Will Adoption Occur if a Practice is Win-Win for Profit and the Environment? An Application to a Rancher's Grazing Practice Choices

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Will adoption occur if a practice is win-win for profit and the environment? An application to a rancher's grazing practice choices

Abstract

Rotational grazing has the potential to provide both economic and environmental benefits; however, the set of ranchers that adopts is much smaller than the set that regards rotational grazing as a win-win practice. To investigate this adoption gap and learn about adoption decisions and motivations, we survey 874 ranchers on the U.S. Great Plains. We find that a large proportion of surveyed ranchers who view rotational grazing as win-win for both profit and the environment do not adopt the practice. We also find that win-win non-adopters are a constrained group for most potential challenges to rotational grazing adoption, especially for high initial costs, water resource limitations, and ranch conditions. Some of these impediments could be relieved by capital to which, however, win-win non-adopters have limited access. Win-win non-adopters are more likely to adopt rotational grazing than others when a one-time subsidy is offered, suggesting that win-win non-adopters hold promise as a target group for subsidies to reduce the cost of adoption. Our analysis shows the importance of understanding the specifics of an adoption gap when making and implementing policies.

Keywords: Adoption gap, capital constraints, ecosystem services, rotational grazing

JEL Codes: D91, Q16, Q18, Q57

1. Introduction

Many conservation practices have been shown to both enhance economic profits and improve the environment. For example, reduced tillage can enhance overall soil health, reduce fuel and labor costs, and increase long-term sustainability and profitability (Hodde et al., 2019; Cusser et al., 2020); nutrient management practices can both increase productivity and mitigate nutrient loss to the environment (Daxini et al., 2018); cover crops can help to improve soil quality, alleviate drought stress, and reduce input costs (Bergtold et al., 2019). The U.S. federal government provides financial and technical assistance to promote conservation practice adoption through various programs such as Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP). Other government and nongovernmental entities also provide voluntary payment programs to support conservation practices (Claassen et al., 2018). Despite various efforts to encourage conservation practices, and despite a vibrant literature that addresses incentives for adoption, adoption rates remain low across practices (Prokopy et al., 2019; Delaroche, 2020).

Many studies have explored factors influencing conservation practice adoption (e.g., Herr et al., 2004; Pannell et al., 2006; Knowler & Bradshaw, 2007; Marshall, 2009; Garbach et al., 2012; Carlisle, 2016; Eanes et al., 2019; Canales et al., 2020; Piñeiro et al., 2020; Rodenburg et al., 2021; Thompson et al., 2021; Lang & Rabotyagov, 2022). A recent study (Prokopy et al., 2019) conducts a comprehensive review of quantitative studies focusing on the adoption of agricultural conservation practices in the United States over 1982-2017. Factors found to be important include farmers' attitudes toward the environment, attitudes towards a particular practice, previous adoption of other conservation practices, social networking, land quality, farm size, and farmer characteristics. However, no universal determinants of adoption have emerged across different practices. Profitability is a very important factor that impacts adoption of win-win, profit-win, and environment-win practices, while perceived environmental outcomes have a positive effect on the adoption of a profit-win practice (Gedikoglu & McCann, 2012). Economic concerns are regarded as the largest barrier to adopting conservation practices such as no-till management (Rodriguez et al., 2009; Wade & Claassen, 2017). In addition, limited access to credit (Adegbola & Gardebroek, 2007; Abdulai & Huffman, 2014; Liu et al., 2018) and rental arrangements on the rented lands (Soule et al., 2000; Carolan et al., 2004; Tong et al., 2017; Ranjan et al., 2019; Leonhardt et al., 2021) are also shown to be potential barriers to conservation practice adoption.

While many factors have been identified as potentially important to adoption in general, few studies have investigated "adoption gap" and its determinants in the context of conservation practices. There is no uniform definition of "adoption gap" in the literature. Some studies on agricultural technologies (e.g., improved pigeonpea varieties, new rice for Africa) identify "adoption gap" as the difference between the mean rate of population exposure to new technology and the actual adoption rate (Diagne, 2006; Diagne & Demont, 2007; Simtowe et al., 2016). They assume that the gap exists due to incomplete diffusion of technology in the population. In Antoci et al. (2022), "adoption gap" is defined as the difference between socially optimum and current adoption shares. In our paper, we define the "adoption gap" as the difference between the group that regards a practice as win-win for profit and the environment and the group that has such win-win views and has actually adopted it.[1] If we consider that it

[1] A similar phenomenon exists in the energy sector, where a large literature documents the "energy efficiency gap," defined as the difference between actual energy use and optimal energy use (Allcott & Greenstone 2012; Gillingham & Palmer 2014). The gap is often defined more broadly as a slower-than-socially-optimal diffusion rate of energy-efficient products. According

would be socially optimal for the ranchers with win-win views to adopt a conservation practice, our definition is close to Antoci et al. (2022). Nowak (1992) states that being unable, but potentially willing, to adopt a new production technique implies the presence of an obstacle or situation where the decision not to adopt is rational. Potential obstacles include technology complexity, large investment costs, labor requirements, limitations due to financial credits, and an unwilling landlord.

The purposes of this paper are to identify whether and why there exists an adoption gap for a type of conservation practice in the context of grazing management. Broadly speaking, there are two types of grazing practices: continuous grazing and rotational grazing. Continuous grazing allows the herd to freely access the entire pasture throughout the grazing season, and it can have adverse environmental impacts (Steinfeld et al. 2006; Alkemade et al. 2013). In contrast, under rotational grazing, pastures are divided into multiple paddocks typically by temporary fencing. Livestock are rotated through paddocks with only one paddock grazed at a time while the other paddocks rest. When the number of paddocks is relatively small and the herd remains on a paddock for weeks or months before moving to the next, the strategy is referred to as low-intensity rotational grazing (LRG). When a large number of paddocks are involved and cattle are moved more frequently, the strategy is referred to as management intensive grazing (MIG) (Undersander et al., 2002). Due to higher stocking density on each paddock being grazed, the livestock are forced to be less picky; they will graze down, and discourage from proliferation, a higher proportion of less preferred plant species. The practice

to Gerarden et al. (2017), potential explanations for this gap fall into three categories, namely market failures, behavioral explanations, and model or measurement errors. Backlund et al. (2012) also summarize barriers to improving energy efficiency, identifying limited access to capital, bounded rationality, and lack of information as potential barriers in that context.

also protects from overgrazing the species that are more productive for beef enterprises and so improves ranch productivity (Chaubey et al., 2010; Teague et al., 2015). Thus, rotational grazing is considered by many researchers to be a profit-increasing and environment-friendly conservation practice compared to continuous grazing (Teague et al., 2009; Jakoby et al., 2015; Park et al., 2017; Searchinger et al., 2018; Wang et al., 2018).

Many researchers have studied the factors influencing the transition from continuous grazing to rotational grazing, including investments in additional fencing, water supply infrastructure, labor inputs and peer effects (Gillespie et al., 2008; Nelson et al., 2014; Manson et al., 2016; Windh et al., 2019; Wang et al., 2020; Che et al., 2022). There have also been many government incentives that promote the adoption of rotational grazing, for example, the U.S. Department of Agriculture (USDA) adapted components of the Conservation Reserve Program to support working grasslands in 2015, through rental payments and cost-sharing subsidies for fencing and watering infrastructure. Despite the potential benefits and much research and policy support, the rotational grazing adoption rate was only about 31% in 2017 (USDA NASS, 2017). To further understand rancher adoption decision processes, we conduct a survey-based study of beef operators on the U.S. Great Plains. We find that many ranchers who view rotational grazing as a win practice for profit do not adopt it. Furthermore, we find that many non-adopters actually view rotational grazing as not only a win practice for profit but also a win for the environment. That is, there is a significant adoption gap between the ranchers who regard rotational grazing as win-win and those who have actually adopted it. We further investigate the factors that result in this adoption gap and explore possible incentive approaches for encouraging those non-adopters to adopt rotational grazing.

Our paper contributes to the literature in the following ways. First, from a conceptual perspective, we discuss a rancher's decision on whether to adopt rotational grazing when accounting for both economic profits and environmental outcomes in a utility maximization framework. Most previous studies that analyze the adoption of conservation practices often focus on profit maximization. However, farmers may have multiple goals for conservation practice adoption, including wealth and financial security, environmental protection, integrity, and lifestyle goals (Pannell et al., 2006). Basarir & Gillespie (2006) find that beef producers regard environmental goals to be more important than maximizing profit. Moreover, while other studies consider farmers' adoption decisions with both profit and environment attributes, their focus differs. For example, Kim et al. (2008) focus on the role of uncertainty in rotational grazing adoption with a cost-share payment. Gedikoglu & McCann (2012) classify livestock practices into win-win, environment-oriented, and profit-oriented practices. They mainly analyze similarities and differences regarding signs and relative magnitudes of factors affecting adoption of different practices. Our framework investigates how ranchers make decisions when considering both profit and environmental outcomes and provides a conceptual framework for examining the adoption gap.

Second, we document the magnitude of the rotational grazing adoption gap and further assess the extent of non-adoption among ranchers who view rotational grazing as win-win in terms of profit and the environment. More than half of non-adopters in our sample regard rotational grazing as a win-win practice. It is important to note that the win-win views analyzed in our sample are those of the ranchers themselves, as distinct from the win-win characterization of a practice by researchers based on laboratory or field experiments. Given that the win-win views are decision-makers' own perceptions, not external data the decision-makers have learned about, understanding the adoption gap is even more important in identifying policy-relevant insights. Third, we use a relatively large survey sample to identify the main barriers that constrain win-win non-adopters and the factors that give rise to these potential barriers. Other studies of rotational grazing have been much smaller, generally with a survey sample of less than 100 (Kim et al., 2008; Nelson et al., 2014; Manson et al., 2016). We also explore ranchers' opinions about rotational grazing with responses from open-ended survey questions rather than by relying on secondary data sources. Finally, we investigate the effects of incentives on the future potential adoption decisions of the win-win non-adopters in comparison with other non-adopters. This is distinct from previous studies regarding conservation practice adoption that focus on all or only non-adopting producers rather than on specific groups of non-adopters (Windh et al., 2019; Wang et al., 2020).

2. Methods

2.1 Theoretical Approach to Assessing Grazing Practice Choices in Different Scenarios of Profit and Environmental Outcomes

We consider the situation where a rancher is making a decision between continuous grazing and rotational grazing. Let $A_i \in \{ext, int\}$ denote the potential decision choice set, where *ext* represents continuous grazing practice, and *int* represents rotational grazing practice. We assume each grazing practice choice has two attributes: economic profit ($\pi(A_i)$) and environmental outcome ($E(A_i)$). The rancher's utility function is given as $U(\pi(A_i), E(A_i))$ and is assumed to be monotonic increasing in both arguments following basic microeconomic theory of individual decision making (Mas-Colell et al., 1995).

Figure 1, Panel a, depicts the two attributes along an indifference curve that indicates the trade-off between profit and environmental outcomes for an individual rancher. Suppose that the profit and environmental outcomes of continuous grazing are located at point *x*. Then any point along an indifference curve passing through *x* represents the same utility or satisfaction level. Any point to the right of (i.e., above) the indifference curve means the rancher is better off than *x* and any point to the left of (i.e., below) the curve, means the rancher is worse off. Denote the profit and environmental outcomes of rotational grazing as *y* for an individual rancher. To assess whether and how the rancher prefers *y* over *x*, we divide the whole area into four quadrants around *x* which represent four categories of profit and environmental outcomes relative to those of continuous grazing: win-win, win-loss, loss-loss, loss-win. These quadrants are discussed in more detail in the paragraphs to follow.

(1) Win-Win case: If rotational grazing is regarded as a win-win practice for both profit and the environment when compared with continuous grazing, then the rational choice by aware ranchers with monotone preferences should be rotational grazing. In Figure 1(a), this means that *y* is located in the shaded area. In this case, a rancher's indifference curve passing through *y* will be to the right of the indifference curve passing through *x*, that is, a rancher will be better off by choosing rotational grazing.

(2) Loss-Win case: If rotational grazing is regarded as a loss-win practice in terms of profit and the environment, then it is not clear whether ranchers with monotone preferences will derive higher utility from rotational grazing and adopt it. In Figure 1(b), take point *y* as an example of rotational grazing outcomes in the loss-win case, where the dashed lines represent indifference curves passing through point *y*. The ranchers with green-colored indifference curves will be better off when choosing rotational grazing (with outcomes y) compared to continuous grazing (with outcomes *x*), as illustrated by the location of the dashed green indifference curve through point *y* being higher (or more to the right) than the solid green indifference curve through point *x*. By contrast, the ranchers with yellow-colored steeper indifference curves treat profit as relatively

more important than the environment. They will be worse off when choosing rotational grazing (with outcomes y) compared to continuous grazing (with outcomes x), so they will be more likely to stick with continuous grazing. A subsidy provides the potential to induce those ranchers to adopt rotational grazing by increasing a rancher's profit and so moving y rightward.

Turning to Figure 1(c), the rancher with the blue solid indifference curve would prefer continuous grazing (*x*) to rotational grazing (*y*). Some policies can be used to rotate the indifference curve downward so that rotational grazing (y) is preferred to continuous grazing (x), as when changing from the solid blue line to the dashed one. As one specific example of policies, the government can promote educational materials about the value of improving water quality and increasing soil carbon sequestration to ranchers so as to shifting their preference function toward environmental outcomes. For the changed preference, as illustrated in Figure 1 (c), now point *y* may lie above the dashed blue indifference curve passing through *x*, such that point *y* leads to a higher utility, i.e., rotational grazing now becomes preferable compared to continuous grazing.

(3) Win-Loss case: Contrary to the third case, when rotational grazing is regarded as a win-loss practice in terms of profit and environment, the region southeast of *x* applies. Still applying the indifference curve examples in Figure 1, Panel b, ranchers who put relatively more weight on profit will be more likely to adopt rotational grazing. However, this win-loss situation is an unlikely scenario because, as mentioned in the introduction, the literature has shown that rotational grazing has beneficial environmental outcomes. This is also borne out in our survey data.

(4) Loss-Loss case: If rotational grazing is regarded as a loss-loss practice compared to continuous grazing, then ranchers with monotone preferences will not switch away from

continuous grazing. In terms of Figure 1(a), if *y* is located in the loss-loss quadrant, then the indifference curve passing through *y* will be lower than an indifference curve passing through *x* for all ranchers regardless of slope.

The above framework provides an approach to thinking about the adoption gap based on ranchers' views about the profit and environmental outcomes of rotational grazing and their adoption status. Turning to Figure 2, the large blue rectangle represents all ranchers (R), within which the red oval (A1+N1+A3+N3) represents ranchers who think rotational grazing increases profit and the green oval (A2+N2+A3+N3) represents ranchers who think rotational grazing increases environmental outcomes. The intersection of the red and green ovals (A3+N3) represents those ranchers who regard rotational grazing as a win-win practice for both profit and environment, just as when *y* is in the win-win quadrant in Figure 1. Then the win-win ranchers' rational choice should be adopting rotational grazing without policy interventions (e.g., subsidies or education). However, if not all the win-win ranchers adopt rotational grazing and the actual adopters are represented by the orange oval (A1+A2+A3), then there exists an adoption gap between win-win ranchers (A3+N3) and actual win-win adopters (A3). The adoption gap (N3/(A3+N3)) is measured as the proportion of win-win non-adopters (N3) among the ranchers with win-win views (A3+N3).

Potential reasons for this adoption gap may include measurement errors, behavioral reasons, and financial, physical or other tangible constraints (Nowak 1992; Backlund et al., 2012; Gerarden et al., 2017). Measurement errors might arise in our case because our measurement of win or loss is based on survey data that asked farmers to state the economic and environmental impacts. This subjective statement might exaggerate the actual benefits or losses. Behavioral factors such as ranchers' retirement status, or a personal disposition toward keeping the status quo provide potential explanations for not adopting. Ranchers who are about to retire countenance many constraints, including limited time to recover investments made where human capital components of these investments cannot be transferred upon retirement. In addition, potential adopters may not be interested in considering a practice change simply because they are content with their status quo. In our case, we focus on the likely effects of financial and physical constraints on adoption decisions because these constraints have traditionally been the focus of policy interventions and also because different types of research methods might be required to examine other reasons.

2.2 Data Collection and Description

In early 2018 we sent out a survey to beef operators in 49 North Dakota and 58 South Dakota counties as well as 81 counties in Central and North Texas. The areas were chosen because they are the northern and southern extremities of the U.S. Great Plains and incorporate a relatively higher proportion of livestock operations than does the Central Plains, where irrigated crop production dominates. The screening criterion for rancher selection is that each respondent operated at least 100 non-feedlot cattle. We purchased contact information for 4,500 randomly selected ranchers in three states from Survey Sampling International. The survey was implemented following the Dillman mail survey administration method (Dillman et al., 2014). A total of 874 recipients completed and returned the survey questionnaires with an overall response rate of 20.6%.

Ranchers were asked to indicate the effects of rotational grazing on both economic profit and the environment. For economic profit, adopters were asked “How has your adoption of LRG or MIG[2] affected (or will likely affect) the economic profit of your ranch during the first 5 years?"; while non-adopters were asked "To what degree do you think that LRG or MIG might affect the economic profit of your ranch in the first 5 years?". Both sets had five option choices with 1="significantly decrease", 2="slightly decrease", 3="no influence", 4="slightly increase", and 5="significantly increase." We encode as a "win" practice for profit whenever a rancher chose "slightly increase" or "significantly increase" for the above questions.

For the environment, ranchers were asked "whether or not you have adopted, please indicate what you observe or expect regarding the following possible benefits associated with LRG or MIG practices on your ranch or neighboring ranchers." The proposed potential benefits include "decreased runoff and erosion", "increased drought resilience/faster drought recovery", and "increased percentage of desirable grass". They were offered four option choices for each benefit with 1="none", 2="slight", 3="medium", and 4="significant." We encode as a "win" practice for the environment whenever the rancher chose "slight", "medium" or "significant" for any of the above three environmental benefits.[3]

We define a rancher as an adopter whenever the rancher was currently practicing LRG or MIG; otherwise, the rancher was held to be a non-adopter. Among the surveyed ranchers, 59% were currently practicing rotational grazing while 41% never adopted or had discontinued the practice. Furthermore, among adopters, we define a rancher as a "win-win adopter" whenever the adopter reported rotational grazing as a win-win practice in terms of its effects on both economic profit and the environment; otherwise, the adopter was categorized into "other adopters."

[2] Definitions of LRG (low-intensity rotational grazing) and MIG (management intensive rotational grazing), as shown in the survey questionnaire, are provided in Supplemental Materials (SM), Figure A1.

[3] Explanations for why these three benefits of rotational grazing are regarded as environmental benefits are presented in SM, Section B.

Similarly, among non-adopters we define a rancher as a "win-win non-adopter" whenever the non-adopter regarded rotational grazing as a win-win practice; otherwise, the non-adopter was categorized as "other non-adopters." In addition, non-adopters were asked "If a one-time subsidy were available to those willing to adopt rotational grazing or MIG practices, then would you adopt?" and were provided with three options, namely "Yes", "No", and "Not sure". The available hypothetical one-time subsidies are $10/acre, $30/acre, $50/acre, $70/acre.[4]

We asked the survey participants to rate a variety of challenges they face regarding rotational grazing practices, including "high installation cost", "water source constraint", "labor and management time constraints", "cash flow constraints", "uncertain outcomes", "rental agreement restrictions", "lack of information, education, or support", "ranch conditions", "unfavorable neighborhood opinions", "unwillingness to take on leadership in new practice adoption", and "weather or climate factors." For each of the listed challenges, respondents were given five choice options (1="not a challenge", 2="minor challenge", 3="some challenge", 4="quite a challenge", and 5="great challenge"). We will examine the connection between these challenges and the adoption gap observed in our data.

The survey also asked the respondents to report their estimated initial costs and labor costs associated with rotational grazing. "Initial cost" refers to the estimated initial investment costs in $/acre for both fencing and water systems. Five categories were provided, namely 1="less than $10", 2="$10-$25", 3="$26-$40", 4="$41-$70" and 5="more than $70".[5] 'Labor' refers to the effects of rotational grazing adoption on labor and management time needed to operate the ranch.

[4] The specific survey question about non-adopters' willingness to adopt with a one-time subsidy is presented in SM, Figure A6.
[5] Only non-adopters were asked to choose among the five options. Adopters were asked to report the exact values, which was converted into the five discrete categories.

Five response alternatives were provided: 1="significantly decreased", 2="slightly decreased", 3="no influence", 4="slightly increased" and 5="significantly increased."

Variables that describe rancher characteristics include "operating years", "education", and "liability ratio." "Operating years" refers to the number of years a rancher has been the primary operator on the current ranch. "Education" refers to the highest level of completed education, which is categorized using 1="less than high school" , 2="high school", 3="some college/technical school", 4="4-year college degree", 5="advanced degree." "Liability ratio" refers to the ratio of total liabilities to total assets for ranchers' farming or ranching operation, and is categorized using 1="0%", 2="1-20%", 3="21-40%", 4="41-60%", 5="61-80%", 6="more than 80%."

In our analysis of adoption gap, we also consider variables that describe ranch characteristics including "grazing acres" (total acres of native rangeland and improved pastures operated), "grazing land share" (the share of grazing acres in total acres on the farm), "lease ratio" (leased grazing land acres divided by total grazing land acres), and "distance" (estimated distance in miles from a rancher's home to her largest tract of grazing land). As we purchased each respondent's address, we collated survey information with public domain data, including land capability classification (LCC), slope, latitude and longitude. We collected LCC and slope data from the SSURGO database. The "LCC I or II" variable denotes the share of all land that has LCC equal to I or II (and so is productive under crop production) within 1-mile of each ranch's location. The choice of 1-mile radius is made to appropriately indicate the extent of productive land in the ranch's vicinity. Similarly, the variable "slope less than 3%" refers to the share of area within a 1-mile radius that has a slope no greater than 3%. This variable is also used to proxy better quality land since such land is easier to manage and is less prone to erosion. The summary statistics for ranch and rancher characteristics among win-win adopters and win-win non-adopters are presented in Table 1.

In the survey, most questions were closed-ended in that respondents checked boxes, but we also solicited general open-ended comments about rotational grazing practices. Specifically, ranchers were asked "Please record any further comments you have regarding rotational grazing or MIG practices", after which ranchers were presented with space for any related comments. We categorized these comments into twelve general themes that are relatively distinct and represent a significant percentage of the total comments. These themes are categorized as (1) water; (2) fencing; (3) cost; (4) labor; (5) government support; (6) rent; (7) retirement and age; (8) environmental benefits; (9) land characteristics; (10) ranch scale; (11) neighborhood; (12) other comments.[6] We compare the frequency of comments in each of the above categories among different groups of ranchers to understand their concerns about rotational grazing.

2.3 Empirical Methods

2.3.1 Ordered Logit Model for the Constraints among Different Groups of Ranchers

One of our modeling objectives is to examine how perceived constraints for adoption might be affected by rancher and ranch characteristics among different groups of ranchers with a focus on win-win non-adopters. As responses to the constraint variables take five ordinal categories (1="not a challenge", 2="minor challenge", 3="some challenge", 4="quite a challenge", and 5="great challenge"), the ordered logit model is an appropriate modeling choice to account for multiple response categories (Wooldridge, 2010). Wang et al. (2020) apply a generalized ordered logit model to assess potential challenges to adopting rotational grazing for all non-adopters. In

[6] SM, Table C1 provides a comment classification rubric as well as example comments in each category.

contrast, we compare the responses on challenges among three groups of ranchers, namely, win-win adopters, win-win non-adopters, and other non-adopters, with an aim to shed light on the underlying causes of the adoption gap. Let y_i be a categorical variable indicating a rancher's opinion on potential challenges to adoption as explained above, i.e., $y_i = 1$ means "not a challenge", $y_i = 2$ "minor challenge", $y_i = 3$ means "some challenge", $y_i = 4$ means "quite a challenge", and $y_i = 5$ means "great challenge". The item y_i^* is the associated continuous latent variable representing the extent of rancher agreement with each rotational grazing challenge. Then we have

(1) $$y_i^* = X_i\beta_i + \varepsilon_i,$$

(2) $$y_i = \begin{cases} 1 \text{ whenever } y_i^* \leq \kappa_1; \\ 2 \text{ whenever } \kappa_1 < y_i^* \leq \kappa_2; \\ 3 \text{ whenever } \kappa_2 < y_i^* \leq \kappa_3;, \\ 4 \text{ whenever } \kappa_3 < y_i^* \leq \kappa_4; \\ 5 \text{ whenever } y_i^* > \kappa_4. \end{cases}$$

where the κ_j parameters are cutoff points for the observable challenge response categories, X_i is the vector of independent variables including ranch and rancher characteristics, β_i is a vector of coefficients to be estimated, and ε_i is the error term.

2.3.2 Modelling Subsidy Responses

To assess how win-win non-adopters might respond to policy incentives differently from other non-adopters, we first compare the willingness to adopt LRG or MIG between win-win non-adopters and other non-adopters when a one-time subsidy is offered. We calculate the elasticities of adoption probability with respect to subsidies at the \$30 amount. We then apply a logit model (Wooldridge, 2010) to examine how non-adopters' willingness to adopt LRG or MIG was affected by initial costs, labor requirements, and rancher and ranch characteristics when a one-time subsidy is provided. We have

(3) $$n_i^* = R_i\delta_1 + Z_i\delta_2 + \mu_i;$$

(4) $$n_i = \begin{cases} 1, n_i^* > 0; \\ 0, n_i^* \leq 0; \end{cases}$$

where n_i is a binary variable indicating whether a rancher is win-win non-adopters (i.e., $n_i = 1$ for win-win non-adopters, $n_i = 0$ for other non-adopters); the item n_i^* is the associated continuous latent variable; R_i is a vector including initial costs and labor requirement; Z_i represents rancher-specific characteristics; δ_1 and δ_2 are vectors of parameters to be estimated; and μ_i is the error term following a standard logistic distribution.

3. Results and Discussions

In this section, we first present the diverse views on the profit and environmental outcomes of rotational grazing among adopters and non-adopters and identify the potential barriers to adoption. We then discuss the summary statistics of the open-ended comments regarding ranchers' views on rotational grazing. Next, we investigate how potential challenges constrain win-win non-adopters and other groups. After comparing responses by win-win non-adopters and by other groups to hypothetical subsidies, we present some back-of-the-envelope estimates of the effects of subsidies on rotational grazing adoption on the Great Plains and in the United States.

3.1 Ranchers' Views on the Profit and Environmental Outcomes of Rotational Grazing and Adoption Challenges

Although adopters and non-adopters expressed diverse views on the profit effects of rotational grazing adoption, Figure 3 shows the majority in both groups viewed rotational grazing as a profit-increasing practice. Indeed, 57% of non-adopters perceived the practice as profit increasing. A greater proportion (83%) of non-adopters thought that rotational grazing would increase the required labor and management time than did adopters (61%). There are also different perceptions about grassland productivity impacts which helps explain the less enthusiastic views about practice profitability among non-adopters. Compared to adopters, fewer non-adopters reported that rotational grazing would prolong the grazing season, increase stocking rate capacity, increase livestock weight gain, or improve livestock health (Figure 4).

Most adopting (99%) and non-adopting (89%) respondents agreed that rotational grazing would improve the environment by increasing desirable grass production, decreasing runoff and erosion as well as improving drought resilience and recovery (Figure 4). A greater proportion of adopters regarded the above environmental benefits to be significant when compared with non-adopters. Table 2 shows that perceptions about economic and environmental effects align well. Most adopters (76%) regarded rotational grazing as a win-win practice. Among non-adopters, about 57% thought rotational grazing to be a win-win practice.[7] Therefore, many ranchers chose not to adopt rotational grazing for reasons other than negative perceptions of potential economic and environmental benefits. In what follows, we investigate the likely drivers of such non-adoption decisions.

It is intuitive that a rancher seeking to stay in business may not adopt a practice whenever environmental gains are not accompanied by profit, as we explained earlier through Figure 1. However, many ranchers viewed rotational grazing as both profit-increasing and environmental-friendly yet did not adopt. The t-test results comparing the responses on potential challenges across win-win non-adopters and other non-adopters are shown in Table 3. Both win-win non-adopters and other non-adopters ranked “high installation cost”, “water resource constraint”, and

[7] To check for robustness, we calculate the proportions of ranchers with different perceptions about economic and environmental effects when only considering one potential environmental benefit, i.e., “decreased runoff and erosion”, see SM, Table C2. We observe consistent results in that most adopters (73%) regarded rotational grazing as a win-win practice while about 49% of non-adopters thought rotational grazing to be a win-win practice.

“labor/management time constraints” as three most challenging constraints: win-win non-adopters ranked “water resource” as the most severe constraint and “labor or management time” as third-most while other non-adopters reversed this ordering. These findings are consistent with previous study findings which concluded that implementing rotational grazing requires additional infrastructure and possibly also additional labor when compared to traditional continuous grazing (Gillespie et al., 2008; Windh et al., 2019). As shown in Table 3, most of these potential challenges are viewed as more constraining for win-win non-adopters than for win-win adopters. One noticeable phenomenon is that win-win adopters ranked “weather/climate factors” as the second greatest challenge, while both win-win non-adopters and other non-adopters only ranked the category as sixth greatest, implying non-adopters might underestimate climate-change-related challenges.

The above differences between win-win non-adopters and other groups are also supported by cumulative percentage response curves to different rating levels of the top challenges.[8] Taking “water resource constraint” as an example in Figure 5, the cumulative percentage lines show win-win non-adopters to be lower than the other three groups, indicating that win-win non-adopters were the most water resource constrained group. Similar results were found for other constraints. Although high initial costs and water resource constraints could to some extent be relieved by capital, win-win non-adopters were also more likely to rank cash flow as a greater challenge, compared to adopters.[9] These findings reveal that more constrained circumstances may explain non-adoption among win-win non-adopters.

[8] More figures for cumulative percentage response curves to different rating levels for top challenges can be found in SM, Section D.

[9] Please see SM, Figure D4 for cumulative percentage response curves to different rating levels for cash flow constraints.

3.2 Summary Statistics of Open-ended Comments

Table 4 summarizes comment frequencies in different categories. Of the 346 comments made, and setting aside the 'other comments' category, the largest set (70, about 20% of all comments) mentioned water and related water resource concerns such as lack of water, and high costs of drilling new wells. The second-largest set (42, about 12% of all comments) was related to fencing concerns including great fencing costs and fencing maintenance. Other comment categories that featured prominently were cost, labor, government support, rent, and retirement each making up 5-11% of total comments. The most commonly mentioned comment categories were consistent with our findings on potential challenges based on ranking choice data explained above, for example, "water resource constraint" was listed by both win-win adopters and win-win non-adopters as the most challenging issue.

Table 4 also compares the comment count in each category among win-win adopters, win-win non-adopters, and other non-adopters. There were no significant differences in comment frequencies between win-win non-adopters and other non-adopters. However, win-win non-adopters provided about 133% more cost-related comments than did win-win adopters, with respective averages of 0.2 and 0.086 per respondent. Win-win non-adopters were less likely than adopters to cite government support as important. One potential reason is that non-adopters were not aware of or were less willing to learn about governmental policies and did not receive support. This suggests that one channel to increase adoption is to facilitate non-adopters' learning about government supports that can help overcome their financial constraints.

3.3 Constraints among Different Groups of Ranchers

We examine ranch and rancher characteristics that affect each of the eight most serious challenges in Table 3, namely those that have an average value of greater than 2.3 among non-adopters and 1.9 among adopters where ‘rental agreement restrictions’ is the common eighth challenge. The estimated coefficients for the three main challenges are presented in Table 5.[10] Generally, for win-win non-adopters and some constraints, education, liability ratio, lease ratio, land quality, and longitude emerged as important factors. To be specific, win-win non-adopters with a higher liability ratio tended to perceive “high installation cost”, “cash flow constraints”, “weather and climate factors”, and “uncertainty outcomes” to be more challenging barriers. A higher liability ratio implies a more limited capacity to borrow from lenders and, therefore, restricts the ability to overcome the potential challenges that a new practice presents. Therefore, capital constraints aggravate the severity of potential barriers and prevent the adoption of rotational grazing among win-win non-adopters.

Similarly, a higher lease ratio was associated with stronger views among win-win non-adopters that “water resource”, “labor or time management”, “ranch conditions”, and “rental agreement restrictions” are constraining. Lessees had little incentive to develop water resources, improve ranch conditions, or increase labor inputs on land they did not own and were, therefore, more likely to perceive rental agreement restrictions as challenging when compared to ranchers who own land. This finding is consistent with other studies that find uncertainty due to short-term leases inhibits tenants’ willingness to adopt conservation practices (Carolan et al., 2004; Tong et al., 2017; Ranjan et al., 2019; Leonhardt et al., 2021). By contrast, when non-adopting ranchers had a higher percentage of high-quality land, as indicated by an increased proportion of the area within a 1-mile radius with productivity classifications LCC I or II, then “labor or management time constraint”, “weather or climate factors”, and “rental agreement restrictions” were perceived as being less challenging.

[10] The estimated coefficients for the other five challenges can be found in the SM, Tables C7-C8.

3.4 Subsidy Responses among Non-adopters

As is shown in Figure 6, win-win non-adopters expressed greater willingness to adopt both LRG and MIG than did other non-adopters when offered a one-time subsidy. Win-win non-adopters were more subsidy elastic than other non-adopters for LRG adoption when a $30 subsidy was offered. To be specific, the percentage increase in the probability of adopting LRG among win-win non-adopters was about 1.32% in response to a 1% subsidy, while the corresponding change among other non-adopters was about 1.18%.

The average marginal effects of logit estimations are provided in Table 6. When compared with other non-adopters, win-win non-adopters' adoption decisions were significantly affected by initial costs. We infer that capital constraints associated with potential barriers can be relieved by incentive subsidies. In addition, win-win non-adopters' LRG or MIG adoption intentions were more responsive to subsidies compared to other non-adopters. When a one-time subsidy increases by one dollar per acre, the probability of LRG adoption increases by 0.9% and 0.5% among win-win non-adopters and other non-adopters, respectively. For MIG adoption, when a subsidy increases by one dollar per acre, win-win non-adopters and other non-adopters' adoption probability increases by 0.5% and 0.4%, respectively.

In addition, win-win non-adopters were more likely to adopt LRG and MIG when a relatively smaller proportion of the area within a 1-mile radius consisted of good-quality soil and flatter lands. This suggests that one potential motivation of these ranchers is to improve ranch conditions and related environmental outcomes of grazing operations. Consistent with this finding, Basarir and Gillespie (2006) emphasized that beef producers regard environmental goals as an important factor influencing decision making. Fewer operating years was also associated with a stronger willingness to adopt LRG, implying that incentive subsidies will likely be more effective among the relatively new grazing operators. These findings suggest that win-win non-adopters should be a suitable target group for incentive subsidy programs to increase the adoption rate of rotational grazing, especially those with poor soil conditions and shorter operating years.

To illustrate the policy implications of our estimate, we develop back-of-the-envelope estimates of subsidy impacts for rotational grazing adoption in the areas. First, we calculate the weighted average marginal effect of subsidies on rotational grazing adoption among non-adopters. Based on the estimated values for LRG in Table 6, when a one-time subsidy increases by one dollar per acre then the probability of adopting LRG will increase by 0.9% among win-win non-adopters, and the probability will increase by 0.5% among other non-adopters. Given the proportions of win-win (56.5%) and other non-adopters (43.5%) in our sample, we calculate the weighted average marginal effect of subsidies on LRG adoption as about 0.7%. Thus we infer an one dollar per acre one-time subsidy increase increases non-adopters' probability of adopting LRG will by about 0.7% on average. To simplify the calculation, we assume that win-win non-adopters and other non-adopters have the same proportions in the areas as our sample and the subsidy estimates for LRG approximate those for general rotational grazing. Next, we draw upon the number of rotational grazing operations from USDA National Agricultural Statistics Service (2017) and calculate the number of non-adopters in each area. We then calculate that a $10/acre increase in a one-time subsidy would lead to about 231, 411, and 8,233 more rotational grazing operations in North Dakota, South Dakota, and Texas, respectively (Table 7).

4. Conclusions

This paper seeks to understand why some ranchers view rotational grazing as a profit-increasing practice with some potential positive environmental outcomes but do not adopt it. We first identify a large proportion of non-adopters who regard rotational grazing as a win-win practice based on a farm survey. Our survey sample allows us to identify the main barriers that constrain win-win non-adopters, including high installation costs, water resource constraints, and ranch conditions. These constraints are challenging since the non-adopters in question likely have limited borrowing capacity and little access to operating capital. We also explore how the win-win non-adopters would respond in their adoption decision were a one-time subsidy provided. We find that operators with poor soil conditions and shorter operating years would be more likely to adopt rotational grazing in response to subsidies.

Our findings have several policy implications. One is that win-win non-adopters are a potential target group for investment subsidies intended to ultimately realize the win-win possibilities for more ranchers. Grazing is a more environmentally friendly way to use the land than cropping, as it could prevent cropping consequences with negative externalities, such as nutrient and chemical runoff, soil erosion, and weed invasion. Thus, making grazing more profitable would discourage conversion to cropping and so would improve social welfare. Another implication regards how it can help those promoting rotational grazing strategies better reach and persuade ranchers by understanding the factors that ranchers consider and the specific circumstances they face. Policymakers can deliver the specific type of assistance the ranchers need in a format compatible with their capabilities. Informal institutions can help policymakers to better understand local conditions and individual producers' circumstances and thus play a positive role in assisting existing policy instruments in natural resource management or grassland protection (Li et al., 2021). A third implication is that incentive policies are likely to be more effective in changing decisions when they adequately address the costs and operational constraints that ranchers face. Limited availability of capital can give rise to liquidity constraints and exacerbate the effects of risk aversion, and is one of the most highlighted constraints to rotational grazing adoption. Financial incentive programs that mitigate ranchers' capital constraints will likely improve the overall adoption rate. Overall, our study underlines the need to fully understand ranch and rancher circumstances, including ranchers' views on profit and environmental outcomes, when developing sound and effective policymaking to promote conservation practices.

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Figures and Tables

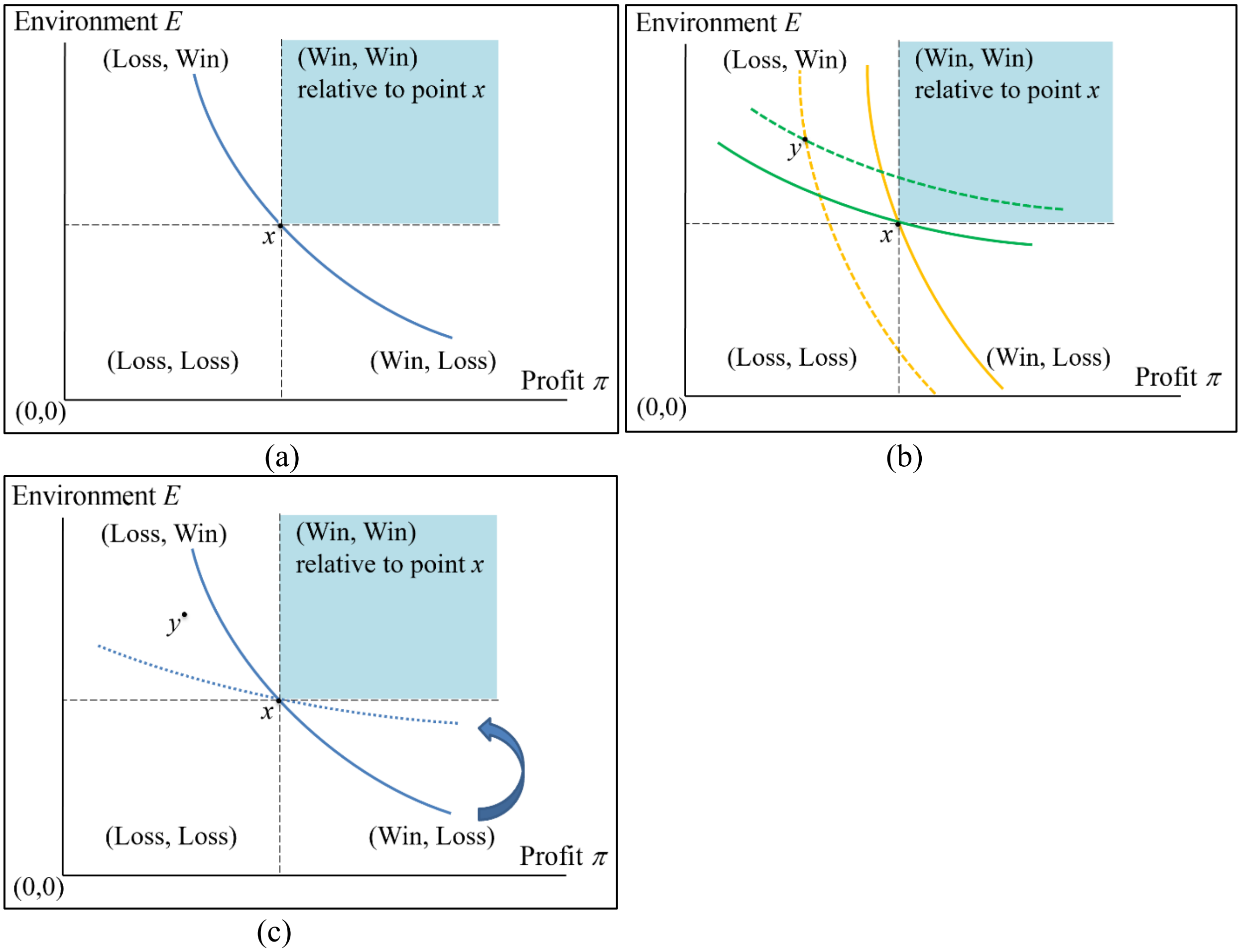


Figure 1 Trade-off between profit and environmental outcomes in a rancher's choice between continuous grazing and rotation grazing. (a) An illustration of a utility curve; (b) an illustration of two ranchers' different preferences toward rotational grazing; (c) an illustration of the impacts of a policy that shifts a rancher's preference toward the environment.

Note: Point x represents the outcomes of continuous grazing; point y represents the outcomes of rotational grazing; and the curves are utility indifference curves.

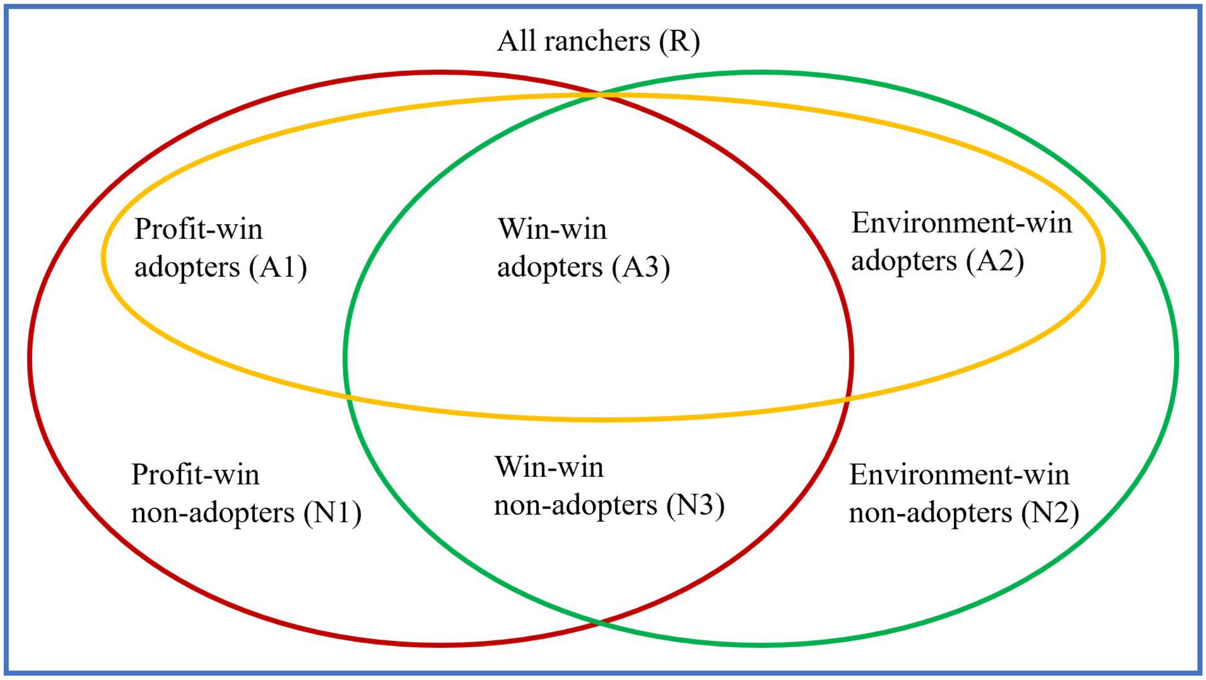
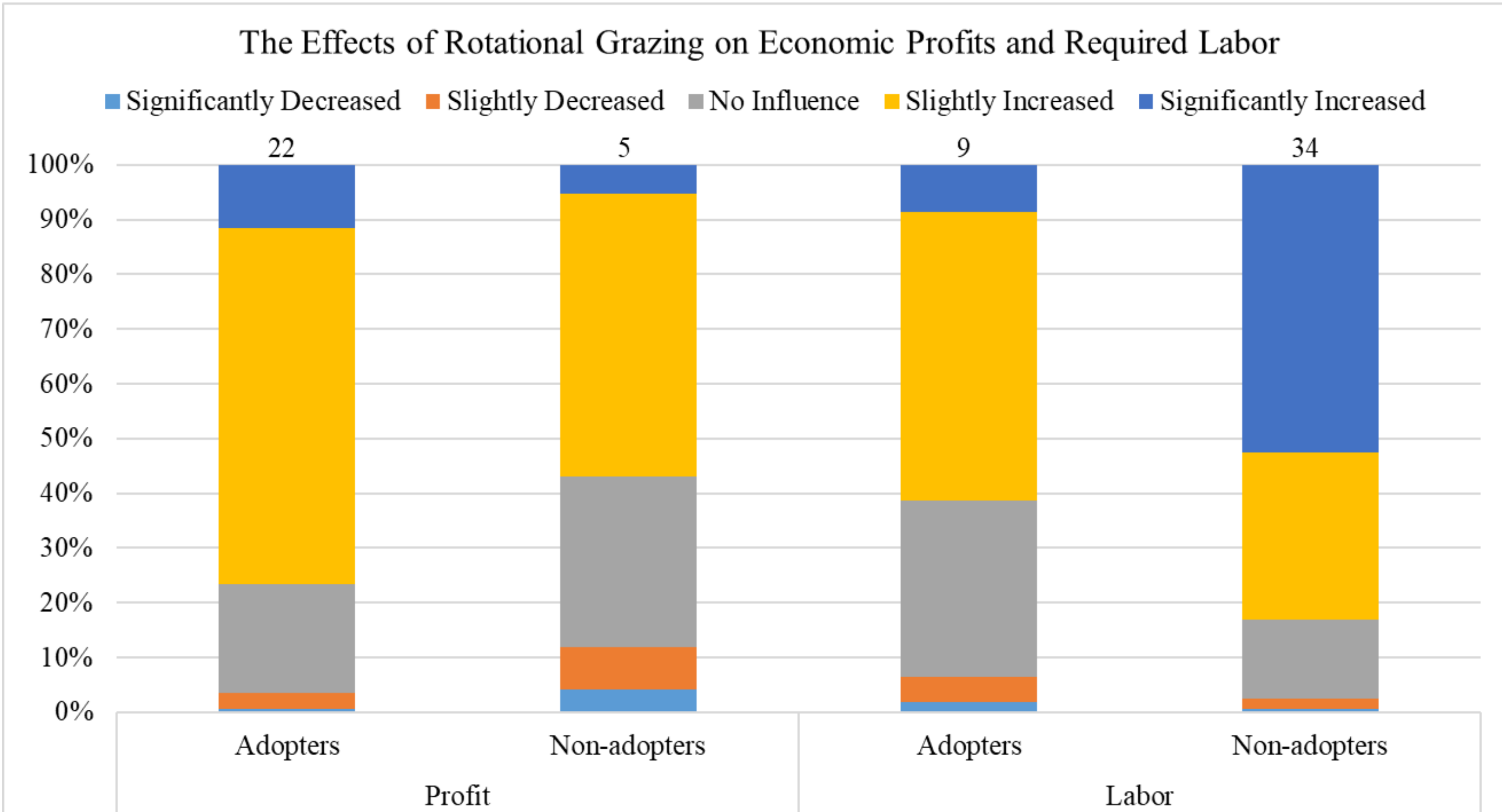


Figure 2 Clarification of "adoption gap"

Notes: The large blue rectangle (R) represents all ranchers. The red oval (A1+N1+A3+N3) represents ranchers who view rotational grazing as a win practice for profit. The green oval (A2+N2+A3+N3) represents ranchers who view rotational grazing as a win practice for the environment. The intersection of red and green ovals (A3+N3) represents ranchers who view rotational grazing as a win-win practice. The orange oval (A1+A2+A3) represents rotational grazing adopters. The area N3 represents win-win non-adopters. The adoption gap (N3/(A3+N3)) is measured as the proportion of win-win non-adopters among the ranchers with win-win views.



Note: The number on top of each column represents the ratio of those who regarded rotational grazing as either slightly or significantly increasing over those who regarded rotational grazing as either slightly or significantly decreasing an outcome.

Figure 3 Adopter and non-adopter opinions about the effects of rotational grazing adoption on ranch profit during the first five years, and on needed labor and management time

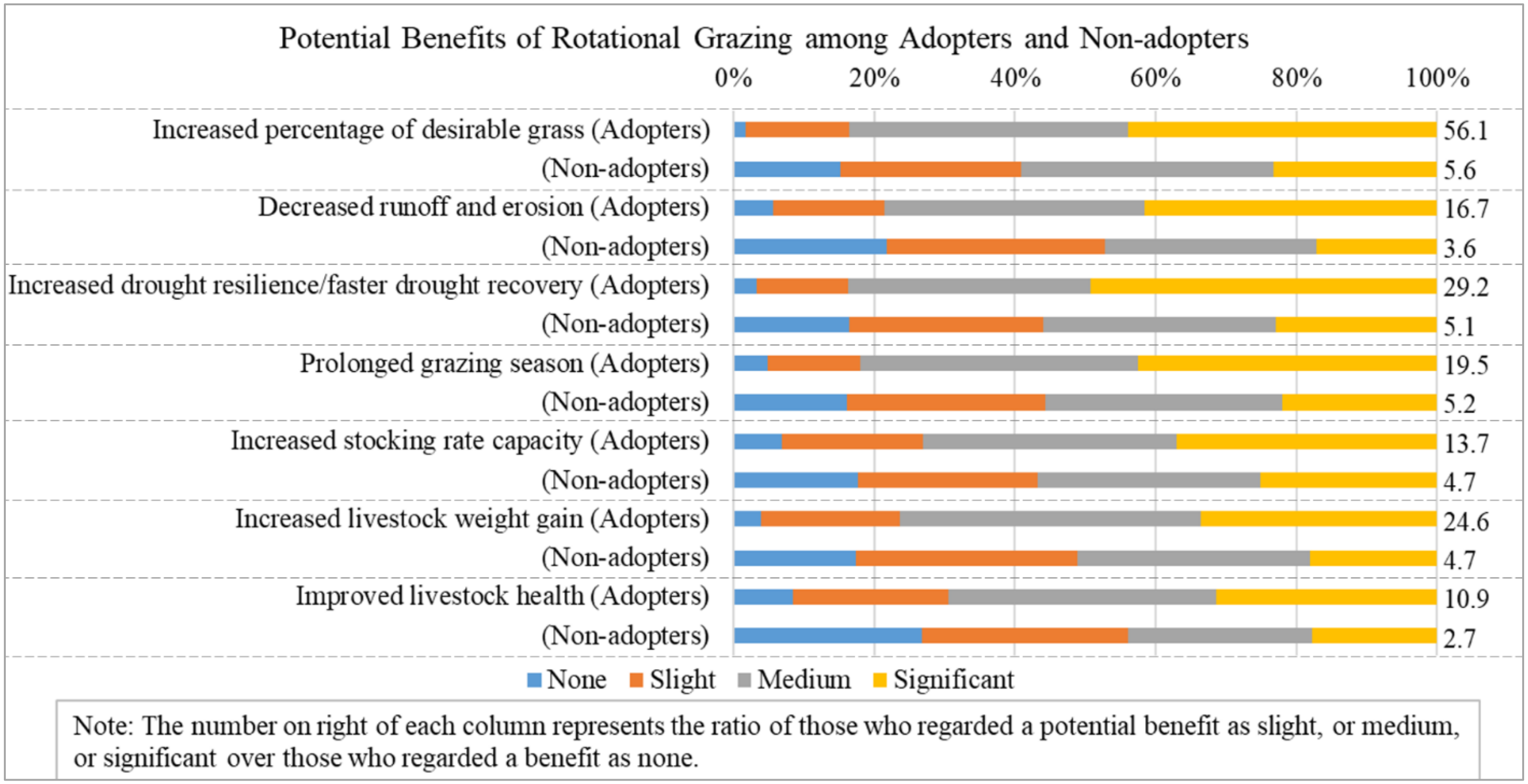


Figure 4 The potential benefits associated with rotational grazing practices among adopters and non-adopters

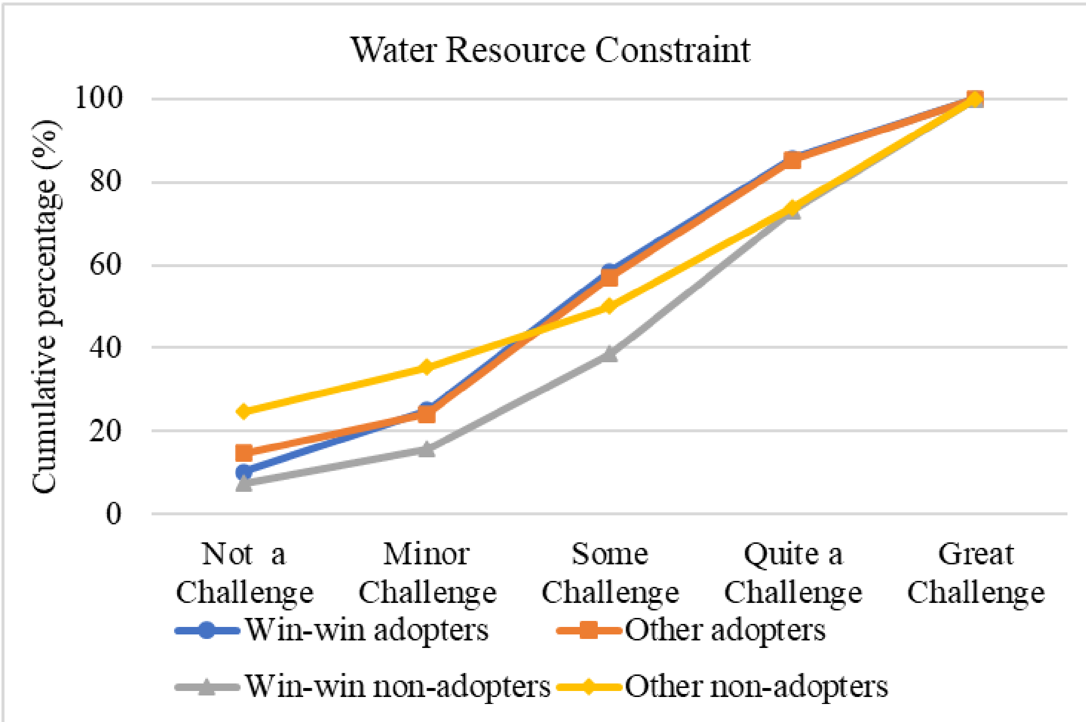


Figure 5 Cumulative percentage of responses to different challenge levels of "water resource constraint" among four groups of ranchers

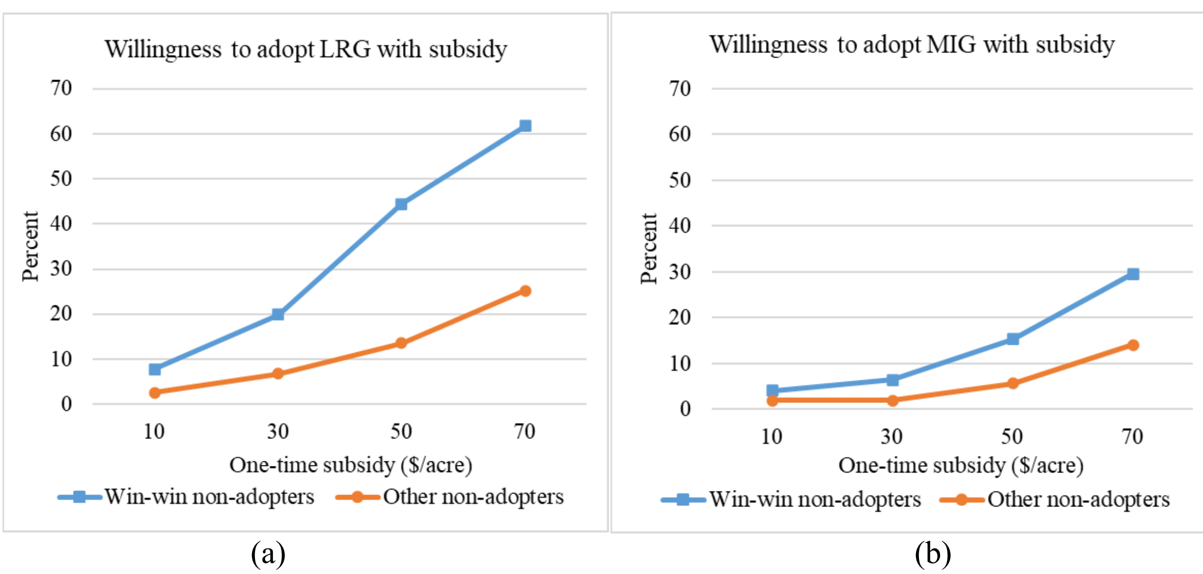


Figure 6 Non-adopters' willingness to adopt LRG or MIG when faced with a hypothetical one-time subsidy

Table 1 Summary statistics for rancher and ranch characteristics

	Win-win adopters				Win-win non-adopters			
Variables	Obs	Mean	Min	Max	Obs	Mean	Min	Max
Operating years	338	34.75	2	68	158	37.32	1	67
Education	340	3.26	1	5	160	3.23	1	5
Liability ratio	327	2.65	1	6	152	2.63	1	6
Grazing acres	330	3,078	0	55,075	156	2,167	0	41,000
Grazing land share	328	0.69	0	1	156	0.66	0	1
Lease ratio	327	0.36	0	1	155	0.29	0	1
Distance	336	11.15	0	200	156	10.29	0	200
LCC I or II	341	46.93	0	100	159	43.84	0	100
Slope ≤ 3%	341	37.84	0	100	159	44.01	0	100
Latitude	341	42.14	30.71	48.84	159	40.59	30.52	48.98
Longitude	341	-99.40	-103.76	-95.87	159	-99.22	-103.49	-95.77
TX	342	0.27	0	1	161	0.40	0	1

Table 2 Economic and environmental outcomes of rotational grazing adoption

Adopters		Economic Profit		
		Improved	*Worsened*	*No impact*
Environmental Outcomes	*Improved*	(Win, Win) 76.4%	(Win, Loss) 3.5%	(Win, No change) 19.5%
	No impact	(No change, Win) 0.2%	(No change, Loss) 0.0%	(No change, No change) 0.4%

Non-adopters		Economic Profit		
		Improved	*Worsened*	*No impact*
Environmental Outcomes	*Improved*	(Win, Win) 56.5%	(Win, Loss) 9.7%	(Win, No change) 23.0%
	No impact	(No change, Win) 1.8%	(No change, Loss) 2.2%	(No change, No change) 6.8%

Notes: (i) Among 520 adopters, 58 (about 11.2%) did not provide any responses to related questions on both economic and environmental outcomes of rotational grazing adoption; among 354 non-adopters, 76 (about 21.5%) did not provide any responses. We do not include those missing observations in the above tables. (ii) For economic profit, ranchers' responses are combined into three categories: "improved", "worsened", and "no impact." For environmental outcomes, there are only two categories: "improved" and "no impact." (iii) The adoption gap is 34%, which is calculated as the proportion of win-win non-adopters among all the ranchers with win-win views.

Table 3 Mean values and t-tests for ranking differences of potential challenges between some rancher groups

Potential Challenges	Win-win adopters		Win-win non-adopters		Other non-adopters		*t*-test (win-win non-adopters vs win-win adopters)		*t*-test (other non-adopters vs win-win non-adopters)	
	Mean	Ranking	Mean	Ranking	Mean	Ranking	*t*	Pr(|T| > |t|)	*t*	Pr(|T| > |t|)
High installation cost	2.850	3	3.555	2	3.188	2	6.668	0.000	-2.379	0.018
Water resource constraint	3.206	1	3.648	1	3.162	3	3.802	0.000	-2.958	0.003
Labor/management time constraints	2.832	4	3.552	3	3.313	1	6.417	0.000	-1.527	0.128
Cash flow constraints	2.524	6	2.945	5	3.031	5	3.779	0.000	0.536	0.592
Uncertain outcomes	2.080	7	2.785	7	2.924	7	6.562	0.000	0.888	0.375
Rental agreement restrictions	1.994	8	2.314	8	2.376	8	2.468	0.014	0.35	0.727
Lack of information/education/support	1.737	9	2.155	9	2.254	9	4.319	0.000	0.655	0.513
Ranch conditions	2.761	5	3.418	4	3.039	4	5.514	0.000	-2.226	0.027
Unfavorable neighborhood opinions	1.346	11	1.455	11	1.603	11	1.317	0.188	1.215	0.225
Unwillingness to take on leadership in new practices adoption	1.465	10	1.819	10	1.896	10	4.141	0.000	0.551	0.582
Weather/climate factors	2.911	2	2.876	6	2.945	6	-0.257	0.798	0.390	0.697

Table 4 Frequency of comments made in 12 categories and frequency comparison by different groups of ranchers

Category	Comment frequency summary: Total comments	Comment frequency summary: Ranchers making at least one comments in category	Frequency of comments of subgroups and comparisons: Win-win adopters	Win-win non-adopters	Win-win non-adopters	Other non-adopters
Water	70	61	0.190	0.244	0.244	0.140
Fencing	42	39	0.164	0.133	0.133	0.093
Cost	30	29	0.086**	0.200**	0.200	0.116
Labor	23	22	0.086	0.111	0.111	0.070
Government support	23	22	0.121**	0.000**	0.000	0.000
Rent	22	18	0.112	0.089	0.089	0.023
Retirement or age	20	18	0.052	0.067	0.067	0.116
Environmental benefits	9	9	0.069*	0.000*	0.000	0.000
Land characteristics	8	8	0.009***	0.089***	0.089	0.023
Ranch scale	6	6	0.000***	0.067***	0.067	0.070
Neighborhood	4	4	0.017	0.000	0.000	0.023
Other	152	124				
Total	346	237				

Notes: (i) ***, **, * denote response frequency differences between win-win adopters and win-win non-adopters, as well as between win-win non-adopters and other non-adopters are significant at the 1%, 5%, and 10% level, respectively. (ii) Each surveyed rancher might report more than one comment.

Table 5 Ordered logit estimated coefficients for “water resource constraint”, “high installation cost”, and “ranch conditions”

Variables	Water resource constraint			High installation cost			Ranch conditions		
	Win-win adopters	Win-win non-adopters	Other non-adopters	Win-win adopters	Win-win non-adopters	Other non-adopters	Win-win adopters	Win-win non-adopters	Other non-adopters
Operating years	-0.019**	0.014	0.007	-0.012	0.011	0.012	-0.003	0.012	0.009
Education	-0.056	0.352*	0.418*	-0.079	-0.032	0.499**	0.092	0.190	0.453*
Liability ratio	0.017	-0.141	-0.136	0.016	0.355**	0.004	0.079	0.132	-0.255
Grazing acres	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	0.000	-0.000
Grazing land share	-1.522***	-0.959	-3.060***	-0.771	0.024	-2.079**	-0.885*	-0.433	-1.913**
Lease ratio	0.449	1.762***	0.489	0.394	0.367	0.470	0.261	1.490***	0.938
LCC I or II	-0.000	-0.005	-0.007	0.001	-0.008	-0.004	0.003	-0.006	-0.010
Slope ≤ 3%	0.000	-0.007	-0.014**	-0.002	-0.007	-0.010	0.003	-0.006	-0.012*
Distance	0.004	-0.002	0.015	0.001	-0.004	0.009	-0.000	-0.002	0.011
Latitude	-0.049	0.151	0.236	-0.039	0.076	0.024	-0.114	0.143	-0.036
Longitude	-0.259***	0.209	-0.101	-0.246***	0.333**	-0.038	-0.311***	0.252*	-0.385**
TX	0.233	1.276	3.095	0.372	0.737	0.818	-0.860	1.483	-0.200
Observations	311	127	94	310	128	97	310	128	94

Note: ***, **, * denote $p<0.01$, $p<0.05$, and $p<0.1$, respectively.

Table 6 Average marginal effects for logit regression of future adoption intentions with a one-time subsidy among non-adopters

	LRG adoption		MIG adoption	
	Win-win non-adopters	Other non-adopters	Win-win non-adopters	Other non-adopters
Subsidy	0.009(0.001)***	0.005(0.001)***	0.005(0.001)***	0.004(0.001)***
Initial costs	-0.038(0.019)**	-0.018(0.013)	-0.061(0.016)***	0.008(0.011)
Labor	-0.011(0.032)	-0.025(0.018)	0.001(0.020)	0.002(0.013)
Operating years	-0.003(0.002)*	-0.003(0.001)**	0.001(0.001)	0.000(0.001)
Education	0.030(0.021)	0.025(0.020)	0.004(0.015)	0.013(0.016)
Grazing acres	0.000(0.000)*	0.000(0.000)	0.000(0.000)	0.000(0.000)
LCC I or II	-0.002(0.001)**	0.001(0.001)	0.001(0.001)	0.000(0.000)
Slope ≤ 3%	-0.001(0.001)***	-0.001(0.001)	-0.001(0.000)***	0.000(0.000)
Distance	0.001(0.001)	0.000(0.001)	0.001(0.001)	-0.004(0.002)*
Latitude	-0.008(0.013)	0.040(0.017)**	0.015(0.014)	0.001(0.012)
Longitude	0.007(0.015)	-0.010(0.013)	0.033(0.015)**	-0.013(0.011)
TX	-0.153(0.152)	0.508(0.214)**	0.379(0.177)**	-0.047(0.150)

Notes: (i) ***, **, * denote p<0.01, p<0.05, and p<0.1, respectively. (ii) Standard errors are in parentheses.

Table 7 Estimates of subsidy impacts on rotational grazing adoption

Year	ND	SD	TX	United States
USDA NASS 2017 Data				
Total number of cattle, goat, and sheep operations	6,316	10,326	155,685	852,907
Number of rotational grazing operations	3,019	4,449	38,070	265,162
Number of non-adopters	3,297	5,877	117,615	587,745
Rotational grazing adoption rate	0.48	0.43	0.24	0.31
Estimated impacts of a $10/acre increase in a one-time subsidy				
Increase in number of rotational grazing operations	231	411	8,233	41,142
Expected number of rotational grazing operations	3,250	4,860	46,303	306,304
Expected rotational grazing adoption rate	0.51	0.47	0.30	0.36

Supplemental Materials for
"Will adoption occur if a practice is win-win for profit and the environment? An application to a rancher's grazing practice choices"

A. Questions in Survey Instrument

This section contains images of the main survey questions used in this paper.

Before continuing with the questionnaire, please read the following definitions to make sure that you understand how we are using terms in this survey.

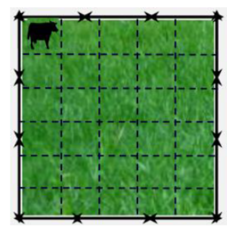
Continuous Grazing	**Rotational Grazing**	**Management Intensive Grazing (MIG)**
Livestock have unrestricted access to the entire pasture or rangeland throughout the grazing season.	Usually 4 to 15 pastures per herd are used and livestock **graze on each paddock for weeks or months** before moving to the next one.	More pastures (usually 16+) per herd are used with short grazing periods of 1 to 14 days followed by a grass recovery period of 20 to 100 days.
		

Figure A1 Definitions of different grazing strategies in the survey questionnaire
Note: Rotational grazing here refers to low-intensity rotational grazing (LRG).

18. Whether or not you have adopted, please indicate what you observe or expect regarding the following possible benefits associated with rotational grazing or MIG practices on your ranch or neighboring ranches.

Potential Benefits	**None**	**Slight**	**Medium**	**Significant**
Increased percentage of desirable grass	☐	☐	☐	☐
Decreased runoff and erosion	☐	☐	☐	☐
Increased drought resilience/faster drought recovery	☐	☐	☐	☐
Prolonged grazing season	☐	☐	☐	☐
Increased stocking rate capacity	☐	☐	☐	☐
Increased livestock weight gain	☐	☐	☐	☐
Improved livestock health	☐	☐	☐	☐

Figure A2 Question about potential benefits associated with rotational grazing adoption

19. Please rate the challenges that you have encountered when practicing rotational grazing or MIG, or how these challenges are hindering your adoption decisions.

Potential Challenges	Not a Challenge	Minor Challenge	Some Challenge	Quite a Challenge	Great Challenge
High installation cost	☐	☐	☐	☐	☐
Water source constraint	☐	☐	☐	☐	☐
Labor/management time constraints	☐	☐	☐	☐	☐
Cash flow constraints	☐	☐	☐	☐	☐
Uncertain outcomes	☐	☐	☐	☐	☐
Rental agreement restrictions	☐	☐	☐	☐	☐
Lack of information/education/support	☐	☐	☐	☐	☐
Ranch conditions (e.g., size and water availability issues)	☐	☐	☐	☐	☐
Unfavorable neighborhood opinions	☐	☐	☐	☐	☐
Unwillingness to take on leadership in new practices adoption	☐	☐	☐	☐	☐
Weather/climate factors	☐	☐	☐	☐	☐

For other challenges not listed above, please describe and rate them here: ________________________________

________________________________.

Figure A3 Question about potential challenges of rotational grazing adoption

27. How has your adoption of rotational grazing or MIG affected (or will likely affect) the economic profit of your ranch **during the first 5 years?**

Effect on profitability in the first 5 years	Significantly Decreased	Slightly Decreased	No Influence	Slightly Increased	Significantly Increased
Rotational grazing	☐	☐	☐	☐	☐
MIG	☐	☐	☐	☐	☐

Figure A4 Question about economic profit of rotational grazing for adopters

33. To what degree do you think that rotational grazing or MIG might affect the economic profit of your ranch in the first 5 years?

Effect on profitability in the first 5 years	Significantly Decrease	Slightly Decrease	No Influence	Slightly Increase	Significantly Increase
Rotational grazing	☐	☐	☐	☐	☐
MIG	☐	☐	☐	☐	☐

Figure A5 Question about economic profit of rotational grazing for non-adopters

37. If a one-time subsidy were available to those willing to adopt rotational grazing or MIG practices, then would you adopt?

One-time Subsidy	37a. **Rotation grazing adoption**			37b. **MIG adoption**		
	Yes	No	Not sure	Yes	No	Not sure
$10/acre	☐	☐	☐	☐	☐	☐
$30/acre	☐	☐	☐	☐	☐	☐
$50/acre	☐	☐	☐	☐	☐	☐
$70/acre	☐	☐	☐	☐	☐	☐

Figure A6 Question about non-adopters' willingness to adopt rotational grazing with a one-time subsidy

B. Supplemental Explanation for Environmental Benefits

Here we explain why the three potential benefits of rotational grazing ("decreased runoff and erosion", "increased drought resilience/faster drought recovery", and "increased percentage of desirable grass") are regarded as environmental benefits.

First, soil erosion is regarded as a major environmental and agricultural problem. Erosion events due to agricultural practice choices, including on grazed land, have occurred throughout recorded history and continue to occur (Pimentel et al., 1995). When erosion occurs then soil water holding capacity declines, possibly leading to further erosion, and less water becomes available for plant growth and for mobilizing what basic plant nutrients the remaining soil can hold.

Second, chronic defoliation in the presence of drought provides opportunities for alien species and weed invasions (McIvor, 2007; Teague et al., 2013), where droughts are common in many rangeland ecosystems. Increased drought resilience and faster recovery can mitigate such degradation effects and reduce stress on rangeland by providing few opportunities for less desirable grass, forbs and shrubs to expand and by improving underlying soil conditions and rangeland health, especially in the face of climate change (Teague et al., 2013).

Third, under rotational grazing the percentage of desirable grasses can increase to replace less desirable grasses and forbs. The dominance of high-seral grasses can improve water holding capacity and nutrient availability (Teague et al., 2013) by enhancing hydrological functions with a higher fungal to bacterial ratio (Pluhar et al., 1987; Teague et al., 2011). In addition, the area of bare ground declines and soil aggregate stability increases areas where high-seral grasses dominate under rotational grazing (Teague et al., 2011). Note that the abovementioned three environmental benefits would also provide ranchers with private benefits especially in the long run. Our focus is to understand why many ranchers do not adopt rotational grazing when they view it as profit increasing with some positive environmental outcomes.

C. Supplemental Figures and Tables

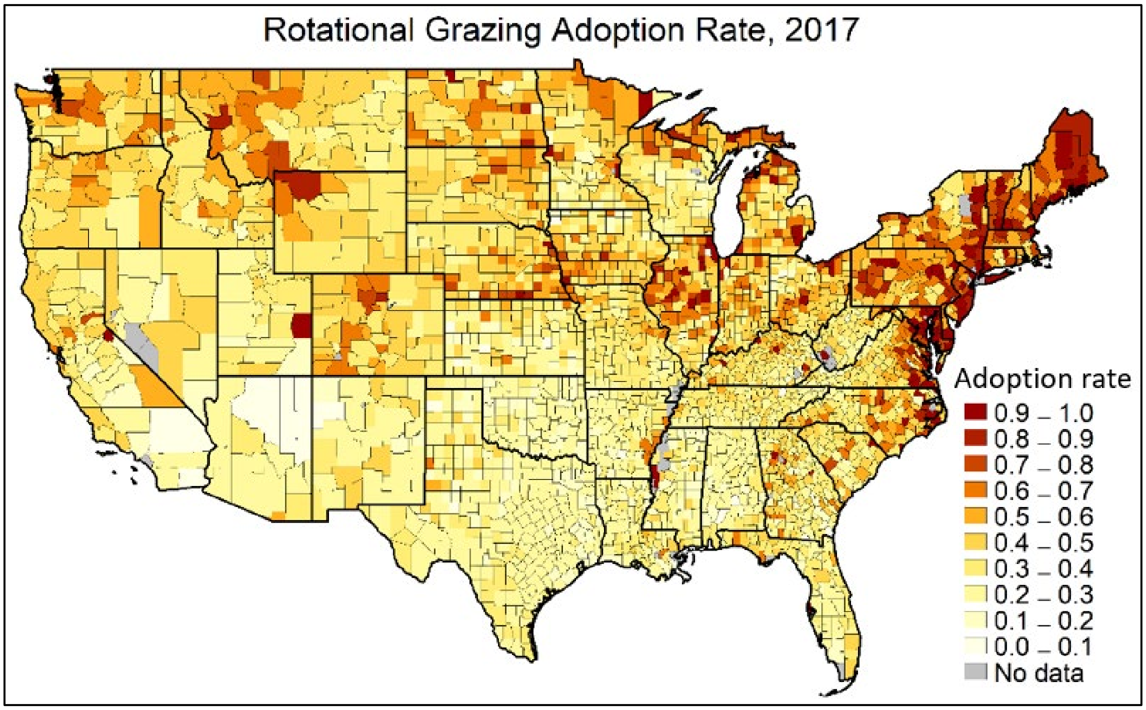


Figure C1 County-level rotational grazing adoption rates in 2017
Note: Adoption rate is calculated by dividing the number of rotational grazing operations over the total number of cattle, goat, and sheep operations within each county.

Table C1 Classification rubric for ranchers' comments regarding their ranching practices

Category	Comments containing or pertaining to					Typical comment
Water	water moisture	drought dry	rainfall rain			"There is no underground water resources" "Limited by access to water" "The uncertain rainfall and unpredictability of rain hinders MIG"
Fencing	fencing	fence	fences	wire	electronic	"Maintaining fences and water gaps" "Not enough water and cost of fencing"
Cost	cost costs costly	costly expensive extra	money pay	initial	maintenance	"Fencing is expensive, labor is expensive" "I like some rotational grazing but the MIG is too much labor and cost"
Labor	time	labor	management	work		"I don't think MIG would be practical for my situation because of lack of labor" "It is good for land but takes extra work"
Government or agency	government	cost-share	NRCS			"Cost-share agreement uncertainty and speculations and meeting deadlines quite a challenge" "I may do more rational grazing if cost-share programs improve"
Rent	rent	rented	leases	leased	landowner	"Hard to improve rented grow because of cost no long-term leases"
Retirement	renting retired	renters old	leasing age	contract	landlords	"I am reducing herd size and acres because of retirement." "We are too old."

Table C1 (continued)

Category	Comments containing or pertaining to					Typical comment
Environment benefits	better grass	weed control	good for land			"I have always used rotational grazing, as a management tool for better grass" "It is good for land"
Land characteristics	hilly	steep	soil	rocky	stony	"Our big pastures are on steep river bottom ground which is tough to work with, great challenge." "We own and rent pastures that are located in rough terrain hill."
	sandy	terrain	ground	rough		
Ranch scale	size	enough	small	larger	herd	"The size of my pastures is small (Great Challenge)." "I think rotational grazing can have benefits but the size of your pastures has to be fairly large for the costs to be feasible"
Neighborhood	neighbors	other	neighborhood	neighbor		"Neighbors' bulls are great challenge" "Unfavorable opinion by other ranch partners."

Table C2 Economic profit and environmental outcome ("decreased runoff and erosion") of rotational grazing adoption

Adopters		Economic Profit		
		Improved	*Worsened*	*No impact*
Environmental Outcome	*Improved*	(Win, Win) 72.7%	(Win, Loss) 3.5%	(Win, No change) 18.4%
	No impact	(No change, Win) 3.9%	(No change, Loss) 0.0%	(No change, No change) 1.5%

Non-adopters		Economic Profit		
		Improved	*Worsened*	*No impact*
Environmental Outcome	*Improved*	(Win, Win) 49.3%	(Win, Loss) 9.0%	(Win, No change) 20.5%
	No impact	(No change, Win) 9.0%	(No change, Loss) 2.9%	(No change, No change) 9.4%

Notes: To check for robustness, this table only considers one environmental benefit, i.e., "decreased runoff and erosion". A "win" for environmental outcome means that ranchers thought rotational grazing adoption decreased runoff and erosion.

Table C3 Mean values and t-test of initial investment costs and annual maintenance costs by group

Category	Win-win adopters	Win-win non-adopters	Win-win non-adopters	Other non-adopters
Initial investment costs	3.393	3.355	3.355	3.579
Annual maintenance costs	2.925	2.770	2.770***	3.323***

Note: ***, **, * denote response frequencies are different at the 1%, 5%, and 10% significance levels.

Table C4 Mean values and t-test of the importance of management goals by group

Management goals	Win-win adopters	Win-win non-adopters	Win-win non-adopters	Other non-adopters
Maintain high economic returns	4.136	4.064	4.064	4.110
Breed high-quality stock	4.299	4.234	4.234	4.100
Improve soil/grassland quality	4.222*	4.082*	4.082	3.944
Improve water quality/wildlife habitat	3.884**	3.667**	3.667	3.586
Be considered one of the best ranchers	2.703	2.748	2.748	2.746
Achieve a desirable work-life balance	3.781	3.748	3.748	3.613

Note: ***, **, * denote response frequencies are different at the 1%, 5%, and 10% significance levels.

Table C5 Mean values and t-test of potential benefits of rotational grazing by group

Potential Benefits	Win-win adopters	Win-win non-adopters	Win-win non-adopters	Other non-adopters
Increased percentage of desirable grass	3.330***	3.019***	3.019***	2.331***
Decreased runoff and erosion	3.181***	2.689***	2.689***	2.161***
Increased drought resilience/faster drought recovery	3.363***	2.988***	2.988***	2.265***
Prolonged grazing season	3.298***	3.000***	3.000***	2.235***
Increased stocking rate capacity	3.196	3.100	3.100***	2.191***
Increased livestock weight gain	3.173***	2.851***	2.851***	2.181***
Improved livestock health	2.997***	2.652***	2.652***	2.044***

Note: ***, **, * denote response frequencies are different at the 1%, 5%, and 10% significance levels.

Table C6 Ordered logit estimated coefficients for “labor management constraints”, “cash flow constraints”, and “weather/climate factors”

Variables	Labor management constraints			Cash flow constraints			Weather/Climate factors		
	Win-win adopters	Win-win non-adopters	Other non-adopters	Win-win adopters	Win-win non-adopters	Other non-adopters	Win-win adopters	Win-win non-adopters	Other non-adopters
Operating years	-0.018*	0.023	0.015	-0.016*	-0.003	0.024	0.001	0.010	0.031*
Education	0.060	0.136	0.603**	0.062	0.072	0.136	0.211*	-0.084	-0.138
Liability ratio	0.130	0.100	-0.184	0.139*	0.431***	-0.001	0.001	0.560***	-0.317**
Grazing acres	-0.000	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	0.000
Grazing land share	-1.221**	0.149	-2.919***	-0.680	1.036	-1.437	0.108	0.229	-0.418
Lease ratio	0.144	1.962***	0.491	-0.039	0.650	0.459	-0.228	-0.309	-0.154
LCC I or II	0.001	-0.013**	-0.008	-0.000	-0.008	-0.004	0.004	-0.013**	-0.005
Slope ≤ 3%	0.002	-0.006	-0.007	0.002	-0.001	-0.014**	0.004	-0.006	-0.002
Distance	0.004	-0.008	0.018*	0.007	-0.002	0.018*	-0.002	-0.006	0.008
Latitude	-0.060	0.203	0.073	-0.073	-0.118	0.263	-0.146*	0.139	0.179
Longitude	-0.211***	0.202	-0.162	-0.096	-0.101	-0.051	-0.288***	0.280*	-0.145
TX	-0.704	0.669	1.151	-0.894	-2.022	3.611*	-1.104	1.538	2.544
Observations	310	126	94	311	127	94	308	127	93

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

Table C7 Ordered logit estimated coefficients for "uncertain outcomes" and "rental agreement restrictions"

Variables	Uncertain outcomes			Rental agreement restrictions		
	Win-win adopters	Win-win non-adopters	Other non-adopters	Win-win adopters	Win-win non-adopters	Other non-adopters
Operating years	0.001	0.003	0.030*	-0.013	0.012	0.015
Education	0.084	-0.005	0.119	-0.149	-0.205	0.129
Liability ratio	0.138	0.561***	-0.142	0.022	0.112	-0.268
Grazing acres	-0.000	-0.000	-0.000	0.000	0.000	-0.000
Grazing land share	-0.669	-0.424	-1.113	-0.758	-0.298	-1.830*
Lease ratio	-0.527	-0.178	0.927	1.064***	1.406**	1.330**
LCC I or II	0.005	-0.004	-0.002	0.004	-0.014**	-0.011
Slope ≤ 3%	0.004	-0.006	-0.006	-0.001	-0.008	-0.002
Distance	0.001	-0.008	0.017	0.009**	-0.000	0.018*
Latitude	-0.121	-0.116	-0.004	-0.007	0.080	-0.029
Longitude	-0.276***	-0.032	-0.274*	-0.040	0.245	-0.089
TX	-0.980	-1.279	0.297	-0.090	-0.141	0.398
Observations	310	126	95	305	123	92

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

D. Cumulative Percentage of Responses to Potential Challenge

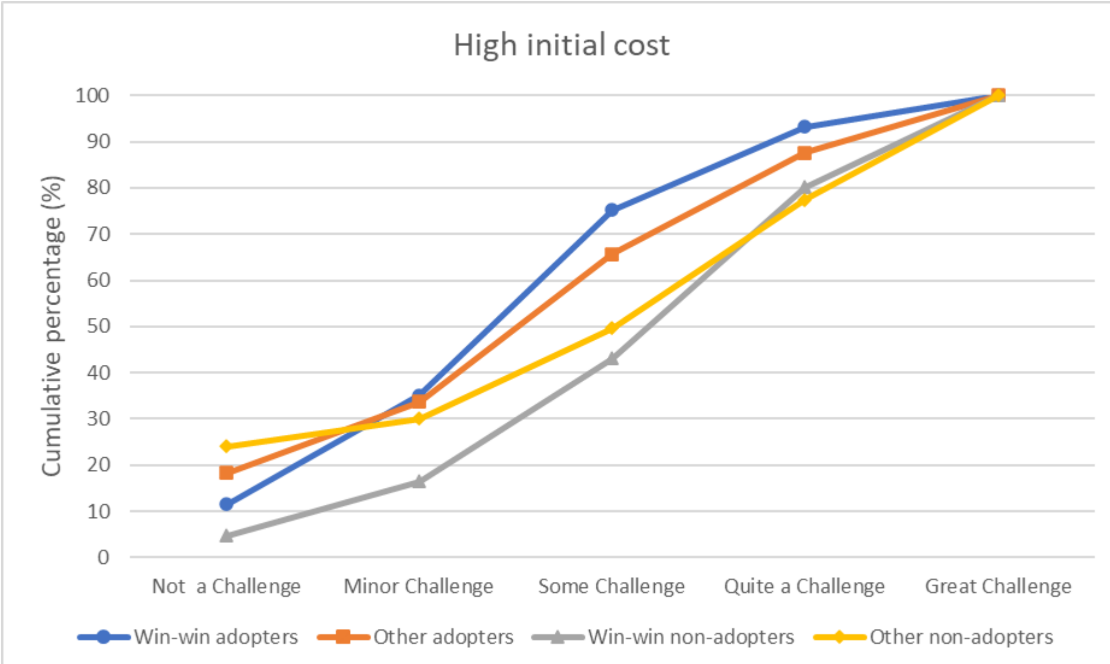


Figure D1 Cumulative percentage of responses to different challenge levels of "high initial cost" among four groups of ranchers

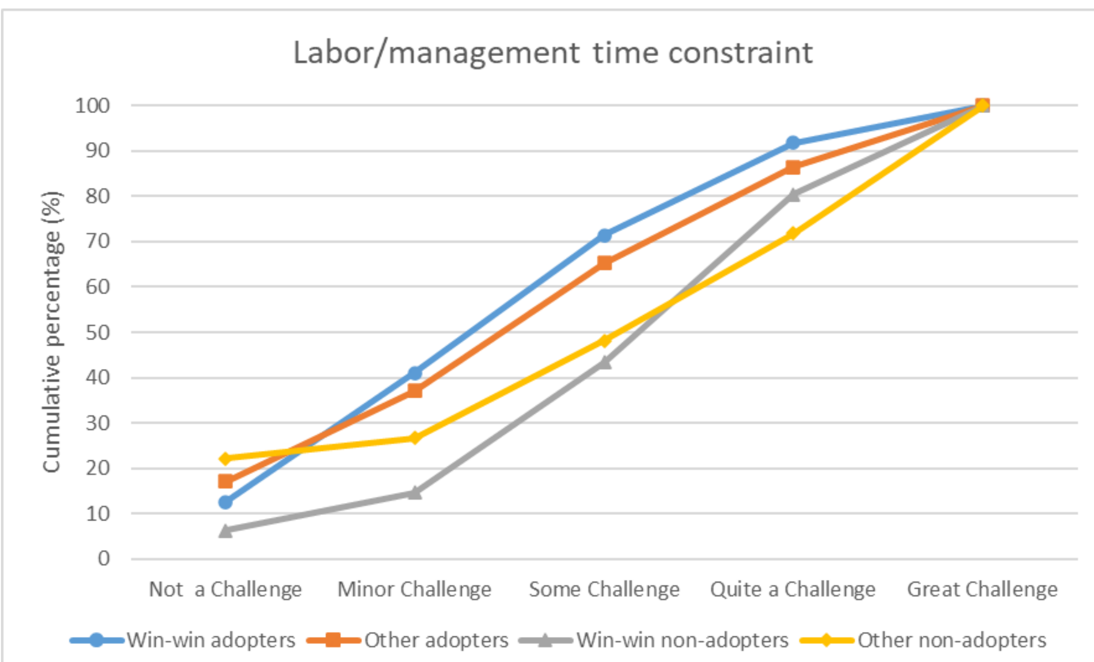


Figure D2 Cumulative percentage of responses to different challenge levels of "labor/management time constraint" among four groups of ranchers

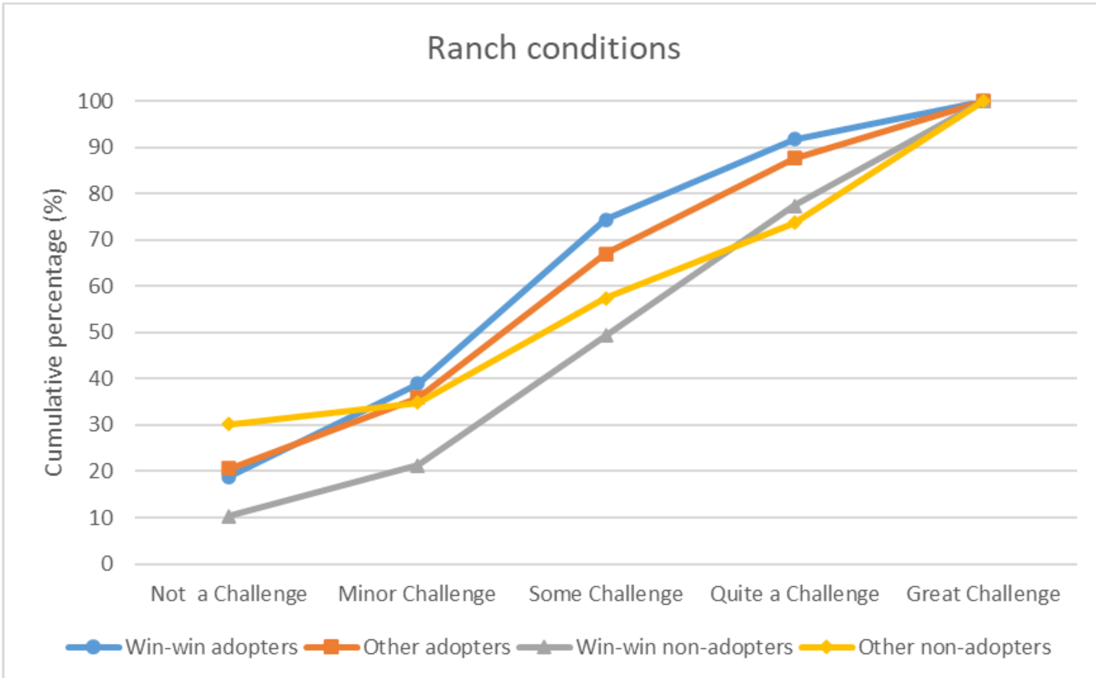


Figure D3 Cumulative percentage of responses to different challenge levels of “ranch conditions” among four groups of ranchers

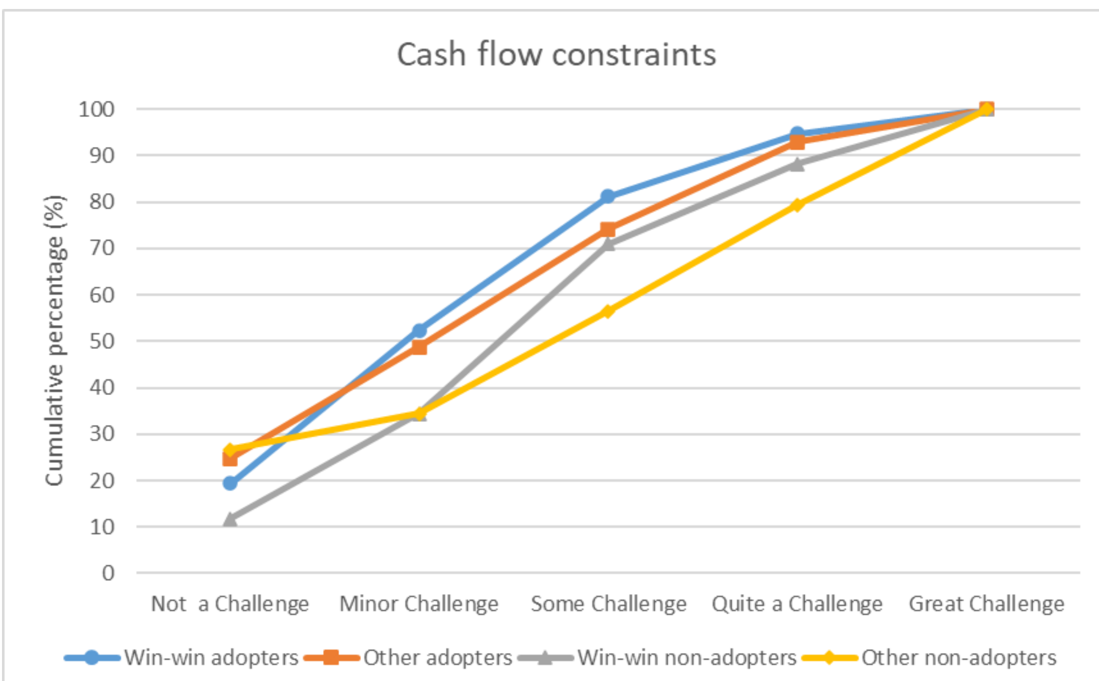


Figure D4 Cumulative percentage of responses to different challenge levels of “cash flow constraints” among four groups of ranchers

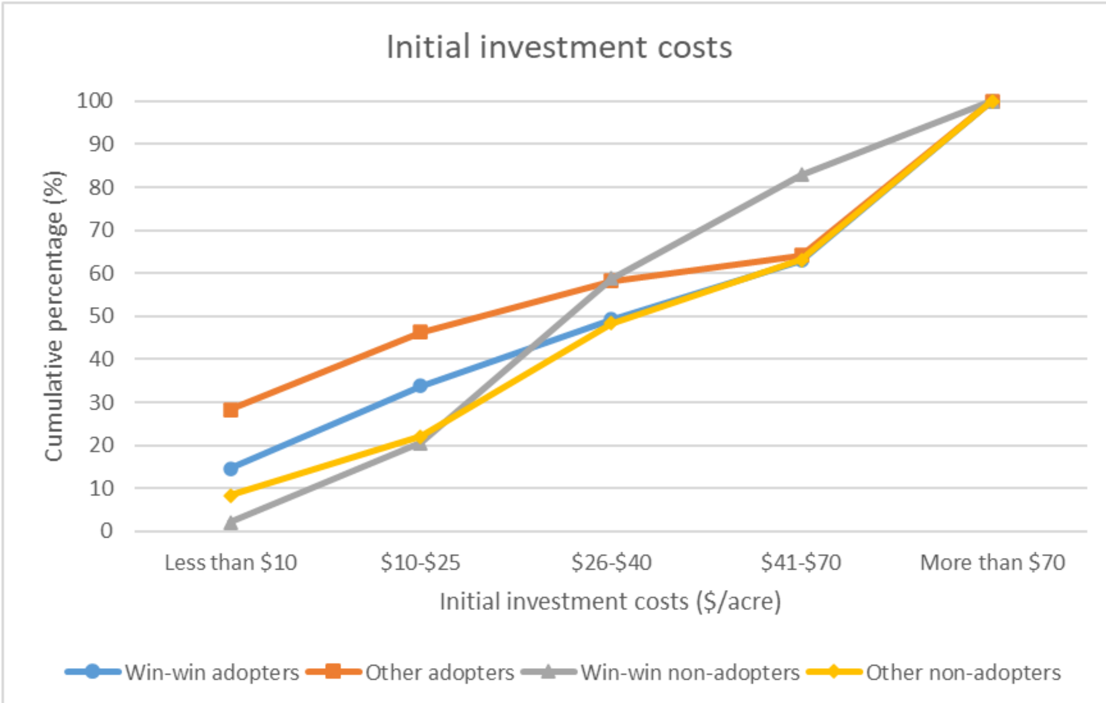


Figure D5 Cumulative percentage of responses to different levels of "initial investment costs" among four groups of ranchers

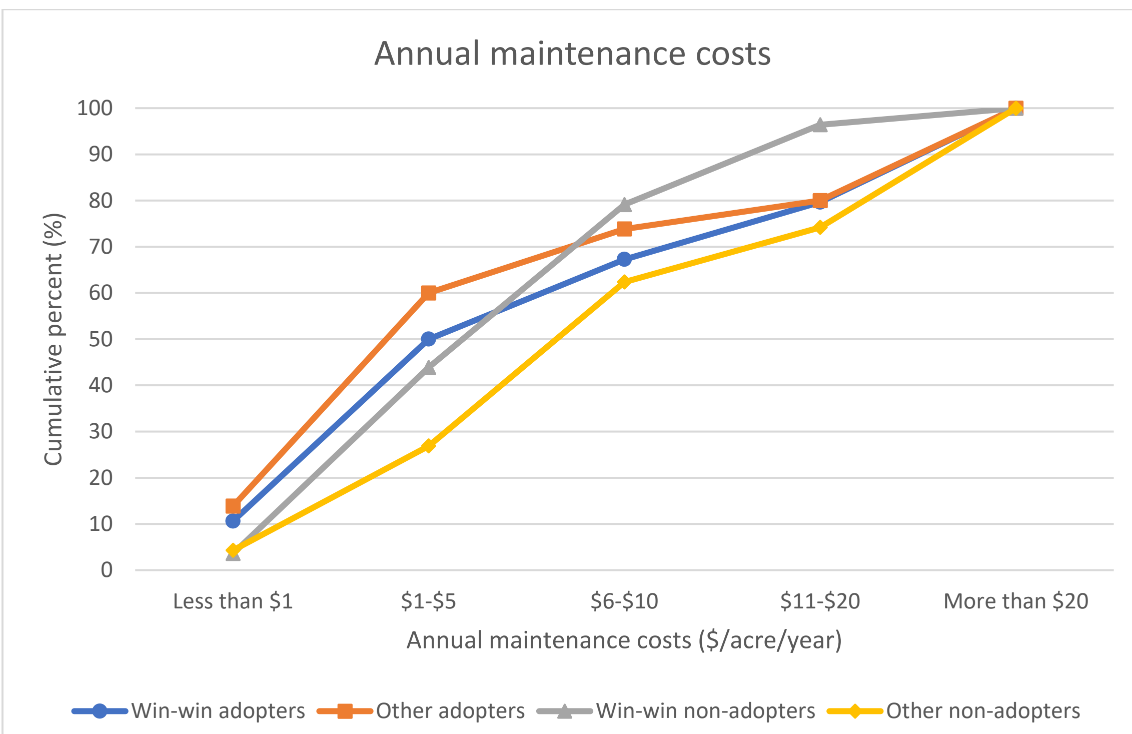


Figure D6 Cumulative percentage of responses to different levels of "annual maintenance costs" among four groups of ranchers

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