5-2021

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Land Use Policy 104 (2021) 105155

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Expanding grass-based agriculture on marginal land in the U.S. Great Plains: The role of management intensive grazing

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A R T I C L E I N F O

Keywords:
Agricultural producer survey
Environment priority
Grazing intensity
Land use conversion
Management intensive grazing
Multivariate ordered probit model

A B S T R A C T

Compared to conventional tillage-based crop production, grass-based agriculture can support substantially more ecosystem benefits. Moreover, management intensive grazing (MIG) has the capacity to enhance grassland resilience, thereby enhancing the profitability of grass-based agriculture. The research reported here is based on a survey of 4,500 producers in the Great Plains of USA, which aimed to study the role of grazing intensity on producers' land use decisions. We received 875 completed questionnaires, representing a 20.6% response rate of 4,250 eligible sample. Results from multivariate ordered probit modeling analysis indicated that, compared to continuous grazing (CG) users, MIG users were 11% more likely to have expanded their grassland area in the past and 13% more likely to convert cropland to grassland in the next 10 years. Other factors, including higher cattle sales, greater liability ratio, poorer land quality and regional factors, were found to significantly influence producers' intentions to purchase and lease more grassland. However, these factors were not significantly associated with the intention to convert marginal land to grassland. Therefore, the adoption of MIG appears to be a key factor for restoring marginal croplands to permanent grassland cover to enhance the environmental benefits across the Great Plains from the social perspective.

1. Introduction

The rapid conversion of ecologically important grassland to marginally productive cropland in the west margins of the Corn Belt of the USA has drawn widespread attention (Lubowski et al., 2006; Claassen et al., 2011; Faber et al., 2012; Lark et al., 2015; Wright and Wimberly, 2013; Wimberly et al., 2017). Conversion of grasslands to tillage-based croplands has been associated with many negative environmental consequences including increased soil erosion (Pimentel et al., 1995), downstream water pollution (Faber et al., 2012), and loss of wildlife habitat (Swengel and Swengel, 2015; Lipsey et al., 2015). Moreover, grassland to cropland conversion, even in the absence of tillage, has led to a significant decrease in soil carbon (Dupont et al., 2010).

Motivations underlying land use changes are multi-faceted but producers have rated economic factors as major drivers of their decision-making (Wang et al., 2017). To a large degree, agricultural producers based their land use decisions on the economic returns to different land use alternatives (Alig et al., 1988; Lubowski et al., 2006). Such profit-driven decision making is also evident in the Conservation Reserve Program (CRP) enrollment rate as high commodity prices tend to induce many producers to withhold their environmentally sensitive land from CRP program (Hellerstein and Malcolm, 2011).

The relative profitability of crop vs. livestock production changes over time according to shifts in market prices (Joshi et al., 2019). In recent years, commodity price declines have reduced profit margins of crop production, especially in marginal growing areas with poor yields. Due to the low revenue and increasing input cost in crop production and a relatively steady cattle market, the grassland to cropland conversion rate dropped significantly from 19.6% during 2007–2012 to 5.2% during 2012–2017 (Wang et al., 2018a) and an estimated 5.7% of South Dakota cropland in 2012 was converted to grassland by 2017.

Utilizing marginally productive land for grass-based agriculture, instead of cropping, is associated with increased environmental and ecosystem benefits. For example, the CRP, which was initially designed to mitigate soil erosion from cropland, has generated large-scale soil health benefits (Li et al., 2017, 2018). In addition, conversion of annually cropped monocultures to perennial grass/legumes can result in

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https://doi.org/10.1016/j.landusepol.2020.105155
Received 6 July 2020; Received in revised form 17 October 2020; Accepted 19 October 2020
Available online 14 November 2020
0264-8377/

higher rates of carbon sequestration (Eagle et al., 2012). Due to the social benefits provided by a well-maintained grassland, many cost-sharing programs are available to help producers protect grassland under the threat of conversion or to offset their initial investment cost on conservation practices. For example, the Natural Resources Conservation Service (NRCS) CRP Grasslands program aims to help landowners to preserve grassland, while maintaining the land for grazing purposes (FSA, 2017). A cost share of up to 50% of the establishment cost can be provided to participants who adopt conservation practices, including rotational grazing (RG). In addition, the Conservation Stewardship Program (CSP) promotes cropland to grass-based agriculture conversion by requiring the establishment of perennial grasses, forbs and/or legume species on former cropland (NRCS, 2017). For those who graze livestock on newly converted grassland to qualify for cost-sharing, CSP requires producers to develop a grazing plan that specifies the number of paddocks to ensure sufficiently short grazing periods and to facilitate root development and post-herbivory recovery of newly established herbaceous plants. Several recently documented stories have indicated that producers used government cost-share programs to fund upfront costs when converting cropland to grassland (Geist, 2019; Millborn, 2019).

Compared with long-term ecological benefits, producers often emphasize the role of enhanced profitability when making land use decisions (Clough et al., 2016). Compared to conventional continuous grazing (CG) grazing management, RG, and especially management intensive grazing (MIG) practices, have the potential to improve grass-based livestock production profits by reducing feed and animal maintenance costs while improving livestock carrying capacity (Stephenson et al., 2004; Wang et al., 2018b). In practice, grazing management approaches can be arranged along a continuum of management intensity. While experimental trials typically have fixed grazing schedule and constant stocking rates, management approaches that respond more adaptively to the dynamics of socio-ecological conditions are more common in commercial ranches (Roche et al., 2015; Teague and Barnes, 2017; Gosnell et al., 2020). Furthermore, unlike the experiment site, paddock sizes in commercial operations can vary substantially. This variation in paddock size, together with grass growth rates, influences the grazing and plant recovery periods. While some studies use the term RG to refer to all practices that involve the movement of livestock among more than one paddock (Briske et al., 2011; Roche et al., 2015), other studies differentiate intensive grazing management approaches from the extensive ones by using terms such as MIG, adaptive multiple paddock (AMP) grazing, holistic planned grazing and so on (Teague et al., 2013; 2015; Barton et al., 2020). In our study, we defined RG practices as those using 4–15 paddocks per herd and retaining livestock in each paddock for "weeks to months" before they are moved to the neighboring paddock. In contrast, we defined MIG as a grazing approach that utilizes 16 or more paddocks per herd and emphasizes short grazing periods in the range of 1–14 days followed by a grass recovery period of 20–100 days.

Periodic resting with RG, in particular MIG, has been shown to decrease negative grazing effects by facilitating recovery of grazed plants. Furthermore, stocking rates can be increased subject to plant growth conditions, as number of paddocks per herd expands, without damaging ecological function (Jakoby et al., 2015; Teague et al., 2015). Both field studies on commercial properties and simulation studies indicate that MIG practice can lead not only to ecological restoration of grasslands but also to larger profit margins and improved income stability (Jakoby et al., 2014, 2015; Stinner et al., 1997; Teague et al., 2013, 2015; Park et al., 2017a, b; Wang et al., 2018b). MIG also tend to economically outperform crop production on marginal land as demonstrated by multi-year experimental data in Adams County, Iowa, where MIG was the most profitable option on highly erodible land with 9–14% slopes while all crop rotations suffered losses (Riley et al., 1997). Moore and Gerrish (2003) also found that MIG provided greater net returns than cropping systems in Missouri, especially on erosive land with poor crop yield potential. Additionally, grazing enterprises, even after accounting for the fencing and water system costs required for RG, incur lower investment costs than cropping enterprises (Moore and Gerrish, 2003; Mitchell et al., 2005). Land converted from cropland or CG grazing to MIG grazing also can result in rapid soil carbon sequestration rates, in one case leading to a soil carbon accumulation rate of 8.0 Mg C ha^{-1} yr^{-1} (Machmuller et al., 2015; Wang et al., 2015). Based on such evidence, MIG practitioners could potentially obtain income from the sale of carbon credits if such a market becomes available (Stephenson et al., 2004).

Even though considerable research has been conducted to determine the potential benefits of RG/MIG on soil carbon sequestration, grassland ecosystem health, livestock productivity, and farm profitability, little research has investigated the effect of RG/MIG management on producers' land use decisions (Stephenson et al., 2004; Stinner et al., 1997; Teague et al., 2013, 2015; Jakoby et al., 2014, 2015; Machmuller et al., 2015; Wang et al., 2015, 2016, 2018b; Park et al., 2017a, b). In addition, no study has analyzed factors that influence producers' decision making regarding the expansion of grass-based agriculture on marginal land. Here we present the results of a producer survey in the Southern and Northern Plains of the USA. This study aimed at investigating the role of grazing management intensity on producers' past and future land use decisions. We compare low intensity grazing management, CG, with moderate intensity grazing management, RG, and high intensity rotational grazing management, MIG. A multivariate ordered probit model is utilized to analyze producers' past and future grassland decisions. Specifically, we investigate the effect of grazing management intensity on changes in grassland acres during the previous ten years and on producers' intentions to convert more cropland to grassland and/or to purchase more grassland during the next ten years. We also examine the effect of producers' emphasis on profit- versus environmental-oriented management goals on their land use decisions. Other factors were also incorporated in the multivariate probit model as explanatory variables that potentially affect producers' decisions to expand grass-based agriculture on marginal land: these include climate and soil conditions, financial constraints, and perceived importance of Extension and government agencies in their decision making.

2. Materials and methods

2.1. Conceptual model

We denote cropland profit function as $\pi_c(q)$, where q denotes land quality, and grassland profits for RG and CG users as $\pi_g^1(q)$ and $\pi_g^2(q)$, respectively. As RG increases forage availability and therefore enhances stocking capacity and profitability, we assume that $\pi_g^1(q) > \pi_g^2(q)$ under all possible land quality q. Both cropland and grassland profit functions are increasing and concave in land quality q. For land that is of sufficiently high quality for crop production, we assume that the profit of cropland prevails, i.e., $\pi_c(q) > \pi_g^1(q) > \pi_g^2(q)$, while for marginal land that is unsuitable for crop production, we have $\pi_g^1(q) > \pi_g^2(q) > \pi_c(q)$.

For simplicity, the conversion cost between different land uses is not considered in this model. We also assume that market prices received by all producers are the same. For a producer who base land use decisions on profitability alone, the land use conversion thresholds for RG and CG users are denoted as $\widehat{q}_r$ and $\widehat{q}_c$, respectively with $\pi_g^1(\widehat{q}_r) = \pi_c(\widehat{q}_r)$ and $\pi_g^2(\widehat{q}_c) = \pi_c(\widehat{q}_c)$ (Fig. 1). We can see that the conversion threshold for RG is greater, i.e., $\widehat{q}_r > \widehat{q}_c$. At land quality between $\widehat{q}_c$ and $\widehat{q}_r$, CG users will perceive higher profitability for crop production, and therefore use the land for cropping purpose, while RG users would prefer grassland over cropland. From this we can infer that, holding land quality constant, RG users are more likely than CG users to convert cropland to grassland and, given that higher intensity grazing management generates larger profit margins than RG with fewer paddocks per herd (Jakoby et al., 2015; Teague et al., 2015), MIG users are even more likely to covert cropland

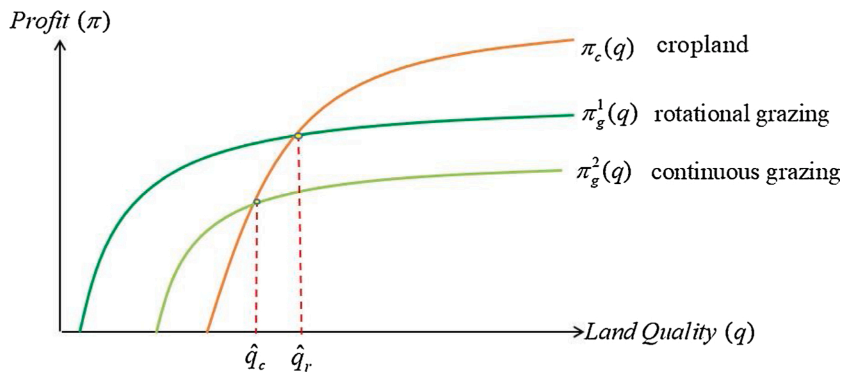

Fig. 1. Different conversion thresholds for producers using different grazing practices.

to grassland. Therefore, assuming that land quality has the same probability distribution for all producers, we hypothesize:

Hypothesis 1. *Ceteris paribus*, producers utilizing higher intensity grazing management practices are more likely to convert cropland to grassland.

The logic behind this hypothesis is that, given that grazing management intensification helps improve the profitability of grassland thereby making it a more competitive land use option when compared to cropland, producers who use higher intensity management are more likely to convert some of their cropland to grassland due to the profit advantage of the efficiently utilized grassland. In addition, most producers do not derive utility from economic benefit alone, but also from environmental benefits (Bastian et al., 2002). Therefore, we denote the utility of a representative crop or grassland producer as $U_i(q) = w\pi_i(q) + (1-w)e_i(q)$ $(i = c, g)$, where w is the weight associated with monetary profit generated from either cropland or grassland, π_i,[1] and $1 - w$ is the weight associated with the environmental benefits, e_i. Assume that regardless of land quality, the environmental benefits associated with grassland is always greater than cropland, i.e., $\forall q$, $e_g(q) > e_c(q)$.

If we assume that $\pi_c(\widehat{q}) = \pi_g(\widehat{q})$ at land quality $\widehat{q}$, then for producers who derive utility solely from profit, i.e., $w = 1$, the land use conversion threshold is $\underline{q} = \widehat{q}$, with $U_c(\underline{q}) = U_g(\underline{q})$. For producers who also derive utility from soil, water and wildlife habitat improvement, i.e., $w \in (0,1)$, the conversion threshold is $\overline{q} > \widehat{q}$, where $U_c(\overline{q}) = U_g(\overline{q})$ but $\pi_g(\overline{q}) < \pi_c(\overline{q})$. We can infer that compared to profit-oriented producers, environment-oriented producers have a greater likelihood to convert to grassland or maintain grassland usage at a lower profit. Therefore, assuming that land quality for all producers has the same probability distribution, we have:

Hypothesis 2. *Ceteris paribus*, producers who are more environment-oriented are more likely to convert cropland to grassland, while those who are more profit-oriented are less likely to do so.

2.2. Empirical model

The main goal of our empirical model is to use the Southern and Northern Plains producer survey data to investigate the role of grazing management intensity and management goals on agricultural producers' past and future land use decisions. Producers' survey responses regarding their past and future land use and herd expansion decisions take values with intrinsic order. Furthermore, producers' past and future land use decisions are generally interrelated. Therefore, we used a multivariate probit model to jointly analyze producers' past and future grassland decisions. The model is specified as:

$$\begin{aligned} Y_1^* &= \beta'_1 X + \varepsilon_1; Y_1 = j \text{ if } Y_1^* \in (\alpha_{1,j-1}, \alpha_{1,j}], \\ Y_2^* &= \beta'_2 X + \varepsilon_2; Y_2 = j \text{ if } Y_2^* \in (\alpha_{2,j-1}, \alpha_{2,j}], \\ Y_3^* &= \beta'_3 X + \varepsilon_3; Y_3 = j \text{ if } Y_3^* \in (\alpha_{3,j-1}, \alpha_{3,j}]. \end{aligned} \quad (1)$$

We denote the rancher decision categories by Y_i and its latent variables by Y_i^* $(i = 1, 2, 3)$, where Y_1 denotes the producers' observable decisions on grassland area changes, attributable to either grassland purchasing/leasing and cropland conversion during the past 10 years, while Y_2 and Y_3 denote the ranchers' grassland purchasing/leasing and cropland to grassland conversion intentions, respectively, during the next 10 years. In our context, we have all three dependent variables taking three possible values with more details provided in the data description section, therefore $j = 1, 2, 3$. Note that we asked producers only to indicate their overall change in grassland area in the past (Y_1) whereas we asked them separately about their future intentions regarding grassland purchasing/leasing and cropland to grassland conversions (Y_2 and Y_3). The vector of explanatory variables is denoted by X. The same explanatory variables are included in three models to capture farm-level variances regarding intensity of grazing management, producers' different emphasis on profit- vs. environmental-oriented goals, producer demographics, farm characteristics, land quality and weather-related variables. The vector of coefficient estimates, β_i' with $i \in \{1, 2, 3\}$ measures the effect of the i^{th} explanatory variable on the expected values of the latent variables, $E(Y_i^*)$, e.g., $\partial E(Y_i^*)/\partial X = \beta_i'$. To compute the marginal effect of explanatory variables on the expected adoption decisions, $E(Y_i)$, we use the coefficient scaled by density function (Greene, 2012). To calculate the average marginal effect for the sample, we computed the density at each observation and then calculated the mean of the individual effects.

We assume that the error terms of model (1), ε_1, ε_2, ε_3, follow standardized multi-variate normal distributions with correlation coefficient matrix $[\rho_{ik}]_{3\times 3}$, where ρ_{ik} $(i, k = 1, 2, 3)$ denotes the tetrachoric correlation between two latent variables Y_i^* and Y_k^*. If ρ_{ik} is significantly different from 0, then we can conclude that ranchers' observable decisions of Y_i and Y_k are interrelated, which then justifies the use of the multivariate probit model.

2.3. Survey description

To understand ranchers' grazing management practices and their land use decisions, we conducted a mail survey of producers in North and South Dakota and in Texas, which represent the northern and southern extremities of Great Plains of USA. In North and South Dakota, we included 49 and 58 counties, respectively, excluding only those that are primarily occupied by forest and public lands. In Texas, we chose 81 counties from four districts located primarily in rangeland areas for inclusion in the study; these included the Panhandle, Rolling Plains, Central and West Central Districts. In each state, 1,500 producers with at

[1] For simplicity, here we assume grassland profit, $\pi_g(q)$, is generated from the optimal grassland management strategy.

least 100 non-feedlot cattle grazing on perennial grassland were randomly selected using proportional sampling methods based on the number of ranching operations in each county. The survey sample was purchased from Survey Sampling International (SSI).

The mail survey was conducted using a questionnaire that incorporated five key areas of inquiry including: 1) ranch operation details; 2) land use and ranch management practices; 3) perception and adoption status of RG or MIG, 4) RG or MIG related issues, and 5) standard demographic information. The survey was administered during late January to early April 2018 using five mailings including an advanced survey announcement letter, the survey questionnaire with a cover letter and a reminder/thank you card to all selected landowners, and then a replacement questionnaire with another cover letter and a final reminder card to landowners who had not responded (Dillman, 1978). Additionally, a third survey questionnaire was mailed to non-respondents in June 2018 to boost the response rate. Of the 4,500 mailings, 250 were ineligible due to undeliverable addresses, addressee no longer operating a cattle operation, or addressee decreased, resulting in an effective sample size of 4,250 producers. We received 875 completed questionnaires from the three states, which represents an overall response rate of 20.6%. Fig. 2 demonstrates the number of respondents from the sampled counties in North Dakota, South Dakota and Texas. More detailed description about the survey and survey region can be found in Wang et al. (2020).

To understand the representativeness of respondents among survey population, we used the purchased information from the SSI and compared grassland acreage and beef cattle numbers among respondents and non-respondents. While the grassland acreage for the respondents (2,120) were significantly greater than the non-respondents (1,660) ($t = 2.93$, $p = 0.0035$), the average number of beef cattle owned by respondents (322) and non-respondents (331) were not statistically different ($t = 0.60$, $p = 0.5506$).

3. Results and discussion

3.1. Data description

Table 1 presents the percentage of CG, RG and MIG users under different categories of land use decisions for the preceding and future 10-year periods. For the preceding 10 years change in acres of grassland, survey participants could select one of the five response options: decreased by >10%; decreased by 5–10%; about the same; increased by 5%–10%; and increased by >10%. Due to a minimal number of respondents choosing the two decreasing categories, we combined the first three categories into 'no increase'. Table 1 shows that only 47.4% of MIG users reported no increase in grassland acres during the preceding 10 years ($Y_1 = 1$) compared to 70.2% of CG users. Moreover, the proportion of MIG users who reported an increase in their grassland acres is higher than those of RG and CG users with 31.6%, 21.5%, and 15.5% of MIG, RG and CG users, respectively, reported >10% increase ($Y_1 = 3$). Based on these results, we can deduce a positive correlation between management intensity and increase in grassland acres during the preceding 10-year period.

With regards to the future 10 years' decisions regarding grassland purchasing/leasing (Y_2) and cropland to grassland conversion (Y_3), survey participants could also choose one of five response options, those being very unlikely, unlikely, somewhat likely, likely, and very likely. Due to the relatively few respondents who selected 'likely' or 'very likely', we combined the three upper categories into one category that is referred to as 'likely'. Table 1 reports intention to increase grassland acreage during the forthcoming 10-year period, through either purchasing/leasing or cropland to grassland conversion by indicated three likelihood categories, for CG, RG and MIG producers. As with the preceding 10-year period, the proportion of respondents that indicated such intention was positively correlated with grazing management intensity. Importantly, whereas 26.7% of CG users stated it is likely they would convert cropland to grassland ($Y_3 = 3$), over a third (35.5%) of RG users, and nearly half (48.3%) of MIG users expressed this land use conversion intention.

Table 2 provides a summary of statistics for all explanatory variables included in the empirical model. Among these, RG and MIG adoption are binary dummy variables for which 1 indicates adopters and 0 indicates non-adopters. In the survey questionnaire, producers were asked to select their adoption status with respect to RG or MIG, as previously defined. Among all respondents, over half (52.7%) were RG adopters and only a small proportion (6.8%) were MIG adopters. These two dummy variables were included to test **Hypothesis 1** that producers utilizing higher grazing management intensity are more likely to expand grassland-based agriculture due to higher profitability on grassland.

An environment priority variable, measuring producers' relative priority on environment vs. profit, is included to test **Hypothesis 2** that producers with a higher relative priority on environment goal are more likely to convert cropland to grassland. Specifically, we asked producers to rank the importance of two environmental and two profit-related goals: improving soil and grassland quality; improving water quality and wildlife habitat; maintaining high economic returns each year; and breeding high quality livestock. For each item, survey participants were provided with five choice options, including not important, slightly important, somewhat important, quite important and very important, which were numerically quantified using scores of 1–5, respectively. We found the added score for the two environmental goals averaged 7.89, while the added score for two profit goals averaged 8.29, with the correlation between two goals as 0.453 ($p < 0.0001$). Due to the significant correlation between these goal variables, including them separately will introduce undesirable multi-collinearity in the model. For our modeling purpose, the added score for the two environmental goals was compared with the added score for two profit goals, and when the former was less than, equal to or greater than the latter, the environment priority variable was quantified as 0, 1, and 2, respectively. The overall average value of 0.778 in Table 2 indicates that, on average, respondents viewed environment goals as less important than profit goals, but there was substantial variability among them (the mean being similar to the standard deviation).

Extension play an important educational role in producers' understanding and adoption decisions of conservation practices (Bates and Arbuckle, 2017; Wang, 2019). In addition, producers' adoption of conservation practices, including cropland to grassland conversion and RG or MIG, can be facilitated by the NRCS through programs such as the CRP Grasslands and CSP (Kim et al., 2005; FSA, 2017; NRCS, 2017). Therefore, we postulate that producers who view Extension and NRCS as more important in their decision making are more likely to convert marginal cropland to grassland. Producers were asked to rate the importance of Extension and government agencies (such as NRCS) in their conservation adoption decisions by using a five-point importance scale (1 = not important, 2 = slightly important, 3 = somewhat important, 4 = quite important and 5 = very important). The median rating was 3 for both Extension and government agencies, indicating producers view them as somewhat important. As the two variables are highly correlated ($r = 0.635$), we averaged the two response values to obtain a single variable, Extension and government agency.

Operation and producer characteristics variables were also included in the model. We postulated that older producers are less likely to convert cropland to grassland due to stronger inertia towards the current practice (Wang, 2019). It has also been shown that an increase in cattle gross sales lead to an expansion of grassland-based agriculture in concert with the trend of specialization (Russelle et al., 2007; Dimitri et al., 2005). Annual gross sales of the beef cattle enterprise were assigned one of six discrete values (Table 2) with a median value of 3 representing \$100,000-\$249,000. We also postulated that producers with a higher liability ratio (ratio of total liabilities to total assets) are more likely to expand grassland-based agriculture due to the lower investment cost associated with livestock than crop production (Moore and Gerrish,

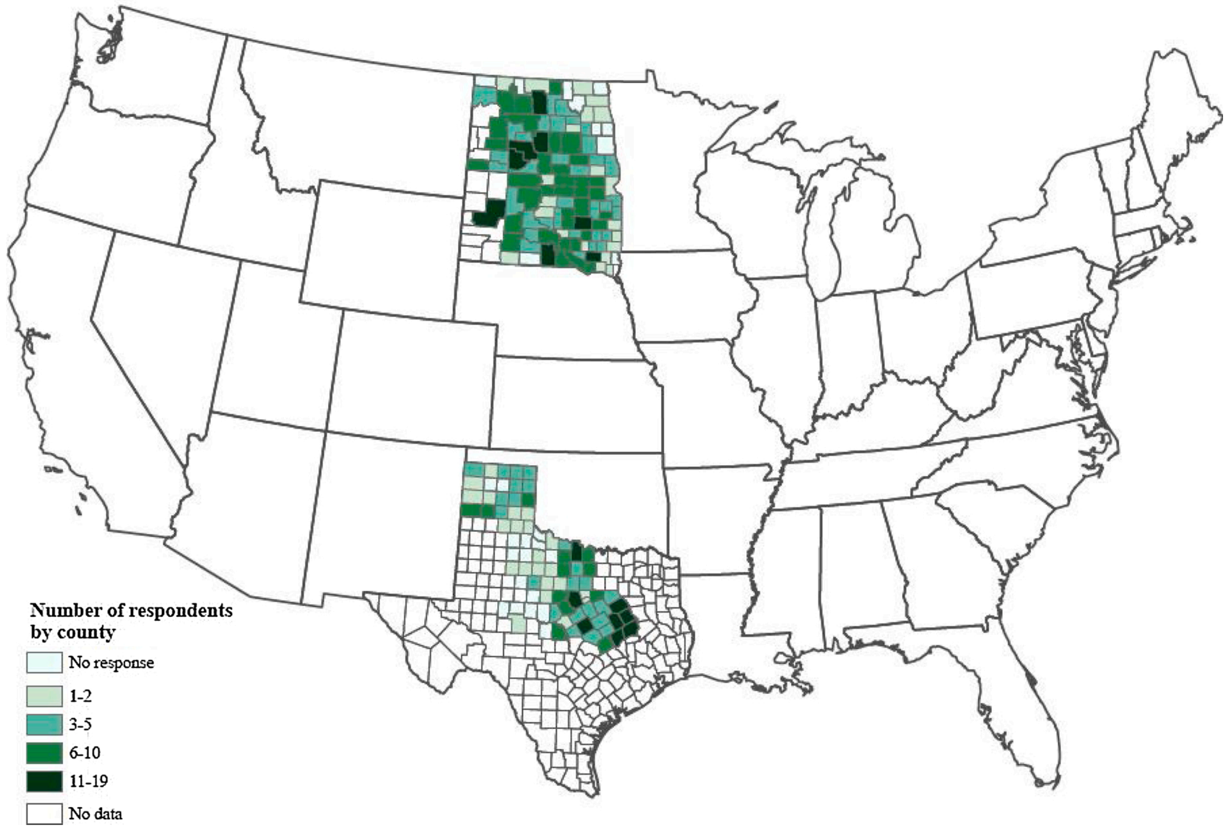

Fig. 2. Distribution of survey respondents in North Dakota, South Dakota and Texas.

Table 1
Percentage of CG, RG and MIG users under different grassland acres change categories, past and future.

	Prob ($Y_i = 1$)			Prob ($Y_i = 2$)			Prob ($Y_i = 3$)		
	CG users	RG users	MIG users	CG users	RG users	MIG users	CG users	RG users	MIG users
Past 10 years		No increase			Increased by 5–10%			Increased by >10%	
Grassland acres change (Y_1)	70.2%	63.0%	47.4%	14.3%	15.5%	21.1%	15.5%	21.5%	31.6%
Future 10 years		Very unlikely			Unlikely			Likely	
Purchasing/leasing more grassland (Y_2)	24.1%	21.0%	17.9%	32.9%	32.2%	26.8%	43.0%	46.8%	55.4%
Cropland to grassland conversion (Y_3)	33.7%	26.1%	15.5%	39.6%	38.4%	36.2%	26.7%	35.5%	48.3%

Note: Y_i ($i = 1, 2, 3$) are the dependent variables in the multivariate ordered probit model. For Y_1, 1 = 'no increase', which includes three sub-categories: 'decreased by >10%', 'decreased by 5–10%' and 'about the same'; 2 = 'increased by 5%–10%' and 3= 'increased by >10%'. For Y_2 and Y_3, 1 = 'very unlikely', 2 = 'unlikely', and 3 = 'likely' (various degrees), which includes three sub-categories: 'somewhat likely', 'likely', 'very likely'.

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

Variable	Description	Obs.	Mean	Std. Dev.	Median	Min	Max
RG adoption	RG adoption status: 0 = non-RG user; 1 = RG user.	874	0.527	0.500	1	0	1
MIG adoption	MIG adoption status: 0 = non-MIG user; 1 = MIG user.	874	0.068	0.251	0	0	1
Environmental Priority	Environmental goal vs. profit goal: 0 = profit-oriented; 1 = indifferent; 2 = environmental-oriented.	874	0.778	0.787	1	0	2
Age	Age of the primary operator	844	64.581	11.039	65	19	94
Extension & gov. agency	Importance of Extension & 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	3	1	5
Gross sales	Gross sales from beef cattle enterprise: 1=less than \$50,000; 2 = \$50,000 to \$99,999; 3 = \$100,000 to \$249,999; 4 = \$250,000 to \$499,999; 5= \$500,000 to \$999,999; 6 = \$1 million or more.	833	3.067	1.298	3	1	6
Liability ratio	Ratio of total liabilities to total assets: 1 = 0%; 2 = 1–20%; 3 = 21–40%; 4 = 41–60%; 5 = 61–80%; 6 = more than 80%.	791	2.622	1.299	2	1	6
Slope less than 3%	Share of land slope less than or equal to 3%	867	0.431	0.383	0.330	0	1
LCC I to IV	Share of land with LCC equal to I, II, III and IV	867	0.751	0.321	0.949	0	1
Precipitation (10^3 mm)	30-year county average annual precipitation amount (1988–2017)	874	0.626	0.199	0.566	0.137	1.192
Texas	Producer location: 1 =Texas producers, 0 =producer from Dakotas	874	0.372	0.484	0	0	1

2003). The liability ratio also was assigned one of six discrete values (Table 2), with the median value being 2 representing 1%–20% of liability ratio.

We included land capability class (LCC) and land slope as explanatory variables, postulating that producers with better land quality are less likely to convert cropland to grassland. Both slope and LCC data were obtained from NRCS SSURGO.[2] LCC I to IV means that the land is generally suitable for cultivated crops, while land with LCC V and above is not suitable for cropping (Soil Conservation Service, 1961). Generally, slopes of less than 3 degrees represent land that is best suited for cropping, while land with steeper slopes is more likely susceptible to soil erosion and therefore less suitable for cultivation. Within 1-mile radius of the location of respondents' farm or ranch, three quarters (75.1%) of the land was determined to be LCC I to IV but less than half (43.1%) was determined to have a slope of less than 3 degrees. This indicates that over half of the respondents' land is not ideal for cropping.

The 30-year (1988–2017) average annual precipitation was also included in the Multivariate ordered probit model. Precipitation data for counties where the respondents were located were obtained from the National Oceanic and Atmospheric Administration (NOAA). The average annual precipitation across all of the counties included in the study ranged from 137 mm to 1192 mm with an overall average of 626 mm. We also included the variable Texas in the model to capture possible land use decision differences between survey respondents in Northern and Southern Plains. This variable takes binary values, with 1 representing respondents from Texas and 0 representing respondents from North and South Dakota. The average value of 0.372 indicates that 37.2% of respondents are from Texas while the rest are from the Dakotas.

3.2. Regional comparisons: Dakotas vs. Texas

Table 3 presents a statistical *t*-test comparison of the mean values of all the variables between Dakotas and Texas. While RG adoption rate in the Dakotas (57.3%) is significantly higher than in Texas (44.9%), the MIG adoption rates are both lower than 10% for both regions and do not differ significantly. Additionally, the lack of statistical difference in the environment priority variable between the Dakotas and Texas indicated there is no regional heterogeneity in profit and environment related goals.

Compared to their Texas counterparts, Dakota producers were significantly younger and rated Extension & government agency support as more important in their decision making. In addition, Dakota producers also had significantly higher beef cattle gross sales and liability ratios; average gross sales of cattle were in the $250,000–499,999 and the $100,000–249,999 ranges in the Dakotas and Texas, respectively. Dakota producers were also more likely to have high quality land (80% vs. 68% with LCC I to IV) but less likely to have land with slopes that are suitable for cultivation (31% vs. 64% land with slopes less than 3% within 1-mile radius). The 30-year mean precipitation also differed significantly between two states with the Texas average being 289 mm (56%) greater than the average for North and South Dakota.

Table 3
Comparison of explanatory variables for North and South Dakota and Texas producers.

	Dakotas			Texas		
	Obs.	Mean	Std Dev.	Obs.	Mean	Std Dev.
RG adoption ***	549	0.573	0.495	325	0.449	0.498
MIG adoption	549	0.074	0.263	325	0.055	0.229
Environmental priority	549	0.763	0.780	325	1.506	0.780
Age***	527	62.080	10.566	317	68.738	10.559
Extension & gov. agency***	532	2.944	1.083	298	2.555	1.723
Gross sales***	520	3.208	1.199	313	2.834	1.420
Liability ratio***	500	2.764	1.291	391	2.378	1.279
Slope less than 3%***	547	0.311	0.343	320	0.638	0.359
LCC I to IV***	547	0.795	0.299	320	0.675	0.342
Precipitation (10^3 mm)***	549	0.519	0.088	325	0.808	0.202

Note: *** and ** indicate that variable means between Dakotas and Texas are different at the significance level of 0.01 and 0.05, respectively, based on both pooled and Satterthwaite t-tests.

3.3. Multivariate ordered probit model

All the correlation coefficients, ρ_{ik} $(i,k = 1,2,3)$, differ significantly from zero at $p < 0.01$ (Table 4), which indicates that ranchers' past and future decisions on grassland-based agriculture (Y_1 to Y_3) are interrelated and, therefore, justifies use of the multivariate probit model. Table 4 shows the coefficient and standard error (SE) estimation results for this model. We further demonstrate the marginal effects of explanatory variables on the preceding and future 10-year periods' grassland change decision variables in Tables 5 through 7 .

After controlling for other potential factors that could affect producers' land use decisions, we found no significant differences in both past and future land use decisions between CG and RG users. By contrast, compared to CG and RG, adoption of MIG was associated with significantly greater increases in grassland acres in the past and with intended future cropland to grassland conversion (Table 4). As indicated in Tables 5 and 7, MIG adopters were 11.4% more likely to have increased grassland acres by more than 10% in the preceding 10 years ($Y_1 = 3$) and were 13.1% more likely to convert cropland to grassland during the next 10 years ($Y_3 = 3$), when compared with CG users. This confirms **Hypothesis 1** that producers with higher grazing management intensity, exemplified by MIG, will be more likely to expand grass-based agriculture by converting cropland to grassland. This is possibly due to their stronger perception of the potential profitability of grassland, which influences their land use decisions. In contrast to land use conversion, grazing management intensity did not influence producers' decisions about purchasing or leasing grassland (Y_2). Furthermore, while RG users indicated a greater likelihood of expanding grass-based agriculture than CG users (Table 1), this was not found to be significant when we controlled for other potential influencing factors (Table 4).

The environment priority indicator played a significantly positive role in cropland to grassland conversion decisions. For each unit increase in the environment priority indicator, the likelihood of converting cropland to grassland ($Y_3 = 3$) increased by 4.6% (Table 7). The observation that grassland is associated with higher ecosystem benefits than cropland (Delgado et al., 2011) could explain why producers who prioritized environmental goals feel more inclined to convert cropland to grassland, as stated in **Hypothesis 2**. Other than management goals, producers' age and contact with Extension and government agencies also significantly affect their land use management decisions. Producers' age was negatively associated with decision to acquire and convert to grassland, indicating older producers were more likely to stick with the status quo and avoid investments in land use conversion with uncertain outcomes. In contrast, producers who regarded Extension and government agency as more important in their decision making indicated a higher preference for grass-based agriculture. When the importance of Extension and government agency increased by one level, producers were 3.6% and 3.1% more likely to purchase/lease grassland and convert cropland to grassland, respectively, in the forthcoming 10 years (Tables 6 & 7). This result is consistent with finding that producers who

[2] More information is available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053627.

Table 4
Estimated coefficients and standard errors (SE) for the multivariate ordered probit model.

	Grassland acres change (Y_1)		Purchasing/leasing more grassland (Y_2)		Cropland to grassland conversion (Y_3)	
Variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
RG adoption	0.094	0.103	−0.035	0.095	0.128	0.091
MIG adoption	0.427**	0.195	0.089	0.191	0.365**	0.184
Environmental priority	0.054	0.060	0.003	0.056	0.128**	0.055
Age	−0.022***	0.005	−0.034***	0.005	−0.012***	0.004
Extension & gov. agency	0.038	0.043	0.091**	0.040	0.088**	0.038
Gross sales	0.239***	0.038	0.198***	0.037	0.052	0.034
Liability ratio	0.043	0.036	0.070**	0.034	0.048	0.033
Slope less than 3%	0.157	0.147	0.311**	0.137	−0.107	0.130
LCC I to IV	0.007	0.160	−0.260*	0.149	−0.107	0.143
Precipitation (10^3 mm)	−0.130	0.345	−0.424	0.329	−0.608**	0.309
Texas	0.197	0.156	0.476***	0.149	0.163	0.140
Intercept 1	0.166	0.434	−2.145***	0.422	−1.070***	0.395
Intercept 2	0.656	0.434	−1.166***	0.418	0.010	0.394
ρ_{12}	0.327***	0.051				
ρ_{13}	0.211***	0.051				
ρ_{23}	0.283***	0.046				
Observations	748		$\chi^2(33)=$	223.74		
Log-likelihood	−2047.42		*Prob.* $> \chi^2(33) = 0.000$			

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 5
Marginal effects (ME) and standard errors (SE) on grassland acres change for the past 10 years (Y_1).

	Grassland acres change, past 10 years					
	No Increase ($Y_1 = 1$)		Increased by 5–10% ($Y_1 = 2$)		Increased by > 10% ($Y_1 = 3$)	
Variable	ME	SE	ME	SE	ME	SE
RG adoption	−0.034	0.038	0.009	0.010	0.025	0.028
MIG adoption	−0.157**	0.072	0.043**	0.020	0.114**	0.052
Environmental priority	−0.020	0.022	0.005	0.006	0.014	0.016
Age	0.008***	0.002	−0.002***	0.001	−0.006***	0.001
Extension & gov. agency	−0.014	0.016	0.004	0.004	0.010	0.012
Gross sales	−0.088***	0.014	0.024***	0.005	0.064***	0.010
Liability ratio	−0.016	0.013	0.004	0.004	0.012	0.010
Slope less than 3%	−0.058	0.054	0.016	0.015	0.042	0.039
LCC I to IV	−0.003	0.059	0.001	0.016	0.002	0.043
Precipitation (10^3 mm)	0.048	0.127	−0.013	0.035	−0.035	0.092
Texas	−0.072	0.057	0.020	0.016	0.053	0.042

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 6
Marginal effects (ME) and standard errors (SE) on purchasing/leasing more grassland for the future 10 years (Y_2).

	Purchasing/leasing more grassland, future 10 years					
	Very unlikely ($Y_2 = 1$)		Unlikely ($Y_2 = 2$)		Likely ($Y_2 = 3$)	
Variable	ME	SE	ME	SE	ME	SE
RG adoption	0.010	0.026	0.004	0.012	−0.014	0.038
MIG adoption	−0.024	0.052	−0.011	0.024	0.035	0.076
Environmental priority	−0.001	0.015	0.000	0.007	0.001	0.022
Age	0.009***	0.001	0.004***	0.001	−0.013***	0.002
Extension & gov. agency	−0.025**	0.011	−0.011**	0.005	0.036**	0.016
Gross sales	−0.054***	0.010	−0.025***	0.006	0.079***	0.015
Liability ratio	−0.019**	0.009	−0.009**	0.004	0.028**	0.013
Slope less than 3%	−0.085**	0.037	−0.039**	0.018	0.123**	0.054
LCC I to IV	0.071*	0.041	0.033*	0.019	−0.103*	0.059
Precipitation (10^3 mm)	0.115	0.089	0.053	0.042	−0.168	0.131
Texas	−0.129***	0.041	−0.060***	0.020	0.189***	0.059

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

utilized Extension and NRCS services are more aware of the benefits of conservation practices and, therefore, are more likely to adopt them (Kim et al., 2005; Wang, 2019).

In addition, certain farm characteristics, such as gross sales and liability ratio, also influence producers' land use decisions. When the size of cattle enterprise increases, as indicated by higher gross sales, producers are more likely to have increased their grassland acres in the preceding 10-year period and are more likely to continue purchasing or leasing new grassland in the next 10 years. This is consistent with the long-term trend of increasing farm and ranch size in the U.S. through land consolidation to achieve greater economies of scale (MacDonald, 2012). Regarding the mode of grassland expansion, we found that larger

Table 7
Marginal effects (ME) and standard errors (SE) on cropland to grassland conversion for the future 10 years (Y_3).

	Cropland to grassland conversion, future 10 years					
	Very unlikely ($Y_2 = 1$)		Unlikely ($Y_2 = 2$)		Likely ($Y_2 = 3$)	
Variable	ME	SE	ME	SE	ME	SE
RG adoption	−0.042	0.030	−0.004	0.003	0.046	0.033
MIG adoption	−0.120**	0.061	−0.011	0.008	0.131**	0.066
Environmental priority	−0.042**	0.018	−0.004	0.003	0.046**	0.020
Age	0.004***	0.001	0.000	0.000	−0.004***	0.001
Extension & gov. agency	−0.028**	0.013	−0.003	0.002	0.031**	0.014
Gross sales	−0.017	0.011	−0.002	0.001	0.018	0.012
Liability ratio	−0.016	0.011	−0.001	0.001	0.017	0.012
Slope less than 3%	0.035	0.043	0.003	0.004	−0.038	0.047
LCC I to IV	0.035	0.047	0.003	0.005	−0.038	0.051
Precipitation (10^3 mm)	0.200**	0.102	0.018	0.013	−0.218**	0.111
Texas	−0.054	0.046	−0.005	0.005	0.058	0.050

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

cattle operations were more likely to expand by purchasing or leasing land rather than converting cropland to grassland (Table 4). This implies that, in contrast to increasing grazing management intensity, increase in farm size generally is unlikely to promote the environmental benefits associated with cropland to grassland conversion. As expected, an increase in liability ratio is also likely to compel producers to switch to grass-based agriculture in the next 10 years. With every 20% increase in liability ratio, producers were 2.8% more likely to indicate that they intend to purchase or lease grassland in the future (Table 6). This implies that producers with greater financial obligations are more inclined towards the grass-based agriculture due to increasing input costs and dwindling profit margins from cropping enterprises.

Other than producer and farm characteristics, land quality and precipitation also affect producers' land use decisions. We found that producers with land that is unsuitable for crop production (i.e., land that is not LCC I to IV or that is greater than 3% slopes) planned to expand grass-based agriculture by purchasing or leasing more grassland. Additionally, in areas with lower average precipitation, producers indicated a greater intention to convert their cropland to grassland. Specifically, for every 10^3 mm decrease in average precipitation, producers were 21.8% more likely to make the conversion because drier regions are more suited for grazing purposes. Finally, regional location also played a role in producers' land use decisions. Compared with North and South Dakota, Texas producers were 18.9% more likely to purchase or lease more grassland in the next 10 years.

Promotion of MIG could potentially serve as a critical strategy for enhancing the conversion rate of marginal croplands to permanent grasslands for livestock production. Our findings suggest producers' decisions to convert marginal cropland to grassland hinge on the overall benefits from such land use conversion, which can be affected by factors such as climate and soil conditions, financial constraints, and livestock management expertise. Globally, increasing aridity, caused by the combined increase in temperature and decrease in precipitation during the growing season, is projected to be a primary effect of climate change in semiarid and arid ecosystems (Dobrowski et al., 2013; Harrison et al., 2015), and has been linked with a decline of the structural and functional attributes of functional ecosystems (Huang et al., 2016; Maestre et al., 2016). Compared to cropland, grassland with diverse adaptive native grass species is more resilient to climate extremes such as drought (Craine et al., 2013). Therefore, it is important for producers located in regions with limited precipitation and/or declining groundwater levels to consider converting marginal cropland to grassland. Additionally, there has been a growing interest in recent years in biologically based low-cost and low impact solutions, such as effective grazing management, to mitigate climate change effect (Gosnell et al., 2020). In this regard, MIG, when compared with CG and RG, provides producers with a better option to enhance carbon sequestration and maximize the economic and environmental benefits on the newly converted grassland (Moore and Gerrish, 2003; Jakoby et al., 2015; Wang et al., 2015; Park et al., 2016a). Additionally, while some have argued that eructation by grazing livestock contributes substantially to global methane levels (Ripple et al., 2014), Teague et al. (2016) countered by demonstrating that conventional crop production with substantial periods of bare ground contributes much more to methane emissions through the anaerobic decay of organic matter in eroded soil that is deposited in water bodies. Therefore, conversion from conventional crop production to permanent grassland cover for livestock production will likely not only reduce soil erosion but may also decrease overall methane emissions from agriculture.

The findings of the current research also suggest that financial subsidies to offset initial fencing and water system costs required to implement MIG could further enhance the adoption of this grazing management approach. Wang et al. (2018) found that the cost of implementing MIG could range from $7.40 to $173 per ha, depending on ranch size, configuration and conditions. Therefore, to facilitate producers' decisions and enhance MIG adoption, it is important to provide producers with accessible and transparent information about variation of installation costs according to property size and the types of fencing and water systems. Additionally, payment for ecosystem services that could be elevated through the adoption of MIG practices, such as carbon sequestration, will increase the profitability and, therefore, the adoption of more sustainable grassland-based agriculture. In turn, this will contribute to an expansion of environmentally and economically sustainable grassland acres in the Great Plains.

4. Conclusion

Lower crop commodity prices and relatively stable cattle market have in recent years motivated an increasing number of producers to revert to grassland-based agricultural production (Wang et al., 2017, 2018a). Compared to cropping, marginal land used for grassland-based production generates higher environmental and ecosystem benefits (Lubowski et al., 2006; Culman et al., 2010; Sullivan and Rinehart, 2010; Eagle et al., 2012). To help understand agricultural producers' decisions regarding grassland expansion through grassland purchase/lease and cropland to grassland conversion, we used survey responses from producers in the Dakotas and Texas to examined factors that affect producers' past and future land use decisions.

We found that 27%, 36% and 48% of CG, RG and MIG producers indicated they were inclined to convert cropland to grassland in the future. After controlling for the other potential influencing factors, grazing management intensity plays a significantly positive role in producers' decisions to convert marginal cropland to grassland. This implies that, besides improving the resilience and profitability of existing grassland, promotion of MIG will likely also increase cropland to grassland conversion, thereby more broadly enhancing environmental and ecosystem benefits on marginal cropland.

Other factors that contribute to the conversion of cropland to grassland were younger age, prioritizing environmental improvement goals, and viewing Extension and government agencies, such as NRCS, as more important information and support sources for land use decision making. In addition, producers in areas with lower average precipitation are also more likely to covert cropland to grassland. Additionally, higher cattle enterprise sales, greater liability ratio and poorer land quality were positively associated with the intentions to purchase or lease more grassland from other producers, but they had little impact on the likelihood of future conversion from cropland to grassland. Compared to producers in North and South Dakota, Texas producers expressed stronger intentions to purchase and lease more grassland. Although these factors potentially contribute to an increase in the size of grass-based operations, they play no significant role in cropland to grassland conversion decisions and, therefore, are unlikely to promote environmental and ecosystem benefits derived from an increasing amount of grassland.

Our findings imply that, in order to encourage producers to convert marginal cropland to grassland, it is critical to emphasize the potentially higher profitability of grass-based production on marginal land. In this regard, Extension and government programs can help producers shift their management focus from short-term profit prioritization to longer-term profit improvement associated with soil and ecosystem improvement through the addition of improved grazing management. Other than subsidies that covers initial investment costs, payments for ecosystem services generated by the use of improved grassland management practices, such as MIG, will likely facilitate the conversion of an increasing amount of marginal cropland to grassland, thereby enhancing economic, environmental and ecological sustainability for agricultural production in the U.S. Great Plains.

CRediT authorship contribution statement

Tong Wang: Conceptualization, Funding acquisition, Methodology, Writing - original draft. **Hailong Jin:** Software, Formal analysis. **Urs Kreuter:** Writing - review & editing. **Richard Teague:** Writing - review & editing.

Acknowledgements

This work was supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2017-67024-26279. We express our sincere gratitude to Iftekhar Uddin Ahmed Chowdhury for his valuable research assistance.

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