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The Role of Carbon Credits on Farmers' Adoption of Climate-Smart Practices in South Dakota

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THE ROLE OF CARBON CREDITS ON FARMERS' ADOPTION OF CLIMATE-SMART PRACTICES IN SOUTH DAKOTA

BY

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABBREVIATIONS

CSPs	Climate-smart Practices
DCR	Diversified Crop Rotation
GHGs	Greenhouse Gases
ICLS	Integrated Crop-livestock Systems
OLS	Ordinary Least Square
SDSU	South Dakota State University
WTA	Willingness to Accept

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ABSTRACT

THE ROLE OF CARBON CREDITS ON FARMERS' ADOPTION OF CLIMATE-SMART PRACTICES IN SOUTH DAKOTA

STEPHEN CHEYE

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Net-zero pledges and carbon credit systems have gained momentum due to the growing urgency to address climate change and limit global warming to below 2°C above pre-industrial levels. Agricultural carbon credits can be a potentially win-win mechanism by providing extra income for farmers while helping to reduce greenhouse gas emissions. Nevertheless, there is a paucity of understanding about farmers' willingness to accept carbon credit incentives and adopt climate-smart practices that sequester carbon. To address this, we analyzed 309 responses from a South Dakota producer survey conducted in 2021. We estimated probit and interval regression models to ascertain the level of carbon credit incentives farmers are willing to accept and adopt climate-smart practices and the factors affecting farmers' willingness to accept carbon credit incentives, and based on our results, about half of farmers would consider adopting climate-smart practices to sequester carbon at a given carbon credit price of about $50/ton. The results indicate that farmers' perceptions of the co-benefits of climate-smart practices such as reduced soil erosion, reduced nutrient runoff, enhanced wildlife habitat, etc., positively affect their willingness to accept carbon credit incentives and adopt climate-smart practices. Also, farmer previous experience with weather extremes had a significant but mixed effect on their willingness to accept carbon credit incentives and adopt climate-smart practices. Other factors, such as the younger age of the farmer, higher gross sales, a higher slope of land, and the importance of webinars and SDSU extension service as information sources, make the farmer more likely to adopt the practices at a given carbon credit value. We suggest that besides financial incentives, higher adoption rates of climate-smart practices might be realized if carbon credit payments are accompanied by information dissemination on the co-benefits of climate-smart practices such as reduced soil erosion, reduced nutrient runoff, enhanced wildlife habitat, and climate change adaptability via university extension programs and webinars.

Keywords: Adoption decision, Carbon credit, climate-smart practices, willingness-to-accept, carbon market.

CHAPTER I

INTRODUCTION

Net-zero pledges and carbon credit systems have gained increased attention due to the growing urgency to address climate change and limit global warming to below 2°C above pre-industrial levels (Bouckaert et al., 2021; Blaufelder et al., 2021; Shockley and Snell, 2021; Wongpiyabovorn et al., 2021). Agriculture is both susceptible to climate change and a major source of the greenhouse gases (GHGs) that are fueling it (Beddington et al., 2012; Metz et al., 2007; NRCS, 2010). In 2020, agriculture accounted for 11% of the total greenhouse gas emissions (EPA, 2022) and thus needs to be effectively decarbonized. Extreme weather events such as severe droughts, floods, and wildfires are anticipated to increase in severity and frequency due to climate change (Center for Climate and Energy Solutions, 2023) and are expected to adversely affect agricultural productivity (USGCRP, 2018).

The agricultural sector, although a key source of greenhouse gas emissions, also serves as a carbon sink, thus helping to combat climate change (World Bank, 2012; Lunik et al., 2021). According to the IPPC's 2019 report, grassland and cropland have a 30-year economic sequestration potential ranging between 0.38 and 2.5 gigatons of CO_2 equivalent per year. The latest global report on climate change mitigation also points out the potential for sustainable agriculture, which could sequester 4.1 Pg CO_2 equivalents per year (IPCC, 2022). Adoption of climate-smart practices can enhance the sequestration of carbon and also minimize the loss of carbon into the atmosphere (Lal, 2004). In addition, they enhance soil cover and crop diversification (Kassam, Friedrich, & Derpsch, 2019) and contribute to soil health (Wade, Claassen, & Wallender, 2015).

Climate-smart practices such as reduced tillage, no-till, cover crops, and diversified crop rotation have the potential to sequester a considerable amount of carbon. For example, in the Corn Belt region, no-till has a carbon sequestration potential of 0.42 tons CO2e acre-1 yr-1, while cover crops such as rye could sequester 0.38 tons CO2e acre-1 yr-1 (McNunn et al., 2020). However, participating in carbon programs and the adoption of these practices have associated costs, such as the cost of machinery and the cost of soil testing and verification in some cases. Besides, the benefits of the practices adoption, such as yield and profits, may not manifest immediately (Saak et al., 2021). As such, providing farmers with carbon credits could incentivize them to switch their practices to these climate-smart practices to store more carbon. In addition to the existing USDA programs such as the Conservation Reserved Program (CRP), Environmental Quality Incentive Program (EQIP), and Conservation Stewardship Program (CSP), the presence of voluntary carbon markets (VCM) presents a potentially win-win opportunity to sequester carbon through incentive adoption of CSPs and provide extra income for producers through carbon credits.

A carbon credit, which represents one metric ton of carbon dioxide equivalent (Oldfield et al., 2021), allows farmers to be rewarded with incentives for adopting practices that sequester carbon. There have been heightened efforts to promote voluntary carbon markets and the adoption of CSPs. For example, the U.S. Growing Climate Solutions Act of 2021 aims to bolster the voluntary market for agriculture carbon credits by limiting the entry barriers for agricultural producers (Congress, 2021). Apart from the federal efforts, several private companies, including the Ecosystem Services Market Consortium (ESMC), Agoro, and Nori, etc., are increasing investment in carbon credits. Despite these efforts, agricultural producers are hesitant to enroll in carbon programs and store carbon. A study by the Purdue University-CME Group Ag Economy Barometer (2021) found that while 39% of producers in the U.S. were informed about opportunities to obtain carbon credit payments, just 7% actively engaged in discussions, and only 1% have signed contracts to store carbon.

Few studies have tried to explore the underpinning factors affecting producers' decisions to adopt CSPs given carbon credits. The literature shows mixed findings on the primary motivations for producers to accept carbon credit incentives and switch from conventional to CSPs that store carbon. While some studies (Cook and Ma, 2014; Mattila et al., 2022; Kragt et al., 2017; Fleming et al., 2019) find that farmers are primarily motivated by co-benefits such as erosion reduction and improved soil health, others have established a strong link between farmers' adoption of carbon farming practices and financial incentives (White et al., 2018; Gramig and Widmar, 2018). According to the Purdue University-CME Group Ag Economy Barometer (2021) survey, most producers (64%) indicated the payment level offered as a motivating factor for their enrollment in carbon credit programs.

In the context of the United States, a narrow strand of literature (e.g., Ma and Coppock, 2012; Ma et al., 2012; Cook and Ma, 2014; Gramig & Widmar, 2018) explored the nexus between row crop farmers' engagement in carbon programs and their adoption of climate-smart practices. These studies addressed aspects relating to farmers' knowledge and attitude toward carbon sequestration, farm and farmer characteristics, the amount of net revenue required to change practices, the level of acreage enrolled, farmers' preferences for different attributes of prospective climate change policies, and their willingness to accept payment to change tillage practices to supply emissions offsets. Based on the extant literature, there is a paucity of studies in the Midwest that examine the carbon credit incentive producers are willing to accept and change their management practices to store carbon. Also, there are very limited existing studies that explore row crop farmers' decision to adopt climate-smart practices given carbon credit in the region, which necessitated this study. Specifically, the study addresses the following objectives:

1. Determine the carbon credit price that farmers are willing to accept to change their management practices to store carbon.
2. Identify the factors influencing farmers' willingness to accept carbon credit incentives and adopt climate-smart practices.
3. Examine the determinants of the level of carbon credits incentive farmers are willing to accept and change their farming practices.

Understanding the supply-side factors of carbon credits will be critical to inform policymakers and stakeholders on how to foster farmers' participation in the carbon market and adoption of climate-smart practices. The rest of this paper will be in the format outlined as follows: The literature on climate-smart practices, the carbon credit market, and the factors influencing farmers' adoption of climate-smart practices and participation in carbon credit programs is presented in Chapter 2. Chapter 3 presents the study methodology, specifically the description of the survey and data and the specification of the empirical models employed to analyze the data. In Chapter 4, the results as well as the discussion of the results are presented. The study's conclusions and recommendations are available in Chapter 5 of the paper.

CHAPTER II

LITERATURE REVIEW

This section of the study presents a review of the literature on carbon sequestration potential and the factors that influence farmers' willingness to accept carbon credit incentives and adopt various climate-smart practices. Also, a review of the carbon markets is presented.

2.1 Agricultural Practices that Sequester Carbon

The potential of climate-smart practices to sequester carbon in soil and reverse the effects of climate change has been well documented. Climate-smart practice comprises a suite of practices that sequester carbon and improve resilience and soil health, such as reduced and no-till, cover crops, diversified crop rotation, and prescribed grazing (USDA, 2021). These practices, as opposed to conventional agricultural practices, are characterized by zero or minimal soil disturbance and enhance soil cover. Essentially, these practices increase the quantity of carbon inputs in the soil and reduce soil carbon losses. The carbon sequestration potentials of these practices are affected by an interplay of various factors such as the climate, soil, topography, and the practices applied (Moore et al., 2021; Lunik et al., 2021; Bruner et al., 2021). Climate-smart practices such as cover crops, crop rotation, no-till, reduced-till farming, and integrated crop-livestock systems (ICLS) have been shown to have significant potential for carbon sequestration in soils. When adopted as a suite, they can synergistically increase soil organic carbon.

Bruner et al. (2021) found that cover crop use under no-till sequestered 1.3 tons of CO2e ac-1 yr-1 relative to no cover crop systems after 12 years. This finding is in line with the finding of McNunn et al. (2020), who estimated that multiple climate-smart practices adopted in the Midwest had a mean reduction potential of 1.1 tons CO2e ac-1 yr-1. These practices can help reduce the amount of carbon dioxide in the atmosphere by storing carbon in the soil. However, there is still skepticism regarding how efficiently the practices can ensure net GHG emission reductions (Moore et al., 2021). Understanding the carbon sequestration potential of these climate-smart practices is key to scaling up their adoption to optimize carbon storage. The carbon sequestration potential of various climate-smart practices is presented in Table 1.

2.1.1 No-till

Conventional tillage disrupts the soil structure that conserves soil carbon, resulting in the release of carbon into the atmosphere. In contrast, no-till, which entails zero mechanical soil disturbance (Swan et al., 2015), is known to increase soil carbon. Also, reduced till practices such as strip-till, which is considered in the same practices standard (CPS 329) as no-till, entail minimal soil disruption, which enriches soil organic carbon accrual (Swan et al., 2015). A study by McNunn et al. (2020) showed that no-till practice could sequester 0.42 tons CO2e ac-1 yr-1 in the Corn Belt region. This sequestration potential is similar to the 0.31 tons CO2e ac-1 yr-1 (Swan et al., 2015; Bergman, 2022) for the moist/humid region and 0.35 tons CO2e ac-1 yr-1 for dry/semi-arid region. McNunn et al. (2020) also estimated that switching from conventional till to reduced till could sequester a net amount of 0.1 tons CO2e ac-1 yr-1. Luo et al. (2010) concluded in a meta-analysis of 69 paired experiments that, while cultivation of natural soils led to soil carbon loss, no significant disparity exists in the soil carbon stock between conventional tillage and no-till.

2.1.2 Cover crops

Cover crops are crops planted between cash crop seasons to serve as a safeguard for the soil (Bergman, 2022). Cover crops enhance carbon sequestration through an increase in total annual plant growth and the buildup of diverse soil microbial communities (Moore et al., 2021). As noted by Ruis and Blanco-Canqui (2017), cover crops augment soil organic carbon through biomass carbon input, soil aggregation, and reducing carbon loss through soil erosion. Abdalla et al. (2019), in a global systematic analysis, found that cover crops could mitigate net greenhouse gas balances by 0.83 tons CO2e acre-1 yr-1. Bruner et al. (2021) estimated the emission reduction potential of cover crops in the Corn Belt States using the Carbon Reduction Potential Evaluation Tool (CaRPE) and the Carbon Management Evaluation Tool (COMET). Based on their estimates, cover crops have a potential of 0.35 tons CO2e acre-1 yr-1, at a depth of 30cm. Their estimated emission reduction is in the range of 0.16-0.35 tons CO2e acre-1 yr-1 for the Corn Belt States within a depth of 50 cm, as estimated by McNunn et al. (2020), who used a Denitrification-DeComposition model (DNDC). These sequestration estimates are in the range provided by Swan et al. (2015) and Bergman (2022), who indicated a sequestration range of 0.21-0.37 tons CO2e acre-1 yr-1.

2.1.3 Diversified crop rotation

According to Wang et al. (2019), diversified crop rotation (DCR) is defined as the cultivation of at least three crops in a rotation, particularly among row crop producers. Crop rotation increases soil organic carbon (SOC) content and CO_2 sequestration by accelerating crop residue recycling into the soil (Hutchinson, Campbell, and Desjardins, 2007). Diverse crop rotations have the potential to sequester 0.21-0.26 tons CO_2e acre^{-1} yr^{-1} depending on the climate zone (Swan et al., 2015; Bergman, 2022). A meta-analysis based on 122 studies was done by McDaniel, Tiemann, and Grandy (2014) to examine the impact of crop rotation on the total soil C and N contents. They discovered that a monoculture's addition of one or more crops in rotation raised the total soil C by 3.6%. The amount of carbon in the soil rose by 8.5% when rotations included a cover crop, or crop that is grown but not harvested, in order to improve the soil and collect inorganic nitrogen. Similarly, King and Blesh (2018), in meta-analysis based on cropping experiments that spun across North America, South America, Europe, Australia, and Asia, points out that on average, crop rotations with cover crops produced an increase in SOC levels by 6.3%, and for perennial crop rotations, SOC increased by 12.5%.

2.1.4 Integrated crop-livestock systems

Also, integrated crop-livestock systems allow for nutrient recycling, which enhances climate change resistance through buffering mechanisms in both field-level biophysical processes (Szymczak et al., 2020). It has been observed that integrating cattle and crops increases soil organic carbon. For instance, Liebig et al. (2020), in a lengthy trial, examined the impacts of the ICL system on soil organic carbon. They found that the soil organic carbon stocks under the grazed treatment likewise grew over time by 10 tons C per ha.

Table 1: Carbon sequestration potential, approach, region, and soil depth of various climate-smart practices

Citation	Region	Practice	Approach	Soil Depth (cm)	Potential (ton CO_2e $acre^{-1}$ yr^{-1})
Bruner et al. (2021)	Corn Belt, Southern Plains	No-till	CaRPE/COMET	30	0.41
Swan et al. (2015); Bergman et al. (2022)	Moist/humid	No-till	COMET Planner	-	0.31
Swan et al. (2015); Bergman et al. (2022)	Dry/semi-arid	No-till	COMET Planner	-	0.35
McNunn et al. (2020)	Corn Belt	No-till	DNDC	-	0.42
Swan et al. (2015); Bergman et al. (2022)	Moist/humid)	Reduced till	COMET Planner	-	0.20
Swan et al. (2015); Bergman et al. (2022)	Dry/semi-arid	Reduced till	COMET Planner	-	0.17
Buner et al. (2021)	Corn Belt, Southern Plains	Cover crops	CaRPE[1]/COME[2]	30	0.35
Swan et al. (2015); Bergman et al. (2022)	Moist/humid	Cover crops	COMET Planner	-	0.37
Swan et al. (2015); Bergman et al. (2022)	Dry/semi-arid	Cover crops	COMET Planner	-	0.26
McNunn et al. (2020)	Corn Belt	Cover crops (clover)	DNDC[3]	50	0.32
McNunn et al. (2020)	Corn Belt	Cover crops (rye)	DNDC	50	0.38
Abdalla et al. (2019)	Global	Cover crops	Meta-analysis	30	0.83
Swan et al. (2015); Bergman et al. (2022)	Moist/humid	Diversified Crop Rotation	COMET Planner	-	0.22
Swan et al. (2015); Bergman et al. (2022)	Dry/semi-arid	Diversified Crop Rotation	COMET Planner	-	0.26

[1] CaPRE – Carbon Reduction Potential Tool
[2] COMET – Carbon Management Evaluation Tool
[3] DNDC – Denitrification-DeComposition

2.2 Carbon Credit Markets

There has been an increase in pledges by various corporations across the globe to attain net-zero or carbon neutrality by 2050, which in recent times has increased the demand for carbon credits. The number of corporations targeting "Net Zero" has increased two-fold to 1,000 companies from 2019 to 2020 (Blaufelder et al., 2021). Certain companies have created a framework that incentivizes agricultural producers to adopt climate-smart practices and generate carbon credits. This presents a potentially win-win opportunity where farmers are rewarded with income for sequestering carbon while allowing companies to offset their emissions.

2.2.1 Types of carbon credit markets

Farmers can earn carbon credits as incentives for storing carbon in soils in a couple of ways. On the basis of how the credit is provided, the markets can be categorized as either offset markets or inset markets (Thompson et al., 2021). With inset markets, initiatives such as education, technical support, and financial aid are collaboratively provided by a corporation to reduce emissions within its supply chain. Offset markets differ in that the carbon credits are generated by producers through carbon sequestration. The credits are then verified and purchased by emitters to compensate for their carbon emissions.

In the offset system, the carbon credit generated can be marketed through a voluntary carbon market or a regulatory carbon market. A mandatory market, also known as a regulatory or compliance market, encompasses entities that are lawfully obliged to reduce their GHG emissions. These markets are framed around regional, national, or internal requirements to mitigate GHG emissions (Rosende, 2022). The emissions by institutions or corporations are restricted by imposing taxes on the emissions or putting a cap on the volume of emissions. In the U.S., the California Cap-and-Trade Program and the Regional Greenhouse Gas Initiative (RGGI) constitute compliance markets. In contrast to the mandatory carbon market, voluntary markets are characterized by corporations that aim to offset their emissions willingly. The standards, procedures, and measurements in the voluntary carbon market are not fixed, unlike those in the regulatory carbon market (Rosende, 2022).

As spotlighted by Plastina and Wongpiyabovorn (2021), the voluntary agricultural carbon market is still nascent with diverse rules, incentives, and penalties. Currently, there is a limited supply of carbon credits (Lunik et al., 2021), while the demand could be up to 1.5 to 2.0 gigatons of carbon dioxide by 2030 and up to 7 to 13 gigatons of carbon dioxide by 2050 (TSVCM, 2021). Also, the carbon market is projected to grow by a factor of 15 by 2030, which could be worth more than $50 billion, and by a factor of 100 by 2050. The demand for offset credits is expected to increase quickly in the future, which will call for an increased supply of credits.

In the United States, there are several private carbon credit companies that offer incentives to farmers to generate carbon credits, which are then bought by large corporations and other entities to offset their emissions (Plastina and Wongpiyabovorn, 2021). The practices that are eligible for farmers to enroll in include cover crops, conservation tillage, nitrogen optimization, diversified crop rotation, improved grazing, and increased biodiversity. Payments to farmers are either per ton or per acre. The price ranges from $15 per ton to $30 per ton for companies that pay farmers on a per-ton basis and from $10 per acre to $31 per acre for companies that offer carbon credit payments for farmers on a per-acre basis. While all programs require additionality, that is, adopting new practices to sequester carbon, some programs qualify practices that have been adopted in the past. Also, some programs allow for "stacking," where producers can enroll in multiple programs if they are not privately funded or do not generate credits, while others prohibit multiple program enrollment of any sort. Regarding the acreage requirement, some programs do not have a minimum number of acres for farmers to enroll, while others require up to 1,000 acres. The contract length required for enrollment ranges from 1 year to 10 years. For some carbon programs, producers can opt out without any penalty, while others require producers to retain the practices for up to 10 years after the contract ends.

2.2.2 Challenges with voluntary carbon credits

Additionality: This requires that the carbon credits be given for carbon sequestration that is only an add-on, such that the abatement would not have happened irrespective of the program (Thamo et al., 2020). Strictly speaking, carbon credits generated for practices that have been historically adopted are not additional. This does not benefit farmers who have already adopted the practices. Some carbon credit companies, in an attempt to motivate producers to enroll in their programs, generate credits based on practices adopted in the past.

Permanence: When farmers revert to conventional practices, the carbon captured is released back into the atmosphere. To avoid reversal, practices must be maintained over a long period of time. Besides tillage, which reverses carbon, other phenomena such as flooding and drought could release carbon stored in the atmosphere back into the atmosphere (Lunik et al., 2021). Permanence might cause hesitancy among farmers to participate in programs if changes occur in a way that makes other methods of production more beneficial (Thamo et al., 2020). Providing farmers with sufficient incentives and increasing education and awareness of the co-benefits of adopting climate-smart practices could be vital to addressing the limitations.

Leakage: This entails GHG emissions that result from actions taken to reduce or offset GHG emissions outside of project boundaries (Oldfield et al., 2021). The emissions may happen in a different location, at a different time, or in a different type of greenhouse gas (Thamo et al., 2020). As stated by Thamo et al. (2020), leakage comprises direct and indirect forms. With direct leakage, emissions result from direct activities to sequester carbon. Indirect leakage results from market adjustments in response to sequestration. Farmers are required to ensure no leakage occurs.

Adoption and program cost: Another challenge for farmers is the cost that comes with switching to climate-smart practices to store more carbon. As shown in Table 2, for example, for 2021, a price of $41 mt CO_2 -eq will yield a breakeven for a switch from reduced till to no-till for soybean, and $28 mt CO_2 -eq yield a breakeven for changing from conventional tillage to reduced till for corn. Besides, farmers are faced with additional costs for soil testing and verification required for generating carbon credits in some carbon programs (IFC, 2013). The NRCS (2022) notes indicate that soil tests typically cost $7 to $10 per sample. Also, while some programs cover the cost of verification, some carbon companies require farmers to pay the verification fees to a third party (Plastina, 2022), which could cost between $3,000 and $5,000 (Gullickson, 2020). For such a high verification cost, farmers with large farms could benefit, while farmers with small acres would be at the disadvantage of farmers with smaller farms.

Table 2: Breakeven prices for crop farm practices used for carbon sequestration in the northern Great Plains

Practice	Crop	Breakeven price (2010 \$/mt CO_2 -eq)	Adjusted breakeven price (2021 \$/mt CO_2 -eq)[4]
Conventional tillage to reduced tillage	Corn	\$23	\$28
Reduced tillage to no-till	Corn	\$14	\$18
Conventional tillage to no-till	Corn	\$18	\$24
Reduced tillage to no-till	Soybeans	\$34	\$41
Conventional tillage to no-till	Soybeans	<\$0	<\$0

Note: Negative break-even prices result from cost savings as a result of changing from conventional till to no-till and switching from reduced till to no-till for soybeans

2.3 Factors Affecting Farmers' Adoption of Climate-smart Practices and Participation in Carbon Programs

The literature shows that the factors influencing farmers' decisions to adopt climate-smart practices and participate in a carbon credit program are eclectic. These factors can be grouped into four key themes as follows: perceived economic benefits, perceived co-benefits, climate change perceptions, and farm and farmer characteristics. In a recent study, Buck and Palumbo-Compton (2022) reviewed 37 studies on the adoption of climate-smart practices and farmers engagement in carbon credit programs. Their review found that the perceived co-benefits of adopting climate-smart practices are a central determinant of adoption, particularly in light of a weak carbon policy and low carbon pricing. To understand the motivations and barriers for broadacre farmers in Australia to

[4] Breakeven prices for 2010 were adjusted for 2021 prices using the 2010 Consumer Price Index for all Urban Consumers (CPI-U). https://www.bls.gov/data/

adopt carbon farming, Kragt, Dumbrell, & Blackmore (2017) estimated a logit model based on survey data from 125 broad-acre farmers. The authors found that farmers’ perceptions of co-benefits relating to yield, productivity, and the environment played a significant role in carbon program participation. The authors therefore concluded that actively promoting the co-benefits and climate change benefits is critical to augmenting farmers' engagement in carbon programs.

Similar to Kragt et al. (2017) and Dumbrell et al. (2016), the authors explored, using a best-worst approach, the carbon farming activities farmers are more likely to adopt and the factors that influence their decision to engage in carbon programs. Based on an analysis of 43 farmer responses to a survey, they found that improved soil quality and reduced soil erosion are regarded by farmers as the most significant benefits of carbon farming. Interestingly, the authors showcased that the prospect of producing carbon credits was not a significant driver for farmers’ adoption of carbon sequestering practices. These findings are in line with those of Kragt et al. (2017). These studies are corroborated by others, such as Davidson et al. (2019), Gosnell et al. (2020), Ogieriakhi and Woodward (2022), and Mattila et al. (2022).

Regarding economic motivations, Dumbrell et al. (2016) found that farmers' engagement in carbon programs was constrained by the price of carbon and the effects of farming practices on productivity and profitability. White et al. (2018) also reached a similar conclusion in a study on farmers’ willingness to participate in carbon credit programs in Vermont, U.S., using a best-worst-choice approach. They suggested that the primary consideration for forest landowners in a carbon credit program is revenue. But the study's focus was on small forest owners. The authors also discovered that factors that favorably influence their readiness to adopt forest carbon credit programs include shorter program length, greater revenue, and lower withdrawal penalties.

With regards to farm and farmer characteristics, Ma et al. (2012) found using a first hurdle probit estimation that older farmers are less likely to consider payment for ecosystem services. Davidson et al. (2019) examined the determinants of farmers' adoption of climate-adaptive practices and found that belief in climate change rarely motivates farmers to adopt climate-adaptive practices; rather, expectations for economic benefits, improvements in soil quality, and biodiversity, among other things, tend to influence farmers adoption of climate-adaptive practices. Also, to understand the interplay between landowner knowledge, value, belief, attitude, and willingness to act towards carbon sequestration, Cook and Ma (2014) analyzed the data of Utah rangeland owners using descriptive and bivariate statistics. Kragt et al. (2017) found that farmers' awareness of other carbon farmers' perceptions of the benefits of reductions in GHG emissions due to changing their practices positively affects their decision to adopt carbon farming and change practices.

CHAPTER III

METHODOLOGY

3.1 Survey Description

The data for the study is based on a 2021 survey in South Dakota, conducted in collaboration with the South Dakota Corn Utilization Council. We resurveyed farmers who completed our survey conducted in 2018[5] South Dakota farmers' survey. We employed a structured questionnaire for the survey. Out of the 708 farmers surveyed in 2018, we attempted to resurvey 687 producers due to missing unique codes for some of the respondents. We obtained 593 eligible producers, as 94 were no longer farming or reachable. The selected farms were first contacted by letter, which included a link to an online survey as well as information about the study. Those who did not respond in the initial round were sent paper questionnaires with stamped return envelopes in four waves. A total of 350 producers completed our survey, which resulted in a 59% response rate. Out of the 350 eligible responses we obtained, 41 observations had incomplete or inconsistent responses. We posit that if a farmer is willing to accept a particular carbon credit value, the farmer would be willing to accept higher carbon credit incentives to change practices based on consistency assumption. As such, we removed all the 41 observations that were either incomplete or inconsistent, which resulted in 309 complete responses.

The survey covered the demographic characteristics of farmers, farm and farming decisions, farm management practices, management decisions and perceptions, and the influence of extreme weather events. The geographic distribution of survey responses by the farmers is presented in Figure 1.

[5] See Wang et al. (2021a) for details of the 2018 survey.

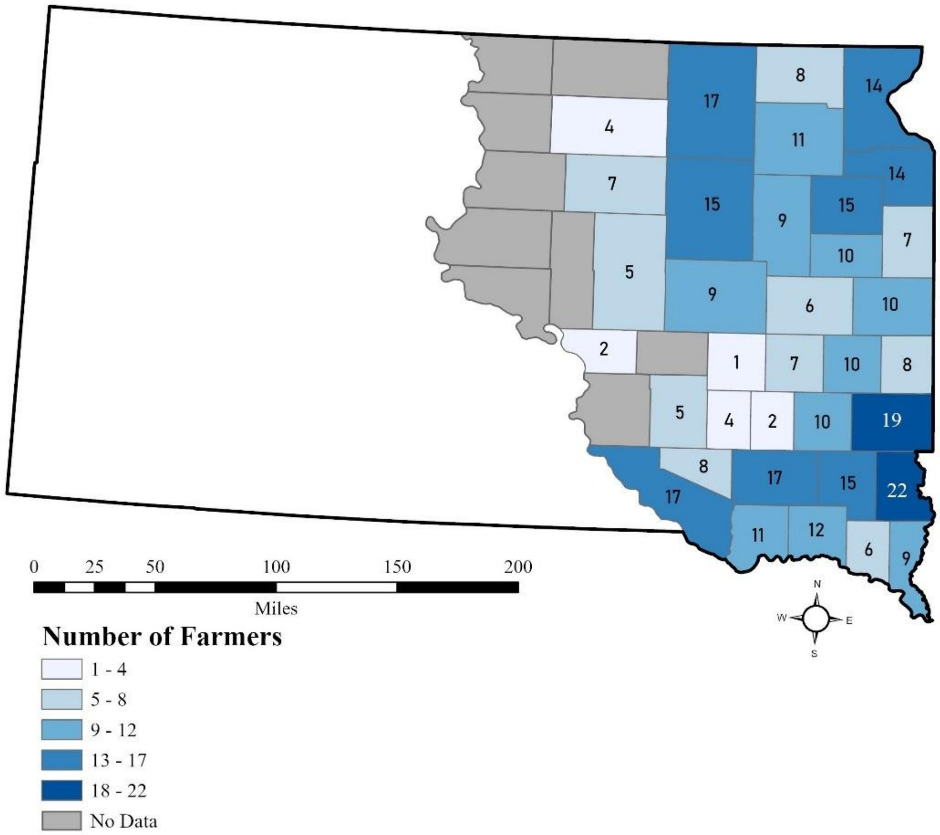

Figure 1: South Dakota County map of respondents

Questions asked about the influence of extreme weather events, the environment, perceptions of farm management decisions, farm management practices, and the demographic characteristics of producers allow us to examine the factors affecting farmers' willingness to accept (WTA) the carbon credit incentive and change their farm management practices.

3.2 Data Description

We asked producers about their willingness to store more carbon and supply carbon credit by changing their management practices. The producers were provided with three response options: yes, no, or not sure, to accept carbon credit payments, which ranged from

\$10 per ton to \$50 per ton, and change their farm management practices, i.e., adopt climate-smart practices that store carbon.

Based on this information, we modeled two dependent variables. First, the information was utilized to create a binary dependent variable: WTA = 1 if the response was yes for all five carbon credit values, or otherwise = 0 if the responses were "no" or "not sure" for all the carbon credit values. This allows for a plausible application of a probit model to determine the factors that influence the decision to adopt climate-smart practices given carbon credit incentives. Secondly, the carbon credit values, which we used to elicit farmers decisions to adopt climate-smart practices, were used to construct six willingness-to-accept intervals: $1 = (-\infty < y^{*} \leq \$10)$, 2 = $(\$10 < y^{*} \leq \$20)$, 3 = $(\$20 < y^{*} \leq \$30)$, 4 = $(\$30 < y^{*} \leq \$40)$, 5 = $(\$40 < y^{*} \leq \$50)$, 6 = $(\$50 < y^{*} \leq \infty)$. This makes the use of an interval regression model plausible to analyze the determinants of the level of carbon credit farmers are willing to accept and adopt as climate-smart practices.

Following Kragt et al. (2017), Dumbrell et al. (2016), and Page and Belloti (2015), we included variables that capture farmers' perceptions of the co-benefits of adopting climate-smart practices, such as improved soil health and enhanced farm benefit, which entail reduction of soil erosion, enhancement of wildlife habitat, reduction of nutrient run-off, etc. We also included variables that represent producers' experiences with severe weather conditions in the past 10 years. Wang et al. (2021) and Saak et al. (2021) have demonstrated that severe weather events can influence the adoption of climate-smart practices as an adaptive measure. In addition, we included a measure of the slope of the farmland of the producers.

The value-belief-norm (VBN) theory (Stern, 2000), the expectancy-value (EV) model (Fishbein, 1963), and the theory of planned behavior (Ajzen, 1985) all postulate that beliefs serve as the basis from which attitudes toward things and behaviors are formed and that these attitudes can be highly predictive of behaviors. Wang et al. (2019) show that the attitudes and perceptions of farmers have a significant influence on their decisions to adopt conservation practices. We as such, included variables such as farmers perceptions about their responsibility to future generations and people leaving their watershed, as well as their perceptions of the yield and profitability of climate-smart practices.

In accordance with Buck and Palumbo-Compton's (2022) suggestion on farmers' underexplored motivations to sequester soil carbon, we included variables such as SDSU extension, farm tours, and webinars or videos that represent information sources from which farmers learn new farming technologies. Variables that capture farm and farmer characteristics, such as farmer age, gross sales in a typical year, and highest level of education attained, were added. Farmers' willingness to consider payment for ecosystem services is influenced by farm and farmer characteristics (Ma et al., 2012). The cost-share received by farmers can reduce their production costs, influence the profitability of their farm businesses, and influence their adoption decisions for conservation practices. To understand these dynamics, we added cost-share as a variable, which measures if a farmer has received cost-share to support the conservation practices he has adopted. Table 3 presents a description of the variables used in our analysis.

Table 3**:** Variable description

Variable	Description	Obs.	Mean	Std. Dev.
WTA	1 = if a farmer is willing to accept carbon credits and adopt climate-smart practices 0 = otherwise	288	0.507	0.501
LCC	(0 < $y \leq 9.99$), 2 = (10 < $y \leq 19.99$), 3 = (20 < $y \leq 29.99$), 4 = (30 < $y \leq 39.99$), 5 = (40 < $y \leq 49.99$), 6 = ($y \geq 50$)			
Independent Variables				
Farm and farmer characteristics				
Age	Age of respondent in years	299	58.003	13.716
Gross sales	Level of gross farm/ranch sales in a typical year (1= <$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)	245	3.269	1.539
Education	Highest level of school completed (1 = high school, 2 = some college/technical school, 4-year college, 4 = advanced degree).	300	2.203	0.863
Severe weather events				
Severe drought	Years of extreme drought conditions (1 = 0, 2 = 1-5, 3 = 5+)	296	1.878	0.327
Severe wet	Years of extreme wet conditions (1 = 0, 2 = 1-5, 3 = 5+)	298	2.064	0.774
Farm management and perceptions				
Soil health	Importance of improved soil health (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important).	296	4.179	0.890
Profitability	Importance of increased profitability (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important).	297	4.353	0.858
Crop yield	Importance of increased crop yield (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important).	298	4.233	0.893
Cost share	1 = if farmer received cost share, 0 = otherwise	286	0.353	0.479
Future responsibility	How responsible are you to future generations (1 = Not at all responsible, 2 = Slightly responsible, 3 = moderately responsible, 4 = very responsible).	297	3.300	0.798
Farm benefit	Benefit of conservation practices to your farm (1 = Not important, 2 = Slightly important, 3 = Moderately important, 4 = Very important).	295	3.380	0.674
Information source				
SDSU Extension	Importance of SDSU extension in your decision making (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Very Important, 5= Does not use)	295	2.301	1.370
Farm tours	Importance of farm tours for learning new farming practices (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important)	296	2.932	1.214
Webinars	Importance of the web for learning new farming practices (1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important)	294	2.874	1.124
Soil variable				
Slope	Slope of the field (degrees)	279	2.977	1.587

3.3 Theoretical Framework

This study adopts the maximum utility and random utility frameworks to model farmers' willingness to accept carbon credit incentive decisions. The theory postulates that a farmer would accept a carbon credit incentive to shift to climate-smart practices if the expected utility the farmer would derive from accepting the incentive and changing the management practice exceeded the expected utility of not accepting the incentive and retaining the conventional practice. The WTA is such that:

$$WTA = \begin{cases} 1 = if\ farmer\ is\ willing\ to\ accept \\ 0 = otherwise \end{cases}$$

The condition for farmers to accept the carbon credits and change their practices is expressed as:

$$E(U_i^Y) > E(U_i^N) \tag{1}$$

$$\begin{cases} U_i^Y = X'\beta_i + \varepsilon_i \\ U_i^N = X'\beta_i + \varepsilon_i \end{cases}$$

Where $E(U_i^Y)$ and $E(U_i^N)$ represent the expected utility of accepting the i^{th} carbon credit incentive and switch the management practices and expected utility of not accepting the i^{th} carbon credit incentive respectively. The vector of the independent variables which influence the willingness to accept the carbon credit value is denoted as X, while ε represents the random error term.

3.4 Econometric Models

Probit Model:

To examine the factors that affect farmers' willingness to accept carbon credit incentives and adopt climate-smart practices, we categorized the farmers' willingness to accept carbon credit incentives and change their practices into two categories: "yes" and "otherwise." Farmers who stated that "yes" they would accept carbon credit and change their practices were denoted "1" and those who indicated either "no" or "not sure" were denoted "0". The dependent variable, willingness to accept carbon credit (WTA), is therefore a binary variable. As such, we employed a probit model to estimate the determining factors of farmers' willingness to accept carbon credit and change their farming practices to climate-smart practices. The model's asymptotic properties restrict the predicted probabilities to a range of 0 and 1, and postulates that, the WTA is observed as 0 or 1 but the continuous variable (WTA*), which determines the value of WTA is latent. This is expressed as:

$$WTA^* = X'\beta + \mu \qquad (2)$$

Where WTA* denotes the latent dependent variable and is the vector of independent variables that affect the willingness to accept. Based on equation (2), the probability of a producer whose WTA equals 1 is expressed as follows:

$$\Pr(WTA_i = 1) = \Pr(X'\beta + \mu_i > 0) \qquad (3)$$

$$= \Pr(\mu_i > (X'\beta)$$

$$= 1 - \Pr(\mu_i < -(X'\beta))$$

The cumulative density function is denoted as F. Therefore, the probability of a producer whose WTA = 1 is expressed as:

$$\Pr(WTA_i = 1) = 1 - \mathrm{F}(-(X'\beta))$$

The empirical expression of the producers' WTA of the carbon credit incentive and their adoption of climate-smart practices is shown in equation (6).

$$WTA = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_{14} X_{14} + \varepsilon \tag{4}$$

Where the β denote coefficients to be determined and X represent a vector of independent variables that influence the producers' willingness to accept carbon credit incentive and change management practices to store carbon.

Interval Regression Model:

In our study, the carbon credit values, which the farmers indicated were their WTA, were used to create six categories. Based on the carbon credit value they indicated and the value at the next level, an interval was formed. As such, we adopted an interval regression with the dependent variable equal to the interval of values the producers showed. If it is used to represent the producers' discrete choices of intervals, a conventional ordered model such as probit or logistic regression can be estimated. Based on Monte Carlo simulations, an interval-data model is often more efficient than a discrete-choice model (Alberini, 1995). It is also feasible to estimate an ordinary least squares (OLS) regression, where the dependent variable will be the midpoint of the various intervals (Yang et al., 2012), but it would fail to report the exact WTA values for each interval. It could nonetheless serve as an ad hoc check for normality, which is assumed in an interval regression (Yang et al., 2012).

The interval regression model is expressed as follows.

$$y_i^* = X_i' \beta + \mu_i \tag{5}$$

Where β is the coefficient associated with each covariate, and μ_i follows a normal distribution. The probability of y_i^*, which denotes the producers' true WTA known to them alone lies between the interval categories, $(j+1)$ and the mutually exclusive intervals of $(-\infty, a_1), (a_1, a_2), \ldots, a_j, \infty)$. The intervals used in our study are: $0 < y^* \leq 9.99$, $10 < y^* \leq 19.99$, $20 < y^* \leq 29.99$, $30 < y^* \leq 39.99$, $40 < y^* \leq 49.99$, $6\ y^* \geq 50$. This is expressed in equation (8) as follows.

$$Pr\left[a_j \leq \mathrm{y}^* \leq \mathrm{a}_{j+1}\right] = Pr\left[y^* \leq \mathrm{a}_{j+1}\right] - Pr\left[y^* \leq \mathrm{a}_j\right]$$

$$= F^*\left(a_{j+1}\right) - F^*(a_j) \qquad (6)$$

The maximum likelihood estimation is thus designed based on the probability of the observation being within an interval, assuming normality. Empirically, the interval regression model of the WTA is expressed as follows:

$$y^* = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_{12} X_{12} + \varepsilon \qquad (7)$$

Where β represents the coefficients to be determined, X is a vector of covariates that influence the carbon credit incentive level that farmers are willing to accept and switch their practices, and ε denotes the random error term.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Summary Statistics

The summary statistics of the dependent variables and the independent variables we used are presented in Table 3. The mean for WTA in Table 3 indicates that about half of the farmers are willing to accept a carbon credit incentive and change their farm management practices. On average, the producers are 58 years old, as shown by the results. This is in line with the average age of 57 years for producers, according to USDA-NASS (2017). The producers, on average, have attained some college or technical education, as determined by the mean of 2.20. Also, the average values for cost-share and gross farm/ranch sales are 0.35 and 3.27, respectively. These demonstrate that on average, 35% of farmers have received cost-share assistance, and on average, farmers have a gross farm or ranch sale of $100,000 to $249,999 in a typical year.

With regards to experience with severe drought and severe wet conditions, the results indicate that, on average, farmers have experienced about 1–5 years of severe conditions in the past 10 years. Concerning the farm management and perception variables, the mean of 4.18 for soil health shows that, on average, the producers perceive climate-smart practices as quite important for improved soil health. Also, producers perceive that adopting climate-smart practices is critical for increased profitability and crop yield. Furthermore, the mean value of 3.38 for farm benefit indicates that farmers on average consider the adoption of climate-smart practices to be moderately important for the farm. The results point out that, regarding responsibility for future generations, farmers feel they are moderately responsible. A sense of responsibility for the well-being of people and the perceived benefits of conservation practices can play a significant role in the actions and decisions of farmers. With regards to the information source variables, farmers regard SDSU extension as slightly important, as depicted by the mean value of 2.30. Based on the results, the producers rate farm tours and webinars as somewhat important for learning new practices.

In Table 4, the summary statistics of key variables between farmers who are willing to accept carbon credit incentives and adopt climate-smart practices and those who would otherwise not accept carbon credit incentives are presented. The t-values show a statistically significant difference between farmers willing to accept the carbon credit incentive and implement the practices and those who will not accept the carbon credit incentive. Table 4 results indicate a significant difference in farm and farmer characteristics, farm management and perception covariates, and information source variables. Farmers who are willing to accept the carbon credit incentive and change their practices record a gross farm or ranch sale of $250,000 to $499,999 in a typical year, while the average farm or ranch sale for farmers who are not willing to accept the carbon credit incentive is $100,000 to $249,999.

Farmers who are willing to accept carbon credit incentives and adopt climate-smart practices are on average 4 years younger than their counterparts who are unwilling to accept carbon credit incentives and change their practices to climate-smart practices to store more carbon. Also, farmers who are willing to accept the carbon credit incentive and adopt the practices rate SDSU extension, webinars or videos, and farm tours as more important to learning new practices compared to their counterparts. In terms of extreme weather variables, the t-test results show that, while there is a significant difference in experience with severe drought conditions between farmers who are willing to accept carbon credit incentives and adopt climate-smart practices and those who are not, there is no significant difference in experience with severe wet conditions

Table 4: Summary statistics of key variables by farmers who are willing to accept carbon credit incentives and farmers who are otherwise not willing to accept and adopt practices

Variable	Means			T-statistic
	Farmers willing to accept (N=146)	Otherwise (N=142)	Combined	
Farm and farmer characteristics				
Age	56.103	59.543	57.781	2.151**
Gross sales	3.609	3.018	3.316	-2.960***
Education	2.359	2.117	2.2411	-2.381**
Severe weather events				
Drought	1.916	1.841	1.879	-1.946*
Wet	2.055	2.066	2.060	0.315
Farm management and perceptions				
Soil health	4.338	4.014	4.179	-3.153***
Profitability	4.438	4.271	4.357	-1.675*
Crop yield	4.315	4.143	4.231	-1.652*
Cost share	0.414	0.292	0.354	-2.139**
Future responsibility	3.396	3.201	3.300	-2.050**
Farm benefit	3.479	3.292	3.388	-2.389**
Information sources				
SDSU Extension	2.714	2.029	2.377	-4.332***
Farm tours	3.172	2.730	2.955	-3.170***
Webinars	3.194	2.600	2.901	-4.671***
Soil variable				
Slope	3.032	2.867	2.950	-0.854

Notes: *p < 0.10, ** p < 0.05, *** p < 0.01 indicate significance of t-statistic of the mean difference.

4.2 Carbon Credit Price Farmers are willing to Accept and Adopt Climate-smart Practices

Figure 2 shows the percentage distribution of farmers willing to accept carbon credit incentives and adopt climate-smart practices. The results indicate that, given $10 per ton of carbon credits, just 4% of farmers would consider switching from conventional practices to climate-smart practices. Markowski-Lindsay et al. (2011), who surveyed Massachusetts family forest owners, found that a carbon credit program that pays $10 per acre per year with a 30-year commitment and withdrawal penalty would only see 4% participation. Cook and Ma (2014) found that based on producers' current knowledge and attitudes, only 4% of respondents indicated they were very likely to engage in carbon sequestration activities.

Also, the results show that at a carbon credit value of $20 per ton, which is the current average carbon credit price provided in the voluntary carbon market, 10% of the farmers are willing to accept that and change their farm practices to store more carbon. The low percentage of producers willing to actively enroll in carbon credit programs and supply carbon credits at the current average price of $20 per ton of carbon credit is substantiated by the Purdue Ag Barometer (2021) survey, which found that most row-crop producers (64%), did not enroll in carbon credit programs to capture carbon due to the payment level offered. Our results also show that, about 25% of the producers would consider switching their practices to climate-smart practices if they were offered a $30 per ton carbon credit. With $40 per ton of carbon, the results reveal that about 39% of the producers would consider adopting climate-smart practices to store carbon.

At a given carbon credit value of $50 per ton, about half of the farmers would consider switching their farming practices to climate-smart practices. According to Gramig and Widmar (2018), Indiana farmers would need to obtain an extra $40 per acre in net profits before switching to no-till farming. That would necessitate a carbon price paid to the farmer of $129 per metric ton (MT) of carbon, in addition to the sum necessary to cover increased production costs and potential yield drag in a no-till system, based on an assumed carbon storage rate of 0.31 MT/acre (Thompson et al. 2021). Moreover, the present value of avoided marginal damages from carbon emission reduction is now estimated to be roughly $50/MT (IGW, 2021). As a result, the price farmers are currently receiving for carbon sequestration is significantly below both the minimum required to encourage widespread adoption and the benefit that carbon sequestration offers to society.

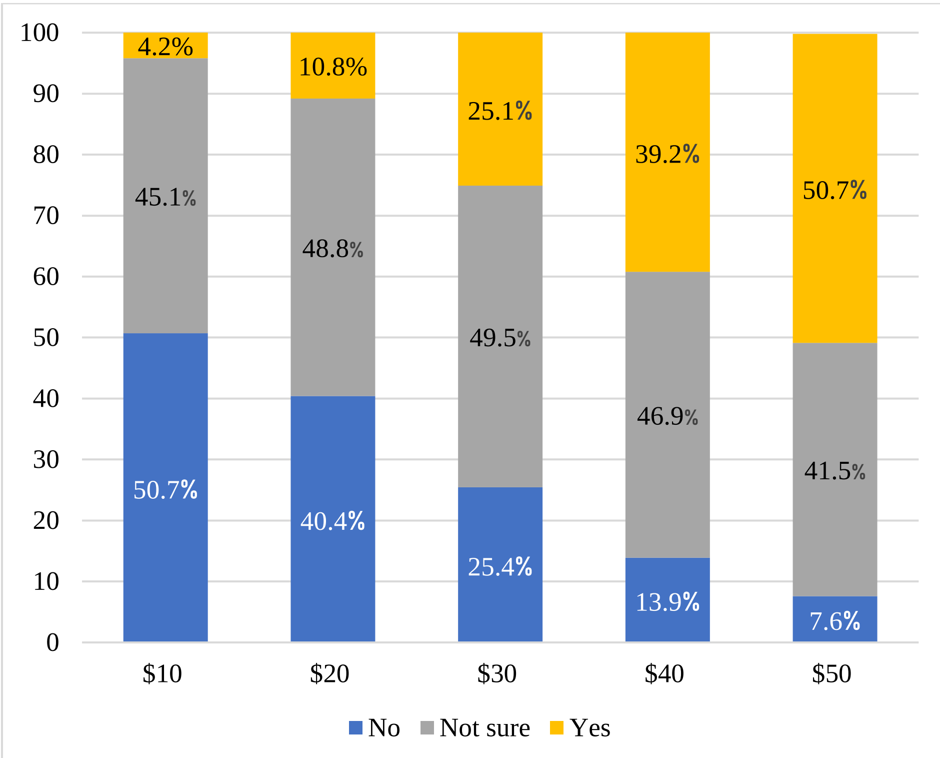

Figure 2**:** Carbon credit incentives farmers are willing to accept and adopt climate smart practices

4.3 Factors Influencing Farmers' Willingness to Accept Carbon Credits and Change Practices

The determinants of farmers' willingness to accept carbon credits and change their practices are presented in Table 5. The model diagnostics presented in the table indicate that the covariates are significantly correlated at a 1% significance level. Table 6 presents the marginal effects of the factors affecting determinants of farmers' willingness to accept carbon credits and change their practices. As shown in Table 6, age of a farmer has a negative correlation at 5% significance level with a farmer's willingness to accept carbon credit incentive and adopt climate-smart practices. This implies that an increase in the age of a farmer makes the farmer 0.7% less likely to accept carbon credit incentives and adopt climate-smart practices. Our finding is congruent with Ma et al. (2012), who observed that older agricultural producers are less likely to consider enrollment in environmental service programs. Wang et al. (2021a) highlighted that older farmers tend to have shorter planning horizons and may not be willing to make changes in farm practices in the future. Several carbon credit programs require farmers to commit to a minimum of a 10-year contract (Wang and Cheye, 2023; Plastina and Wongpiyabovorn, 2021). Older farmers may be more risk-averse and hesitant to participate in new programs that they perceive as uncertain or risky.

Our results also indicate that gross farm sales had a significant and positive effect on the willingness to accept carbon credit incentives and adopt climate-smart practices. An increase in gross farm sales makes the farmer 4.5% more likely to adopt climate-smart practices, given the carbon credit incentive. This is plausible because farmers who earn higher gross sales are more likely to operate larger croplands and thus benefit from economies of scale. Prokopy et al. (2019) note that an increase in farmers' revenue makes them more likely to invest in conservation practices.

Regrading farmers' previous experience with severe wet and drought conditions, the results show a contrasting effect on adoption of climate-smart practices given carbon credit incentives. While previous experience with severe drought had a significant and positive relationship with the willingness to accept carbon credit incentives and adopt climate-smart practices, experience with severe wet conditions had a negative effect on the willingness to accept carbon credit incentives and adopt climate-smart practices. The marginal effects results show that an increase in years of experience with severe drought makes the farmers 24.6% more likely to adopt climate-smart practices given carbon credit incentives. This finding is congruent with our hypothesis and in line with the findings of Etumnu et al. (2023), Wang et al. (2021a), and Saak et al. (2021), which indicate that drought conditions make farmers more likely to adopt conservation practices as an adaptive response measure. Wang et al. (2021a) found that farmers in the margins of the U.S. Corn Belt were more likely to adopt diversified crop rotation as an adaptive strategy to deal with water deficits. Also, Ding et al. (2009) observed a burgeoning adoption level of no-till in drought-affected regions during a multi-year drought.

In contrast to the effect of previous experience with severe drought conditions, an increase in years of experience with severe wet conditions makes farmers 34.9% less likely to adopt climate-smart practices. This result is as expected and corroborated by studies such as Ding et al. (2009). Wet conditions can delay the date of planting crops and increase soil erosion and nutrient leaching, which can negatively impact crop yields and soil health. Ding et al. (2009) found a significantly negative correlation between wet conditions and the adoption of no-till. During wet conditions, farmers might prefer conventional tillage methods to make the soil suitable for planting.

The results also indicate that the farm benefit is positive and significant at 5%. This shows that a unit increase in how farmers feel about the farm benefits (i.e., reduced soil erosion, reduced nutrient loss, increased water holding capacity, and improved wildlife habitat) of climate-smart practices makes them 14.7% more likely to adopt climate-smart practices given carbon credit incentives. A study by Dumbrell et al. (2016) found that farmers perceive improved soil quality and reduced soil erosion as the most important potential co-benefits of carbon farming. Farmers who perceive the benefits of climate-smart practices, including reduced soil erosion, are more likely to see the long-term value of adopting these practices. They may also be more willing to invest in the necessary inputs and equipment to implement these practices.

Watershed responsibility, as per our results, has a negative correlation with willingness to accept carbon credit incentives and adopt climate-smart practices. While this finding is contrary to our expectations, it indicates that a unit increase in watershed responsibility makes the farmer 12.3% less likely to accept the carbon credit incentive and adopt climate-smart practices. However, in instances where farmers do not receive enough monetary or other rewards to protect the environment, they may be less likely to adopt such practices.

Regarding SDSU extension, the results show that a unit increase in the importance of SDSU extension makes farmers 9.2% more likely to adopt climate-smart practices given carbon credits. Extension services could be a key information source to farmers, especially regarding climate change adaptive measures. This viewpoint is corroborated by Davis (2009), who stated that extension may aid farmers in preparing for increased climate unpredictability and uncertainty, developing backup plans to handle exponentially growing risk, and mitigating the effects of climate change by offering guidance on how to handle droughts, floods, and other such calamities. A meta-analysis of 367 adoption studies by

Ruzzante et al. (2021) found that contact with extension agents positively affects adoption of agricultural technologies.

We also found that using webinars or videos as an information source for learning about climate-smart practices positively correlated with adoption of those practices given the carbon credit incentive. A unit increase in the importance of webinars as an information source makes the farmer 14.3% more likely to adopt climate-smart practices given carbon credits. Webinars can be especially useful for farmers who have limited access to traditional sources of information, such as agricultural extension services. These digital tools can also be more convenient for farmers who may not have the time or resources to attend in-person training sessions or workshops. Concerning the slope of the field, we found a highly significant and positive relationship with the decision to adopt climate-smart practices given the carbon credit incentive. It indicates that as the slope of the field increases, the farmer is 8.7% more likely to adopt climate-smart practices given carbon credits. A steeper field is more vulnerable to soil erosion and degradation, so farmers are more likely to use conservation practices in steeper fields. For example, planting cover crops such as grasses and legumes helps protect the soil from erosion by providing ground cover. Also, no-till farming helps preserve the soil structure and reduce soil erosion.

Table 5**:** Probit model estimates of the factors affecting the willingness of farmers to accept carbon credit incentive and change practices

Variable	**Coef.**	**Std. Err.**
Farm and farmer characteristics		
Age	-0.018**	0.008
Gross sales	0.114*	0.066
Education	0.054	0.119
Severe weather events		
Drought	0.617**	0.298
Wet	-0.874**	0.415
Farm management and perceptions		
Soil health	0.022	0.144
Farm benefit	0.368**	0.186
Future responsibility	0.065	0.143
Watershed responsibility	-0.308**	0.129
Technical support	-0.179	0.100
Information sources		
SDSU Extension	0.230***	0.083
Farm Tours	0.090	0.099
Webinars	0.358***	0.110
Soil variable		
Slope	0.219***	0.072
Cons	-1.181	1.357
Number of obs.	199	
LR $Chi^2(14)$	52.98	
Prob > Chi^2	0.0000	
Log likelihood	-111.382	

Notes: *p < 0.10, ** p < 0.05, *** p < 0.01 indicate significance of t-statistic of the mean difference.

Table 6: Marginal effects of the factors affecting the willingness of farmers to accept carbon credit incentive and change practices

Variable	Marginal Effect	Std. Err.
Farm and farmer characteristics		
Age	-0.007**	0.003
Gross sales	0.045*	0.026
Education	0.021	0.047
Severe weather events		
Drought	0.246**	0.119
Wet	-0.349**	0.165
Farm management and perceptions		
Soil health	0.009	0.057
Farm benefit	0.147**	0.074
Future responsibility	0.026	0.057
Watershed responsibility	-0.123**	0.051
Technical support	-0.071*	0.040
Information sources		
SDSU Extension	0.092***	0.033
Farm Tours	0.090	0.099
Webinars	0.143***	0.044
Soil variable		
Slope	0.087***	0.029
Cons	-1.181	1.357
Number of obs.	199	
LR $Chi^2(14)$	52.98	
Prob > Chi^2	0.0000	
Log likelihood	-111.382	

Notes: *p < 0.10, ** p < 0.05, *** p < 0.01 indicate significance of t-statistic of the mean difference.

4.4 Determinants of the Level of Carbon Credit Incentive Farmers are willing to Accept and Adopt Climate-smart Practices

Table 7 reports the coefficient estimates of the factors affecting the level of carbon credit incentive farmers are willing to accept and switch their farming practices to climate-smart practices. The marginal effects of the factors affecting the level of carbon credit incentive farmers are willing to accept and switch their farming practices to climate-smart practices are presented in Table 8. The model diagnostics indicate that the independent variables are correlated at a 1% significance level.

With regards to farm and farmer characteristics, the results show that age has a positive and statistically significant effect on the level of carbon credit farmers are willing to accept and change their practices. The marginal effects show that an increase in the age of the farmer makes the farmer 20.0% more likely to accept a higher carbon credit incentive and adopt climate-smart practices. Typically, older farmers are less likely to accept carbon credit payments and change their practices. Carlisle (2016) highlights that younger timeframes adopt soil health practices at higher rates, possibly because they have longer decision-making horizons and are more environmentally oriented, and perhaps because older farmers are more used to their methods of farming. Ma et al. (2012) identified that older farmers are less likely to participate in programs that pay for environmental services. Considering the hesitancy of older farmers to engage in carbon credit programs and switch their practices to climate-smart practices, a higher carbon credit incentive would more likely motivate them to switch their practices.

Previous experience with severe wet conditions was found to negatively correlate with the level of carbon credit incentive farmers are willing to accept and change their management practices. Interestingly, a unit increase in years of experience with severe wet conditions makes farmers 111.9% less likely to accept a higher carbon credit payment and adopt climate-smart practices. This finding provides an insight into farmers maladaptation to severe wet conditions in the region. Ding et al. (2009) noted that while farmers may use, for example, no-till or strip-till to conserve soil moisture, when water reserves are low, they are deterred from using these practices when springtime weather is wet. It is likely that farmers will be hesitant to accept carbon credit incentives, even if they are high enough to adopt these practices. Severe wet conditions can make it problematic for farmers to access their fields, plant crops, and implement conservation measures such as cover cropping or reduced tillage.

With respect to the farmer's perception of co-benefits, soil health is found to be significantly and negatively correlated with the level of carbon credit incentive farmers are willing to accept and adopt climate-smart practices. This indicates that a unit increase in the perception that climate-smart practices enhance soil health makes farmers 56.6% less likely to accept higher carbon credit incentives and adopt climate-smart practices. Soil health enhancement, as a co-benefit of adopting climate-smart practices, has been found to be a strong motivation for farmers decisions to adopt climate-smart practices. Dumbrell et al. (2016) found that Western Australian farmers consider improved soil quality to be the most important benefit of carbon farming. Other studies, including Mattila et al. (2022), Davison et al. (2019), Carlisle (2016), and Kragt et al. (2017), highlight soil health enrichment as a key driver of farmer participation in carbon farming. In the Northern Great Plains, Wang et al. (2019) determined that farmers' values on soil health were an important motive for conservation practice adoption behavior.

The results also show that a unit increase in crop yield makes farmers 70.9% more likely to accept a higher carbon credit incentive and adopt climate-smart practices. Conservation agriculture practices have been shown to enhance crop yields (Zheng et al., 2014). However, the yield benefits of conservation practice adoption may be uncertain or reduced in the early years (Saak et al., 2021). For example, a meta-analysis by Pittelkow et al. (2015) found that no-till reduced yields, on average, by 5.1%. As such, farmers may be inclined to receive higher carbon credit incentives to switch practices as a result of the uncertainties.

According to our results, farm benefits have a positive and significant effect on the level of carbon credit incentive farmers are willing to accept and adopt climate-smart practices. A unit increase in farm benefit makes farmers 39.7% more likely to accept high carbon credit incentives and switch their practices. Farm benefits include reduced soil erosion, improved wildlife habitat, reduced nutrient loss into waterways, etc. Farmers' perceptions of the co-benefits of climate-smart practices can be heterogeneous. For example, farmers with highly erosible land may be more likely to adopt the practices given a low carbon credit incentive. Also, farmers who are aware and concerned that their practices lead to negative externalities such as water pollution may be more likely to accept a low-carbon credit incentive to adopt practices that minimize the externality.

Cost-share, based on our results, is negatively correlated with the level of carbon credit incentive farmers are willing to accept and change their practices. Farmers who received a cost share were 46.8% more likely to accept higher carbon credit incentives and adopt climate-smart practices. The relationship between cost-share and the adoption of climate-smart practices is mixed. Wang et al. (2021b) found that the cost-share received did not have any significant effect on the future adoption of cover crops in South Dakota. A study by Dobbs and Pretty (2008) found that while government incentives were effective in enrolling farmers in entry-level contract tiers, they were ineffective in making farmers enroll in conservation programs that required more substantial changes in farming practices.

Also, Ogieriakhi and Woodward (2022) highlighted that in an Ohio study, more than half had negative feelings about cost-share programs because the application process tends to be time-consuming, the programs have onerous design and implementation requirements, and the required contracts require long-term commitments. Therefore, although government incentives and carbon markets can encourage farmers to adopt climate-smart practices, incentives may be less successful because they do not boost farmers' profitability (Ogieriakhi and Woodward, 2022). It is conceivable that greater carbon credit incentives may be required to get past farmer resistance.

Concerning farmers' perceptions about profitability, we found that a unit increase in profitability perception makes farmers 51.2% less likely to accept a higher carbon credit incentive and adopt climate-smart practices. Climate-smart practices can improve the resilience of farming systems to adverse effects such as droughts and floods, reducing the risk of crop failure and income loss. Wang et al. (2021b) examined farmers' perceptions of cover crop profitability and the likelihood of future usage in South Dakota. Their results revealed that about 40% of long-term (10+ years) users perceived a profit increase greater than 5%. In a choice experiment, Gramig and Widmar (2018) showed that farmers would prefer an increase in profits from adopting conservation tillage without having to receive government payments. In a similar direction, Bagnall et al. (2020) indicated that farmer-themed profitability had a strong influence on the adoption of soil health management practices. Thus, a perceived increase in profitability of climate-smart practices will more likely make farmers less likely to demand a higher carbon credit incentive and adopt the practices.

Future responsibility has a significant effect on the level of carbon credit incentive farmers are likely to accept and change their practices. The results indicate that a unit increase in the perception of future responsibility makes farmers 41.7% more likely to accept a lower carbon credit incentive and adopt climate-smart practices. When farmers view themselves as stewards of the land, they may be more inclined to adopt practices that promote sustainability and protect the environment. Mitter et al. (2019) provide support for this finding, indicating that strong responsibility for future generations influences the use of environmentally friendly farming practices. Also, Page and Bellottin (2015) show that non-financial incentives such as a sense of stewardship ethics and passing the land on in better form can positively correlate with taking part in conservation projects.

Table 7**:** Interval regression model estimates of the determinants of the level of carbon credit incentive farmers are willing to accept and change practices

Variable	**Coef.**	**Std. Err.**
Farm and farmer characteristics		
Age	0.200***	0.075
Gross sales	0.226	0.893
Severe weather events		
Drought	-4.241	3.274
Wet	-11.193*	5.827
Farm management and perceptions		
Soil health	-5.664***	1.573
Crop yield	7.089***	2.203
Farm benefit	3.972*	2.074
Cost-share	4.682*	2.509
Profitability	-5.120**	2.481
Future responsibility	-4.171**	1.686
Information sources		
SDSU Extension	0.138	0.987
Farm Tours	-0.680	1.075
Cons	75.900	18.501
Number of obs.	99	
Right-censored obs.	19	
Interval obs.	80	
LR $Chi^2(12)$	44.31	
Prob > Chi^2	0.0000	
Log likelihood	-133.343	

Notes: *, **, *** represent $p < 0.10$, $p < 0.05$, and $p < 0.001$ respectively

Table 8: Marginal effects of the determinants of the level of carbon credit incentive farmers are willing to accept and change practices

Variable	Variable	Marginal Effect
Farm and farmer characteristics		
Age	0.200***	0.075
Gross sales	0.226	0.893
Severe weather events		
Drought	-4.241	3.274
Wet	-11.193*	5.827
Farm management/ perceptions		
Soil health	-5.664***	1.573
Crop yield	7.089***	2.203
Farm benefit	3.972*	2.074
Cost-share	4.682*	2.509
Profitability	-5.120**	2.481
Future responsibility	-4.171**	1.686
Information sources		
SDSU Extension	0.138	0.987
Farm Tours	-0.680	1.075
Cons	75.900	18.501
Number of obs.	99	
Right-censored obs.	19	
Interval obs.	80	
LR $Chi^2(12)$	44.31	
Prob > Chi^2	0.0000	
Log likelihood	-133.343	

Notes: *p < 0.10, ** p < 0.05, *** p < 0.01 indicate significance of t-statistic of the mean difference.

CHAPTER 5

CONCLUSION AND IMPLICATIONS

As climate change continues to cause considerable losses and threats, net zero pledges and carbon markets have significantly increased, which provide agricultural producers with incentives to sequester carbon. To determine the role that agricultural carbon credits play in farmers adoption of climate-smart practices, we analyzed survey data conducted in 2021 in South Dakota. The study focused on achieving three specific objectives: to determine the carbon credit price that farmers are willing to accept and change their farming practices to sequester more carbon; to examine the factors behind the willingness to accept the incentives and change practices given carbon credit incentives; and to analyze the determinants of the level of carbon credit incentive farmers are willing to accept and change their practices to climate-smart practices. To achieve these objectives, we employed a descriptive approach, a probit regression, and an interval regression model, respectively. Our study establishes four key findings as follows:

We found that half of the farmers in the study area were willing to switch from their conventional practices to climate-smart practices if they were paid \$50 per ton. We noticed that as the price of carbon credits increases, more farmers are willing to switch from conventional to climate-smart practices that sequester carbon. This finding suggests that the current carbon credit price offered to farmers, which averages \$20 per ton in the voluntary market, might not be enough to motivate farmers to switch their practices. Also, we found that the willingness of farmers to accept a carbon credit incentive and adopt climate-smart practices is influenced by their perception of co-benefits such as improved soil health and enhanced farm benefits, which entail reduced soil erosion, reduced nutrient run-off, enhanced water quality, etc. Our results suggest that while farmers are less likely to demand a higher carbon credit incentive with perceived soil health improvement in mind, they are more likely to demand a higher carbon credit incentive with other associated perceived benefits such as reduced erosion, enhanced wildlife habitat, reduced nutrient run-off, etc.

Economic incentives play a significant role in farmers willingness to adopt climate-smart practices, given carbon credit incentives. We found that farmers' perception of increased profitability from the adoption of climate-smart practices makes them more likely to accept a lower carbon credit incentive and adopt the climate-smart practices. As expected, farmers previous experiences with extreme weather events such as severe wet and severe drought conditions affect their willingness to accept carbon credit incentives and adopt climate-smart practices. Consistent with Ding et al. (2009), the experience of severe drought conditions makes farmers more likely to adopt climate-smart practices given carbon credit incentives. On the contrary, experience with severe wet conditions makes farmers less likely to adopt climate-smart practices, given carbon credits. These findings might be explained by farmers varying adaptive capacities to the severe weather events in the region. Apart from the key findings indicated, we found that other factors such as higher gross sales, younger age of the farmer, perceived responsibility for future generations, and information sources such as SDSU extension service and webinars make farmers more likely to accept carbon credit incentives and adopt climate-smart practices.

The implications of these findings include the following: Firstly, it is pertinent that policymakers and carbon credit companies consider incentivizing farmers with a higher carbon credit to motivate farmers to adopt the practices and sequester carbon. While farmers are currently offered an average carbon credit price of $20/ton, our results reveal that most of the farmers would consider switching their practices to store more carbon if they were paid about $50/ton. Secondly, it is important to understand farmers' perceptions and responses to severe weather events such as severe wet weather and severe drought. According to our results, while previous experience with severe drought increases the likelihood of a farmer adopting climate-smart practices, previous experience with severe wet conditions makes a farmer less likely to adopt climate-smart practices at a given carbon credit value. This finding suggests that though conservation practices such as no-till, reduced till, and cover crops are suitable adaptive strategies for severe drought conditions, different adaptive strategies might be relevant to adapting to severe wet conditions. These findings provide insight for policymakers and extension agents to increase farmers' awareness of climate change and appropriate adaptation measures to counter the adverse effects of climate change.

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