock production and promote desired forage species to maximize grazing efficiency through the adoption of Best Management Practices (BMPs) (Ortega-S, Lukefahr, and Bryant, 2013; Sliwinski, Burbach, Powell, & Schacht, 2018b; Vallentine, 2001). Traditional grazing management practices, such as rotational grazing, grazing fences, brush control, and herding, focus on homogenizing grazing distribution to maintain uniform cattle productivity (Bailey and Brown, 2011; Fuhlendorf and Engle, 2001). In addition, reduced use of fire and burrowing mammals to promote livestock production has resulted in homogenous rangelands reducing habitat types necessary for a variety of wildlife to thrive (Augustine and Derner, 2012; Freese, Montanye, and Forrest, 2010; Fuhlendorf, Engle, Elmore, Limb, & Bidwell, 2012). However, structurally homogenous rangelands are prone to threats from Woody Plant Encroachment like redcedar and blackberry, uncharacteristic wildfires, overgrazing, and land use change (Berg et al., 2015; Stroman, Kreuter, and Wonkka, 2020; Twidwell et al., 2013).

The rangeland scientific community recognizes that it is of utmost importance to develop multiple innovative management practices that embrace grassland ecosystem heterogeneity to ensure long-term conservation and the provisioning of benefits from natural ecosystems

(Fuhlendorf et al., 2010; McGranahan, Hovick, Elmore, Engle, & Fuhlendorf, 2018). For rangeland management professionals to effectively promote innovative management practices, it is crucial to examine the motivations and barriers behind producers' and landowners' adoption behavior that can potentially enhance rangelands' ecological health and productivity.

Adoption of innovative technologies is influenced by characteristics of the individual (such as age, income, education), innovation attributes (such as compatibility, complexity), and social system (such as attitudes of peers, social norms), among others (Rogers, 2010). Research on voluntary adoption of rangeland management practices suggests that producers and landowners are faced with other adoption determinants such as management costs, regional attributes (such as grassland type, environmental factors) (Saltiel, Bauder, and Palakovich, 1994), and farm characteristics (such as size, ownership) (Bultena and Hoiberg, 1983). Additionally, most studies on the adoption of BMPs and other rangeland management practices generally focus on single-practice adoption, assuming that the decision is made independently of previous or potential future opportunities for adopting additional complementary practices (Holley et al., 2020). Increasingly, rangeland scientists have realized that the adoption of single pasture management practice on private grassland does not promote vegetation heterogeneity (With, King, and Jensen, 2008) and has proven to be detrimental to floral and faunal biodiversity in the rangeland regions (Becerra et al., 2017; Toombs, Derner, Augustine, Krueger, & Gallagher, 2010).

Historically, fire and mixed animal grazing has been an integral part of grassland ecosystems in the Great Plains for maintaining its productivity and heterogeneity for providing diverse habitats (Samson, Knopf, and Ostlie, 2004). Research has shown that mixed animal grazing, when two or more species graze together, can promote animal performance (Wright, Jones, Davies, Davidson, & Vale, 2006), enhance forage quality and biodiversity (Abaye, Allen, and Fontenot, 1994), remove woody plants, and maintain healthy rangelands (Masson, Mesléard, and Dutoit, 2015). Disturbance by fire combined with animal grazing is termed pyric-herbivory. Pyric-herbivory has played an important role in the evolution and resilience of grasslands by promoting heterogeneous vegetation (Fuhlendorf et al., 2010) and can potentially be utilized as a management strategy for the sustainable use and management of rangelands. Therefore, rangeland scientists have recommended management practices of patch-burn grazing (PBG) and mixed-species grazing (MSG) that are known to provide the best results on rangelands (Fuhlendorf, Winter, and Smith, 2013; Morton, Regen, Engle, Miller, & Harr, 2010). Despite the benefits associated with these management systems, widespread adoption remains low (Wilcox et al., 2022). Although their reasonable success in experimental scale plots, broader acceptance, and landowner willingness to adopt PBG and MSG is largely unknown. Therefore, it is crucial to understand the perceptions of landowners towards different attributes of these practices that influence the likelihood of their adoption. In addition, understanding the relative preference among other management options and exploring their substitute and complementary relationships is crucial for designing effective educational outreach and incentive-based policies to enhance voluntary adoption.

This study uses data from a survey of a representative sample of rangeland owners in the Southern Great Plains of the U.S. to understand their perceptions towards three key innovation attributes: compatibility, relative advantage, and complexity of PBG and MSG management practices. We also examined how land and landowner characteristics are associated with the likelihood of adopting PBG and MSG practices. Interestingly, PBG and MSG could complement each other in creating rangeland heterogeneity and controlling woody plant encroachment when carried out together as a set or practice bundles (Hobbs et al., 1991; Morton et al., 2010; Weir et al., 2013). So, it is likely that landowner perceptions towards innovation attributes of PBG are correlated with the attributes of MSG, and the propensity to adopt PBG and MSG could be interrelated as complements.

Our study offers two contributions to the existing literature on adopting best management practices to improve the rangeland conditions in the imperiled grassland biome. First, factors affecting landowner adoption decisions or barriers to adoption of best practices, including

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patch-burn grazing, mixed-species grazing, prescribed fire, and brush control, are avidly discussed in social science-focused research on range management (Adhikari et al., 2023; Kreuter et al., 2008; Meredith, Brunson, and Hardegree, 2021; Toledo, Sorice, and Kreuter, 2013), characters of these innovations have received little attention. Second, previous efforts have been primarily focused on individual strategy, without exploring complementarity between multiple BMPs. The MSG can be incorporated within the recently burned patches of the PBG system, allowing for a diverse range of species interactions and vegetation growth across the rangelands (Wilcox et al., 2022). As research suggests that these practices lead to better outcomes together to control woody plant encroachment (Wilcox et al., 2022), it is imperative to know whether landowner's propensity to adopt one strategy translates to adopting the other. To this end, we have analyzed the potential influence of one set of attributes on others and assessed the relative preference for PBG and MSG.

The bivariate Multiple Indicator–Multiple Causation (MIMIC) framework provides a comprehensive approach to analyze the complex relationships between multiple indicators hypothesized to influence the latent adoption variables while addressing the problem of dimensionality (Holley et al., 2020). The statistical modeling technique focuses on controlling the effects of unobserved interaction components between PBG and MSG perceived by landowners as latent variables. It can examine the association between these latent variables and adopt PBG and MSG as rangeland management practices to understand how producers perceive relative preferences between these two practices. Results from this empirical approach will enable policymakers and pasture management practitioners to understand better how private landowners perceive innovation attributes of alternative management strategies and gauge the likelihood of adopting a single practice or a bundle approach based on relative preferences.

Background

Government agencies and land management practitioners often recommend management practices based on stocking maximization principles to optimize livestock production across grazing lands. From a production economics standpoint, ranchers would continue livestock farming if marginal costs of farm management do not exceed the marginal revenues coming from additional cattle. Nonetheless, efforts are geared towards efficient grazing for livestock productivity as financial and biological conditions impact the economic stocking rates (Frasier and Steffens, 2013). For instance, strategies for prescribed grazing promote forage species that maximize grazing efficiency (Ortega-S et al., 2013; Sliwinski et al., 2018b; Vallentine, 2001). However, such practices have created uniform grazing lands, diminishing the diversity of habitats (Freese et al., 2010; Fuhlendorf, Engle, Elmore, Limb, & Bidwell, 2012). In addition, they fail to consider historical disturbances crucial to rangeland ecosystem health and the maintenance of biodiversity (Fuhlendorf et al., 2009).

PBG and MSG are innovative management practices aiming to improve rangelands' ecological health and productivity. PBG is designed to mimic historical grazing and fire interaction. It involves controlled burning of a portion of a pasture while allowing livestock to graze freely and then burning a different part of the same pasture in the following year (Fuhlendorf et al., 2013). This practice benefits a variety of species of plant and wildlife, promoting biodiversity. Additionally, the nutritious regrowth of recently grown forage provides livestock with higher crude protein and minerals (Satter et al., 2005). Although PBG can benefit grasslands and potentially enhance livestock performance and productivity, specific outcomes can vary depending on the characteristics of grassland, animal species, and overall management practices (Augustine, Derner, and Milchunas, 2010; Limb et al., 2011; Winter, Fuhlendorf, and Goes, 2014). Based on the early work conducted in Oklahoma, the PBG has been identified as an alternative paradigm for range management to increase floral and faunal diversity (Fuhlendorf and Engle, 2001). Several outreach and extension efforts are underway in the state to understand ecological and socioeconomic issues pertaining to this BMP (OSU Extension, 2024).

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MSG is a rangeland management practice where two or more livestock species are grazed together or separately on the same land during a single growing season (Byington, 1985; Glimp, 1988). MSG increases grazing efficiency by facilitating the maximum utilization of all types of forages and also reduces the accumulation of biomass that can control wildfires significantly (Liu et al., 2015; Rouet-Leduc et al., 2021). Different types of livestock can be grazed together; however, a combination of small ruminant grazers such as cattle and browsers such as sheep and goats are highly preferred because they have different preferences for forage (Fraser, 2018). Also, browsers, like goats, feed on the saplings of woody vegetation like Redcedar, threatening rangelands (Archer et al., 2017). As a range management practice, MSG has been found to be common in some parts of Texas, mainly in its Edwards Plateau (Walker et al., 2015).

However, the desired widespread adoption of these practices has not been achieved as expected, and studies have been conducted to analyze the adoption behavior of landowners (Adhikari et al., 2023). The lack of widespread adoption can be attributed to several factors, including traditional management preferences of landowners and ranchers who associate homogenous rangelands with higher agricultural productivity (Becerra et al., 2013; Joshi, Becerra et al., 2017) and may perceive fire as a threat to their livestock, forage resources, and infrastructure (Sliwinski, Burbach, Powell, & Schacht, 2018a).

The Diffusion of Innovation theory explains the adoption process of new practices and is widely applied in communication and innovation studies (Rogers, 2010). The theory explains how new technologies are adopted and spread due to potential adopters' perception of five attributes influencing the adoption rate: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2010; Rogers, Singhal, and Quinlan, 2014). According to Rogers et al. (2014), *relative advantage* refers to the perceived benefits of adopting an innovation compared to the existing practices or alternatives. *Compatibility* refers to the extent to which an innovation is perceived as compatible with potential adopters' values, beliefs, and needs. *Complexity* refers to the perceived complexity of undertaking an innovation. *Trialability* is testing an innovation on a small scale before full adoption. Finally, *observability* refers to the degree to which the benefits of an innovation are readily observable.

The attributes of innovation have been routinely researched in several disciplines, including health (Scott, Plotnikoff, Karunamuni, Bize, & Rodgers, 2008), agriculture (Lavoie, Dentzman, and Wardropper, 2021), engineering (Shah Alam et al., 2008), and natural resources (Mascia and Mills, 2018). Pertaining to the natural resource sector, Mascia and Mills (2018) utilized the Diffusion of Innovation theory to study the technical, cultural, and political characteristics that influence the adoption process of conservation practices. Hedjazi (2007) explored public perception concerning the acceptance of balancing livestock with grazing capacity, which has been adopted as a national project to aid in rangeland promotion in Iran. Noga et al., (2015) employed the theory to investigate how small farmers in the Okavango Delta region, Botswana, perceive and adopt innovative practices that mitigate human-elephant conflicts and minimize crop losses. They found that limited interaction with extension workers hindered awareness and unfavorable perception of some of the innovation practices were significant barriers to adoption for the subsistence farmers.

Landowners have varying motivations, constraints, and readiness levels to adopt new management practices on their rangelands. For example, the widespread adoption of PBG and MSG on lands where livestock production is a primary objective would necessitate substantial reassurance to livestock producers that their production will not be compromised (Winter et al., 2014). To achieve broader social acceptance, it is essential first to understand landowners' adoption behavior comprehensively. Such knowledge will enable targeted outreach and policy initiatives to promote the widespread adoption of these best practices. Thus, this study examines how range landowners perceive the characteristics of PBG and MSG as innovative grazing management practices. Furthermore, the study aims to elucidate their relative preferences and synergetic relationships between two different management practices.

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Table 1. Statements representing three key innovation adoption attributes with means of the degree of agreement measured using a five-point Likert scale (1 = Definitely not true, 2 = Probably not true, 3 = Unsure, 4 = Probably true, 5 = Definitely true)

Variable name	Statements	Means (SD)
	Patch-burn grazing (PBG)	
	Compatibility	
PBG1	Patch-burn grazing is compatible with my rangeland.	2.96 (1.13)
MSG1	Mixed grazing is compatible with my rangeland.	3.21 (1.15)
PBG2	Patch-burn grazing can be conducted with minor changes on my ranch.	2.99 (1.13)
MSG2	Mixed grazing can be conducted with minor changes on my ranch.	2.79 (1.12)
	Relative advantage[a]	
PBG3	Patch-burn grazing is more convenient than my current practices.	2.47 (1.00)
MSG3	Mixed grazing is more convenient than my current practices.	2.27 (0.94)
	Complexity	
PBG4	Patch-burn grazing is difficult to conduct.[b]	3.46 (1.05)
PBG5	I have enough land to practice patch-burn grazing.	3.39(1.11)
MSG4	Mixed grazing is difficult to conduct.[b]	3.33 (0.95)
MSG5	I have enough land to practice mixed grazing.	3.37 (1.08)

PBG = Patch-burn grazing.
MSG = Mixed-species grazing.
[a]Only one statement for "relative advantage" was retained to maintain acceptable range of goodness-to-fit scores (CFI, RMSEA) and cronbaches alpha values.
[b]Reverse coded.

Data

The target population was the private rangeland owners of four states: Kansas, Nebraska, Oklahoma, and Texas. For our sample, a list of names and addresses of random 3,000 landowners (750 for each state), who had more than 100 acres of land, was bought from Dyanta LLC. A mail survey was conducted to collect the required data for the study following the tailored design method protocols suggested by Dillman, Smyth, and Christian (2014). The Institution Review Board of Oklahoma State University approved the procedures and survey instruments used to conduct the study. The survey instrument included an invitation postcard, participant information sheet, 10-paged questionnaire, and reminder postcard. The 10-page questionnaire was developed with the help of rangeland experts. A pilot testing of the questionnaire was conducted with the rangeland owners. The survey was completed in March 2021. We received 523 responses for a response rate of 17.5%. Out of the total responses, 26 respondents did not participate, citing reasons such as they did not own the property anymore, the point of contact was deceased, etc.

The survey questionnaire included five sections. The first section gathered information about the characteristics of landowners and their land. The second section asked about the landowner's experience with prescribed fire, PBG, and MSG. The third section of the questionnaire included statements about the adoption attributes of PBG and MSG, for which respondents showed their extent of agreement or disagreement. Finally, the last section collected demographic information of the landowners. The survey is available from the authors upon request.

In the third section of the survey, statements representing the three key innovation attributes: compatibility, relative advantage, and complexity were used to measure the degree of agreement for each management practice using a five-point Likert scale (Table 1). Two statements

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represented compatibility and complexity while one statement represented relative advantage, totaling five statements for PBG and five for MSG. It is worth mentioning that we included only one statement for each 'relative advantage' attribute to ensure statistical robustness, maintaining an acceptable range of goodness-to-fit statistics (CFI >0.90) and Cornbach's alpha (0.70). The descriptive statistics with the statements used in the survey are provided in Table 1. While a higher degree of agreement for compatibility and relative advantage represents a higher likelihood of adopting the management practice, the case was the opposite for complexity. Therefore, the two complexity statements for each practice were reverse-coded to maintain uniformity in the direction of the degree of agreement between the three key innovation attributes.

Methods and procedures

This study performed a bivariate Multiple Indicator–Multiple Causation (MIMIC) model by introducing two latent variables that simultaneously explain the likelihood of adoption of two management practices—PBG and MSG practices. MIMIC models have been used in the agriculture sector to analyze the efficiency with which inputs are utilized in agricultural production at the aggregate level (Gao and Reynolds, 1994; Richards and Jeffrey, 2000), technology adoption (Borges, Tauer, and Lansink, 2016; Lambert, Paudel, and Larson, 2015), and BMP adoption (Holley et al., 2020). The MIMIC framework is appropriate for representing the utilization of various distinct management practices based on underlying factors (Krishnakumar and Nagar, 2008).

A typical MIMIC model consists of (i) a measurement model defining the relationships between a latent variable and its indicators and (ii) a structural model specifying the effects of causal variables on the latent variable (Holley et al., 2020). Landowner i provides a degree of agreement for different attributes belonging to PBG and MSG. The degree of the agreement provided for the innovation attributes belonging to PBG and MSG may be correlated because of unobserved variables associated with dissonant or complementary attributes. The likelihood to adopt PBG or MSG practices is a system of linear index functions:

$$\begin{bmatrix} \eta_i^p \\ \eta_i^m \end{bmatrix} = \begin{bmatrix} Z_i & 0 \\ 0 & Z_i \end{bmatrix} \begin{bmatrix} \Gamma^p \\ \Gamma^m \end{bmatrix} + \begin{bmatrix} \varsigma_i^p \\ \varsigma_i^m \end{bmatrix}, \tag{1}$$

where $(\eta_i^p,\ \eta_i^m)$ are latent variables (adoption likelihood); Z_i is a $g \times 1$ vector including operator demographic and land characteristics variables (Table 2); $(I^p,\ I^m)$ are conformable vectors of coefficients; and $(\varsigma_i^p,\ \varsigma_i^m)$ are error terms with expected values, correlation (ρ), and variance of

$$\begin{bmatrix} \varsigma_i^p \\ \varsigma_i^m \end{bmatrix} \sim BVN\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix} \right). \tag{2}$$

The variances in equation (2) are normalized to 1 to identify the latent variable component of the bivariate MIMIC model. The ordinal attributes indicators are regressed on the latent variables using the equation system.

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Table 2. Descriptive statistics of landowners' demographics and characteristics of the land

Variables	Definitions	Mean (*SD)
Mixed	Grassland type, coded as 1 for Mixed-grass Prairie, 0 otherwise	0.76
Tall	Grassland type, coded as 1 for Tall-grass Prairie, 0 otherwise	0.11
FSM	Landowner choice, 1 if fact sheets/magazines were chosen to learn about range management, 0 otherwise	0.45
NRCS	Landowner choice, 1 if landowner used NRCS to learn about range management, 0 otherwise	0.37
Uni	Landowner choice, 1 if the landowner used University/County extension to learn about range management, 0 otherwise	0.44
CRedC	Landowner preference, 1 if the landowner wants to control Redcedar, 0 otherwise	0.56
CBBerry	Landowner preference, 1 if the landowner wants to control Blackberry, 0 otherwise	0.22
CostMT50	Average cost, 1 if the average cost per acre to conduct management activities on the rangeland is more than $50, 0 otherwise	0.24
Age	Landowner age in years	67.24 (12.17)
Education	Landowner education, coded as 1 for high school, 2 for high school or GED, 3 for some college, 4 for bachelor's degree, 5 for associate or technical degree, and 6 for graduate degree.	3.80
OK	Landowner resident, 1 if the landowner is from Oklahoma, 0 otherwise.	0.33
TX	Landowner resident, 1 if the landowner is from Texas, 0 otherwise.	0.18

*SD (standard deviation) is only reported for continuous variables.

$$\begin{bmatrix} p_{1i}^{*} \\ \vdots \\ p_{Ji}^{*} \\ m_{1i}^{*} \\ \vdots \\ m_{Ki}^{*} \end{bmatrix} = \begin{bmatrix} \alpha_{10}^{p} \\ \vdots \\ \alpha_{J0}^{p} \\ \alpha_{10}^{m} \\ \vdots \\ \alpha_{K0}^{m} \end{bmatrix} + \begin{bmatrix} \lambda_1^p & 0 \\ \vdots & \vdots \\ \lambda_J^p & 0 \\ \alpha_1^p & 0 \\ 0 & \lambda_1^m \\ \vdots & \vdots \\ 0 & \lambda_K^m \end{bmatrix} \begin{bmatrix} \eta_i^p \\ \eta_i^m \end{bmatrix} + \begin{bmatrix} \varepsilon_{1i}^{p} \\ \vdots \\ \varepsilon_{Ji}^{p} \\ \varepsilon_{1i}^{m} \\ \vdots \\ \varepsilon_{Ki}^{m} \end{bmatrix}, \tag{3}$$

where $(\alpha_{j0}^{p}, \alpha_{k0}^{p})$ are constants, $(\lambda_j^p, \lambda_k^p)$ are factor loadings and the expected values of the $(\varepsilon_{ji}^{p}, \varepsilon_{ki}^{p})$ are 0. The factor loadings correlate the propensity to adopt PBG or MSG practices with the kth or jth degree of agreement for the statement, respectively. The indicator functions (p^{*}, m^{*}) are modeled using the logistic distribution, which means the error variances of the indicator functions are restricted as $\mathrm{Var}(\varepsilon_{ji}^{p}) = \mathrm{Var}(\varepsilon_{ki}^{p}) = \frac{1}{3}\pi^2$, $\mathrm{Cov}(\varepsilon_{ji}^{p}, \varepsilon_{ki}^{p}) = 0$ for identification. The variance–covariance restrictions are the usual assumptions maintained when performing multinomial logistic regression. Cross-equation covariances are mediated through (i) the parameter r in equation (2), and (ii) through the (λ_j, λ_k) factor loadings.

In this research, the degree of agreement for the three key innovation attributes (indicators) is modeled as a single latent variable, conditioned on respondent characteristics, representing the adoption likelihood. Demographic variables and land characteristics were used in the bivariate MIMIC model, along with the degree of agreement for the ten statements. The demographic variables and land characteristics served as the explanatory variables. This approach allows arbitrary correlation between the errors of the two latent variables using propensity scores. Whether the landowners conduct PBG and MSG separately or together, the complementary

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between these practices has been well documented (Cummings et al., 2007; Cummings, Fuhlendorf, and Engle, 2007; Fuhlendorf and Engle, 2004; Scasta et al., 2016). Specifically, both practices are effective in controlling woody plant encroachment and invasive forage species. Therefore, a simultaneous analysis that allows the errors to be correlated makes intuitive sense. The factor loadings capture the relationships between the latent variables and the propensity to adopt PBG or MSG practices. In a bivariate MIMIC model, the variance–covariance restrictions are similar to the assumptions maintained in multinomial logistic regression, where it is assumed that the errors or residuals of the model are uncorrelated and have equal variances. The bivariate MIMIC model was estimated in STATA software using the Generalized Structural Equation Modeling (gsem) command (StataCorp, 2015).

Results

We received 523 responses from the 3000 surveys we sent out, giving us a response rate of 17.5%. There was some variation in the number of respondents across the four states. Among the 523 respondents, 32% of them were from Oklahoma, 28% were from Kansas, 22% were from Nebraska, and 18% were from Texas. The demographic characteristics of landowners across the four states were not statistically different except for their age. The descriptive statistics of dependent and independent variables are provided in Tables 1 and 2. On average, landowners owned about 752 acres of rangeland. The average age of the landowners was 67 years, ranging from 29 to 94 years. About 13, 76, and 11% of the landowners had short-grass prairie, mixed-grass prairie, and Tall-grass prairie, respectively. About 44% of the landowners were individual owners. Fact sheets/magazines (45%), university/county extension (44%), and Natural Resources Conservation Service (NRCS) and US forest service (38%) were the leading sources of information that landowners relied on for effective rangeland management. Redcedar (56%), Blackberry (22%), and sericea lespedeza (21%) were the top three woody species plants that landowners wanted to control on their lands. Over one-fourth, (76%) of the landowners spent less than $25 per acre to conduct all the management activities on their rangelands.

A total of 10 statements, five statements for each PBG and MSG, had a significant impact on latent variables PBG-adopt and MSG-adopt, respectively, with significant factor loadings (Table 3). Among those statements, only around one-third (34% for PBG and 31% for MSG) felt that these best management practices are compatible with their land. More positive perceptions towards the compatibility, relative advantage, and trialability of the practices are found to be associated with a higher likelihood of adoption of the practices (Lavoie et al., 2021; Pannell et al., 2006). The correlation between the two management practices-PBG and MSG was statistically significant and positive. Therefore, the results indicated a complimentary relationship between both PBG and MSG indicating that the relative preference for the two practices tends to increase or decrease together.

Six out of 12 explanatory variables had a significant influence on the relative preference for PBG (Table 3). Landowners learning about rangeland management through NRCS positively influenced the adoption propensity of PBG. Landowners wanting to control blackberries on their land positively impacted the likelihood of adopting PBG. Compared to short-grass prairie, landowners with Mixed-grass prairie were likelier to adopt PBG. Landowners from Oklahoma and those with higher incomes had a positive association with the adoption propensity. Finally, older landowners were negatively associated with the relative preference for PBG.

Similarly, five out of 12 explanatory variables had a significant influence on the relative preference for MSG (Table 3). Having Mixed-grass prairie compared to short-grass prairie was positively associated with the relative preference for MSG. Landowners learning about rangeland management through fact sheets and magazines positively influenced the relative preference and hence adoption propensity of MSG. Landowners who wanted to control blackberries on their land and those from Texas positively impacted the relative preference for MSG. Landowners with

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Table 3. Estimates from bivariate Multiple Indicator–Multiple Causation for patch-burn grazing and mixed-species grazing innovation propensity

Statement	Factor loading	cut1	cut2	cut3	cut4	Causal factors	Coefficients
Patch-burn grazing (PBG-adopt)							
PBG1		−0.98*	−0.18	0.66	1.89***	Mixed-grass	0.27*
PBG2	0.88***	−1.61***	−0.75	−0.04	1.53***	Tall-grass	−0.21
PBG3	0.66***	−0.48	0.52	1.73	2.63	Factsheets	0.09
PBG4	0.28***	−1.78	−0.71	0.17***	1.02***	NRCS	0.25***
PBG5	0.41***	−2.03***	−1.24**	−0.44	0.72	Redcedar	0.05
						Blackberry	0.63***
						Cost >$50k	0.27**
						Age	−0.01***
						Education	0.03
						OK	0.36***
Mixed-species grazing (MSG-adopt)							
MSG1		−1.72***	−0.64	0.02	1.21**	Mixed-grass	0.47***
MSG2	1.014***	−0.80*	0.23	0.90*	2.05***	Tall-grass	0.06
MSG3	0.887***	−1.30***	−0.16	1.11**	1.71***	Factsheets	0.13*
MSG4	0.631***	−1.10**	0.11	1.22**	2.40***	NRCS	0.05
MSG5	0.548***	−1.45**	−0.81	−0.13	1.44**	Redcedar	0.02
						Blackberry	0.12
						Cost >$50k	0.28***
						Age	−0.01***
						Education	0.00
						TX	0.439***
Correlation		0.45***					
Log-likelihood		−5624.67					

Note: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% levels.

higher incomes had a positive association with the relative preference. Finally, older landowners were negatively associated with the relative preference for MSG.

The results from Table 3 were used to calculate percentage changes in log odds associated with each statement that represents the relative preference of PBG or MSG. The percentage changes in log odds were calculated following Lambert et al. (2015) and presented in Table 4. The entries in Table 4 can be interpreted as a percentage change in the log odds of a change in agreement level by one level for a statement given a one-unit change in the covariate. For instance, having a mixed-grass compared to having other types of vegetation was associated with a 31% increase in log odds of an increase in agreement level by one level for compatibility of patch-burn grazing (PBG1). Likewise, an additional year in age was associated with a 1% decrease in log odds of a decrease in agreement level by one level for PBG1.

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Table 4. Percentage changes in propensity odds

Covariates	PBG1	PBG2	PBG3	PBG4	PBG5	MSG1	MSG2	MSG3	MSG4	MSG5
Mixed-grass	31.00	26.82	19.51	7.85	11.71	60.00	61.06	51.72	34.52	29.38
Tall-grass	−18.94	−16.87	−12.94	−5.71	−8.25	6.18	6.27	5.47	3.86	3.34
Factsheets	9.42	8.24	6.12	2.55	3.76	13.88	14.09	12.22	8.55	7.38
NRCS	28.40	24.61	17.94	7.25	10.79	5.13	5.20	4.53	3.21	2.78
Redcedar	5.13	4.50	3.36	1.41	2.07	2.02	2.05	1.79	1.27	1.10
Blackberry	87.76	74.09	51.56	19.29	29.47	12.75	12.94	11.23	7.87	6.80
Cost > $50k	31.00	26.82	19.51	7.85	11.71	32.31	32.83	28.19	19.32	16.58
Age	−1.00	−0.88	−0.66	−0.28	−0.41	−1.00	−1.01	−0.88	−0.63	−0.55
Education	3.05	2.68	2.00	0.84	1.24	0.00	0.00	0.00	0.00	0.00
OK	43.33	37.27	26.82	10.61	15.90	–	–	–	–	–
TX	–	–	–	–	–	55.12	56.07	47.61	31.92	27.20

Notes: Entires are calculated as $100 \times [\exp(\lambda_k.\gamma_k) - 1]$, where $\lambda_k =$ factor loadings of statement and $\gamma_k =$ coefficients of independent variable as reported in Table 3.

Discussion

Our findings are consistent with the literature on adopting BMP and other innovative rangeland management practices. Soule, Tegene, and Wiebe (2000) thoroughly discuss how different types of ownership can impact the adoption of new BMPs, depending on investment requirements and associated short-, medium-, and long-term benefits. Previous research also notes that regulations, access and control, stakeholder engagement, funding opportunities, and cultural considerations vary between ownership types (Baumgart-Getz, Prokopy, and Floress, 2012; Soule et al., 2000). Age is often negatively related to adopting innovative practices, as they may require investment upfront and yield long-term benefits (Baumgart-Getz et al., 2000). Feder and Umali (1993) found that younger and more educated farmers are more likely to perceive higher net returns from new and innovative practices and are more likely to adopt them.

Our findings suggest that elderly landowners had a lower relative preference for both management practices, while those spending more than 50 dollars had a higher relative preference. These findings are consistent with the previous research, which has shown a lack of interest among elderly landowners in the active management of their land (Adhikari et al., 2023, Joshi and Arano, 2009). Since PBG and MSG are known to improve productivity, economic returns, and health of the rangeland system (Fuhlendorf and Engle, 2001; Hintze, Bir, and Peel, 2021), landowners willing to spend more on management activities will likely be interested in those opportunities.

Our findings underscore the importance of education and outreach in promoting PBG and MSG. The decision to invest in new practices or technology, in general, is influenced by the quantity, variety, and reliability of information sources that producers utilize for learning about them (Jenkins et al., 2011). Agencies such as the NRCS and university/county extension have been very actively involved in communicating with landowners about the PBG and MSG. Also, factsheets and magazines are the standard outreach outlets used by these organizations. By providing credible information, educating the farmers, and targeting specific adopters, these outlets can help shape the attitudes and behaviors of clientele toward adopting new management practices (Taylor and Wong, 2002).

The proliferation of woody plants poses a critical threat to the sustainability of rangelands (Archer et al., 2017; Ge and Zou, 2013; Harr et al., 2014). Previous studies have highlighted the

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vulnerability of the Great Plains grassland ecosystems to woody encroachment, necessitating a shift towards a proactive management approach (Knapp et al., 2008; Twidwell et al., 2013). Although range landowners who prefer to control Redcedar in their property did not have strong preferences, those wanting to control Blackberry were more likely to prefer both PBG and MSG. Redcedar trees are difficult to control with prescribed fire after they reach a certain height (Smith, 2011), but fire can be effectively used for other brush control. Blackberry was the second most woody plant that rangeland owners wanted to control on their land (Adhikari et al., 2023). This explains the positive association between the adoption propensities of PBG and MSG with the landowners who want to control woody plants on their land. These findings are similar to previous studies that indicate a tendency to adopt practices that offer immediate advantages rather than those with less obvious benefits but potentially more significant long-term environmental benefits (Gillespie, Kim, and Paudel, 2007; Kim, Gillespie, and Paudel, 2005).

While PBG and MSG offer individual benefits to the landowners, their combined implementation can significantly improve rangeland health by controlling woody plant encroachment (Wilcox et al., 2022). Interestingly, study findings suggest that landowners having positive perceptions about PGB in terms of its relative advantage, compatibility, ease in adoption (less complexity) were found to express similar opinions concerning MSG as well. This complimentary perception is encouraging for university Extension and natural resource management agencies aiming to control woody encroachment in the southern Great Plains. To capitalize on this synergy, outreach programs can target landowners who are open to PBG and guide them with effective MSG implementation as well.

Study results reveal regional differences in respondent preferences for both MSG and PBG. While ranchers traditionally favor homogenous pastures (Fuhlendorf and Engle, 2001), sheep and goats have historically accounted for a significant portion of livestock in the western rangeland of Texas (Wilcox et al., 2012). Likewise, PBG has been at the forefront of natural resource extension programing in Oklahoma (Weir et al., 2013). These factors might have contributed to higher preferences for MSG and PBG among landowners in Texas and Oklahoma, respectively.

Study results have important management implications. As previous results suggest (Lavoie et al., 2021; Pannell et al., 2006), landowners are more likely to adopt innovations that they perceive as less complex and have more relative advantage or compatibility with current practices. In contrast, PBG and MSG's were perceived to have higher complexity and lower relative advantage as a significant number of landowners expressed consternations. For example, almost half (49%) of the landowners did not perceive PBG as more convenient than their current practices. An even higher percentage (61%) of landowners did not think MSG was more convenient than their status quo practices. Since landowners will continue their existing land use practices unless they see significant superiority of innovation (Pannell et al., 2006), exploring techniques that can make MSG and PBG more profitable than existing practices is imperative. A recent study in Oklahoma suggests that MSG with breeding goats resulted in the highest net economic returns (Hintze et al., 2021). Through open-ended responses, landowners provided several qualitative insights that offer useful information for outreach need in our study region. For example, while landowners seem to agree that patch burning and MSG could be beneficial practices, they did not have enough land or time to adopt these. For some landowners, they refrain from conducting prescribed fire as they had past experiences of fire escape. Others suggested that the loss of goats to predators and the cost of fencing did not make it profitable. Multiple landowners reported that the cost of fencing for multi-species was the primary obstacle. In summary, information on MSG and PBG primarily stems from experimental research, more operational analysis with real-world applications is essential to ensure adoption success with these techniques.

One limitation of our study is worth noting. Despite reasonable efforts, our response rate was less than our desired target. Although we have seen a declining trend in survey responses in the natural resources discipline (Aguilar, 2008; Cleary, Joshi, and Fairbanks, 2021;

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Mehmood, Zhang, and Armstrong, 2003; Thompson and Hansen, 2012) and non-response bias analysis did not identify significant concerns, we recommend some caution while interpreting study findings. Likewise, our study was not focused on trialability and observability, which are also essential characteristics of innovation adoption. Therefore, their inclusion in future research would provide additional insights into the adoption behavior of various landowners regarding PBG and MSG.

Conclusions

Rangelands are facing a growing susceptibility to woody encroachment, wildfire hazards, and reduction in diverse habitat types, necessitating a shift towards innovative grazing practices to address sustainable rangeland management. This study utilized the bivariate MIMIC model to process landowners' perceptions in the Southern Great Plains on the innovation attributes of compatibility, relative advantage, and complexity of PBG and MSG into two latent variables representing PBG and MSG adoption propensities, respectively. A better understanding of landowners' perception towards innovation attributes of PBG and MSG and the relative preference for these two management options can inform targeted and effective educational and incentive programs and overcome adoption barriers.

Our findings acknowledge the importance of innovation characteristics in adopting PBG and MSG. Landowners who believed PBG and MSG were compatible with their land imply that they perceived the practices as suitable and appropriate for their specific land characteristics and conditions. Similarly, landowners who saw PBG and MSG as providing a relative advantage compared to their present practices were more inclined to adopt them if they believed it would bring benefits or improvements over their current land management methods. Landowners who found PBG and MSG less complex were more willing to adopt them, suggesting that they perceived PBG and MSG as easier to implement than other practices, making them more likely to consider adopting them. These findings align with prior research indicating that producers and landowners tend to adopt practices offering more immediate benefits than those with less visible but more significant long-term environmental benefits.

Finally, our findings suggest that by recognizing the ecological advantages and positive complementarities that can arise in the combined implementation of PBG and MSG techniques, integrating these practices into broader policy frameworks related to land use, conservation, and agriculture can enhance awareness and foster widespread adoption, including support from policymakers. Targeted incentive-based policies like tax breaks, subsidies, or cost-sharing programs can encourage adoption by mitigating financial challenges associated with transitioning to these management practices. Engaging stakeholders in the decision-making process can facilitate customized management strategies to local contexts and effectively address region-specific barriers.

Data availability statement. Data was collected through a mail survey. The collected data is promised to be kept confidential.

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