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Farmer perceived challenges toward conservation practice usage in the margins of the Corn Belt, USA

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Abstract

While conservation practices promote soil health and reduce the negative environmental effects from agricultural production, their adoption rates are generally low. To facilitate farmer adoption, we carried out a survey to identify potential challenges faced by farmers regarding conservation tillage and cover crop adoption in the western margin of the US Corn Belt. We found farmers' top two concerns regarding conservation tillage were delayed planting, caused by slow soil warming in spring, and increased dependence on herbicide and fungicides. Narrow planting window and lack of time/labor were perceived by farmers as the two primary challenges for cover crop adoption. Some sense of place factors, including the commonly included dimensions of attachment, identity and dependence, played a role in farmers' perceived challenges. For example, respondents more economically dependent on farming perceived greater challenges. We found that farmers' challenge perceptions regarding reduced yield and lack of time/labor significantly decreased as years of usage increased, implying that time and experience could dilute some challenges faced by farmers. Our findings indicate that social network use, technical guidance and economic subsidies are likely to address the concerns of farmers and facilitate their adoption of conservation practices.

Introduction

In the USA, current intensive agricultural production has led to undesirable effects on the environment and a gradual decrease in land productivity (Kassam *et al.*, 2014; McDaniel *et al.*, 2014; Benitez *et al.*, 2017). The average soil loss over the last 100 yr of crop cultivation across the Midwest has been estimated to be 7.2 ± 4.8 Mg ha^{-1} yr^{-1} (Thaler et al., 2022). Historic and modern soil erosion reduces cropland productivity and agroecosystem resiliency. Soil, nutrient and agrochemical losses are also major sources of water pollution. Between 2007 and 2009, nitrogen (N) leaching to water sources from intensively cultivated croplands in southern Minnesota amounted to 7–12 lbs N acre^{-1} yr^{-1} (Minnesota Pollution Control Agency, 2013). A high water N level could further lead to undesirable outcomes in aesthetic-, health- and economic-related issues (Khan *et al.*, 2018; Wang *et al.*, 2021a).

The negative environmental consequences of crop production can be reduced by lowering tillage intensity, improving N use efficiency and/or using regenerative farming practices (Yadav *et al.*, 2017; Zomer *et al.*, 2017; Baffaut *et al.*, 2020). Conservation practices such as conservation tillage and cover crops can increase soil productivity, reduce erosion and slow climate change (Chalise *et al.*, 2019; Joshi *et al.*, 2019; Page *et al.*, 2020; Singh *et al.*, 2020). While a large and continually growing body of research examined factors associated with conservation practice adoption, not enough focus has been placed on 'barriers to adoption, especially cultural (e.g., community norms) and structural (e.g., policy–market interface)' (Prokopy *et al.*, 2019).

This paper studies farmer perceived challenges toward two conservation practices, conservation tillage and cover crops. Conservation tillage refers to any tillage practice that leaves at least 30% of crop residues on the soil surface after cash crop planting (Kassam *et al.*, 2009; Hagen *et al.*, 2020). Some common practices that fall under the conservation tillage category include no-till, reduced tillage, mulch tillage and ridge tillage (Kassam *et al.*, 2009). Conservation tillage helps preserve soil moisture in dry areas, improve soil and water quality, and, in many instances, can increase long-term crop yields (Busari *et al.*, 2015; Canales *et al.*, 2020; Saak *et al.*, 2021). Using observational data from a study conducted in Corn Belt states between 2005 and 2018, Chen *et al.* (2021) showed that conservation tillage had a positive effect on corn and soybean yields. A long-term (1992–2016) experimental study conducted in New York found that a continuous no-till practice increases soil heath and crop yields (e.g., corn) in the temperate region than plow-till practice (Nunes *et al.*, 2018). They further indicated that the positive effect of no-till practice on crop productivity depends on soil type and whether the farming system adopted other conservation practices or not. No-till practices can present trade-offs associated with herbicide use, however, as a general practice, reducing tillage intensity provides multiple well-documented agroecosystem, soil health and water quality benefits (Hagen *et al.*, 2020; Hess *et al.*, 2020).

Cover crops, referred to crops planted to cover the soil surface during fallow periods, protect soil on croplands that otherwise would be bare between harvest and planting of cash crops, typically from fall until spring in temperate climate zones or during the winter in tropical and subtropical climates. Cover crops help improve soil health and water filtration, control weeds, pests, and diseases and provide wildlife habitat (Pullaro *et al.*, 2006; Oliveira *et al.*, 2019; Chen *et al.*, 2022). Mahama *et al.* (2016) found that the integration of leguminous cover crops has the potential to reduce nitrogen requirement and increase grain yield. Cover cropping also affects the whole farm profitability of Midwest farmers with differing effects across state and cover crop types (Plastina *et al.*, 2020). When implemented together, conservation tillage and cover crops can be used to improve agricultural system sustainability. While there is geographic variation, the complementarity benefits between these two conservation practices exists partly because no-till seeding equipment with minor additions could be utilized to plant cover crops, which can mitigate weed problems in no-till lands (Bergtold *et al.*, 2019; Lee and McCann, 2019; Canales *et al.*, 2020).

Despite the benefits, some conservation practices, such as cover crops, are not widely adopted by farmers. According to the 2017 Census of Agriculture, between 2012 and 2017, the adoption rate of cover crops was approximately 4% of total croplands (U.S. Department of Agriculture, 2019). Between 2017 and 2020, winter cover crops were planted in 4–5% of row crop acres in the Midwest (CTIC, 2022). The nationwide adoption rates of conservation tillage increased from 44% in 2012 to 51% in 2017 (U.S. Department of Agriculture, 2019). In the Corn Belt states, the conservation tillage adoption rate was 44%, while cover crops were only planted on 3% of the total corn and soybean acres (Hagen *et al.*, 2020). Emerging challenges associated with conservation practices, such as herbicide-resistant weeds, may result in discontinuation of such practices. During 1998–2016, tillage intensity across the US corn–soybean cropping systems first decreased with the adoption of herbicide-tolerant crops and then increased with emerging weed resistance and is likely to further increase as weed resistance persists (Lu *et al.*, 2022).

To facilitate farmers' adoption and effective use of conservation practices, this study investigated farmer perceived challenges toward using conservation tillage and cover crops at the margin of US Corn Belt, as well as potential factors that affect such perceived challenges. Conservation tillage and cover crops were selected in this study because of their potential complementarity in improving soil health and farm profitability over the long term. We investigated the effect of farmer characteristics, adoption duration, farmers' sense of place (SOP), farm management strategies and biophysical and climate factors on farmers' perceived challenges. A survey designed to identify the adoption challenges for conservation tillage and cover crops was mailed to South Dakota farmers located and the data were analyzed using ordinal logistic regression. Specifically, we targeted farm operators in central and eastern South Dakota where the production of corn and soybean is dominant to understand the challenges of using these two conservation practices in a corn–soybean cropping system at the west margins of the US Corn Belt.

Challenges associated with conservation tillage and cover crops

Previous studies indicated that major challenges to the adoption of conservation practices include biophysical conditions, opportunity costs and resource constraints (Greiner and Gregg, 2011; Hayden *et al.*, 2018; Kasu *et al.*, 2019; Fleckenstein *et al.*, 2020; Wang *et al.*, 2020, 2021b). Reported challenges associated with conservation tillage include increased herbicide use and reduced crop yield (Fernandez-Cornejo *et al.*, 2012; Reimer *et al.*, 2012). The reliance on pesticides to control pests also poses a threat to water quality in nearby streams. Yield reduction under no-till in corn-producing areas of South Dakota was mainly caused by wet fields in spring, which delayed the planting of cash crops (Reimer *et al.*, 2012). A global meta-analysis found that compared to conventional tillage, no-till decreases wheat and corn yields by 2.6 and 7.6%, respectively, due to high soil moisture (Pittelkow *et al.*, 2015). Adoption decisions related to conservation tillage could be also influenced by challenges such as biophysical conditions and opportunity costs (Carlisle, 2016). Moreover, non-adoption decisions of conservation tillage could arise from the uncertainty about its effectiveness and perceived non-necessity (Reimer *et al.*, 2012).

The challenges with cover crop adoption in the USA include lack of technical knowledge on seeding rate and proper planting, lack of time, labor and equipment (e.g., roller-crimper), and most importantly, narrow planting window (Reimer *et al.*, 2012; O'Connell *et al.*, 2014; Roesch-McNally *et al.*, 2018; Daryanto *et al.*, 2019; Clay *et al.*, 2020). Cover crop seeds cost, establishment and termination costs and yield reduction risks could also pose concerns for farmers (Daryanto *et al.*, 2019; Clay *et al.*, 2020). Regarding the yield reduction risk, a recent study conducted in US Midwest found that cover crops, particularly non-legume, reduced the corn yield but had no significant negative effect on soybean yield (Qin *et al.*, 2021). Additionally, high production costs associated with corn–soybean rotations have created strong path dependencies which discourage change due to the additional costs of cover crops (Roesch-McNally *et al.*, 2018; Spangler *et al.*, 2022). Other challenges associated with cover crops include reducing the amount of water available for the cash crop and cool soil temperatures that slow germination (O'Connell *et al.*, 2014; Clay *et al.*, 2020).

Previous studies indicated that farm and farmer characteristics can influence the perceived challenges associated with the adoption of several different conservation practices (Reimer *et al.*, 2012; Clay *et al.*, 2020; Wang *et al.*, 2020, 2021b). For example, landowners with more owned land and better land quality perceived lower challenges with rotational grazing practices in the US Great Plains (Wang *et al.*, 2020, 2021b). Furthermore, farming motivations could affect perceived challenges as survey findings in Northern Australia showed that compared with 'conservation and lifestyle' or 'social' oriented farmers, 'financial/economic'-oriented farmers tended to rate 'opportunity costs' and 'resource constraints' as more important challenges (Greiner and Gregg, 2011). Farmers who had more knowledge and experience with cover crops perceived a lower degree of challenges related to the practice (Clay *et al.*, 2020). Additionally, tenant farmers expressed concerns about adopting cover crops as long-term improvement

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in soil fertility could potentially increase the cash-rent auction price in subsequent years (Roesch-Mcnally *et al.*, 2018).

SOP often considers the affective, cognitive and/or attitudinal relationships between spatial settings and people (Low and Altman, 1992; Jorgensen and Stedman, 2001). Previous studies have indicated that some SOP dimensions, such as attachment, identity and dependence, may provide useful measures to understand farmer's conservation behavior in agricultural landscapes, yet findings have been inconsistent. For example, Wyoming and Colorado farmers who reported economic dependence on their property were not interested in holding a conservation easement, an environment-friendly land-use practice (Cross *et al.*, 2011). However, place attachment reported by Indiana farmers was a significant and positive predictor of conservation tillage practice on their working lands (Mullendore *et al.*, 2015). Multiple studies argue that additional research on the relationship between SOP, its various dimensions and conservation practice adoption among agricultural producers is needed (Low and Altman, 1992; Jorgensen and Stedman, 2001; Eaton *et al.*, 2019). In particular, Eaton *et al.* (2019) advocate for the modification of existing SOP dimensions and items to better capture working landscape dynamics, including (1) the inclusion of economic dependence as a distinct dimension of overall dependence; (2) addressing the role of scale and (3) incorporating a conservation ethic dimension. While one study looked at the relationship between SOP and cover crop adoption in Iowa (e.g., Bennett *et al.*, 2023), to our best knowledge, no previous study has investigated how factors such as farm and farmer characteristics and farmers' SOP is related to perceived challenges with conservation tillage or cover crops.

Methods

Data collection

We conducted a mail survey in spring 2018 to understand existing farming practices implemented by agricultural producers in 36 counties of eastern South Dakota (Fig. 1), a major crop growing region in South Dakota dominated by a 2-yr corn–soybean rotations (O'Brien *et al.*, 2020). The survey was mailed to a sample of 3000 farm operators, identified using proportionate stratified-random sampling from a list of farming operations that participated in Farm Service Agency (FSA) programs. The sample size for each stratum (i.e., county) was proportionate to the number

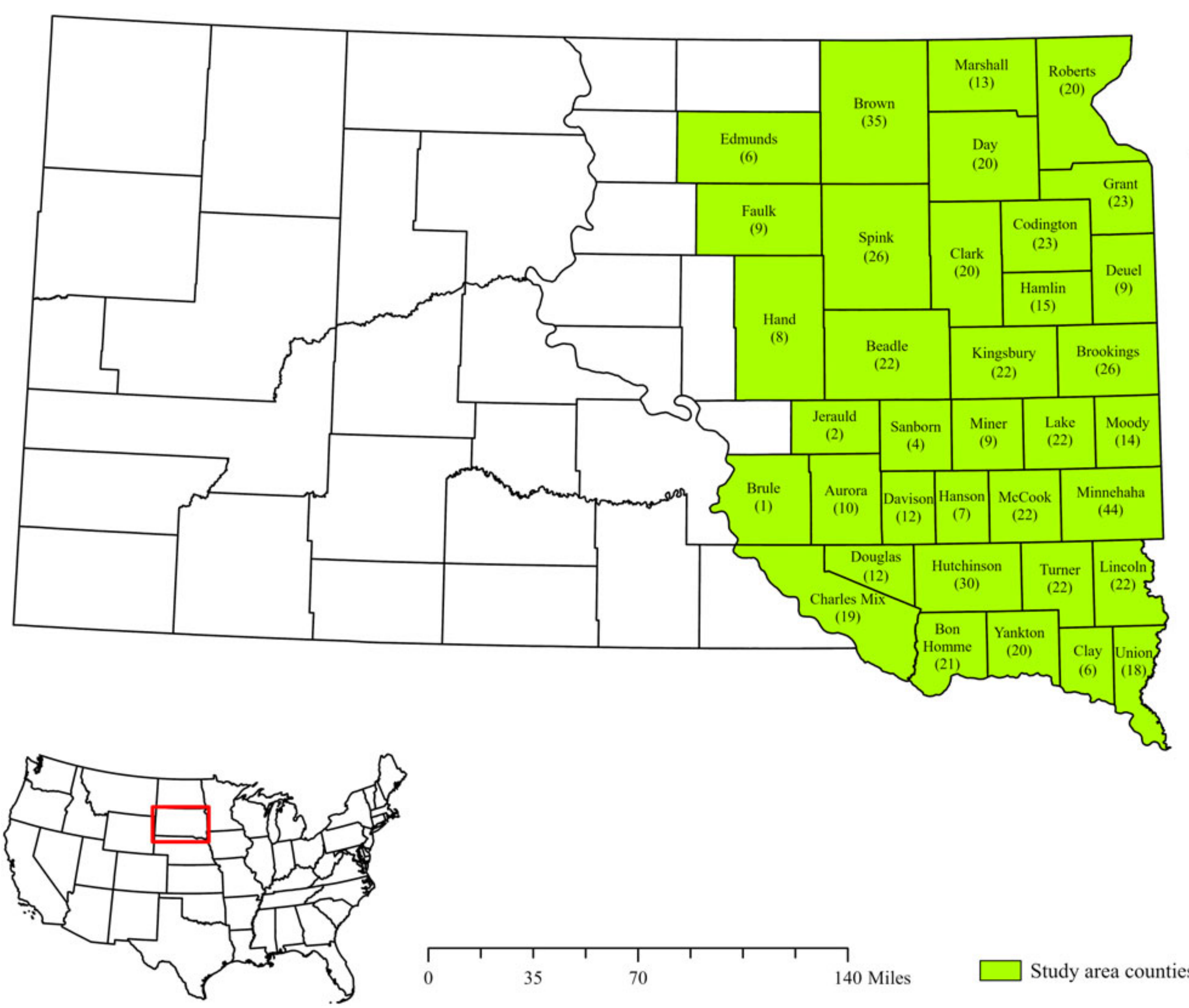

Fig. 1. Study area in eastern South Dakota with the number of responses for each county in parentheses.

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of active farm operations in each study county. The selection of FSA program participants ensures that the farm operators selected had adequate farmlands for conservation practices (Adusumilli and Wang, 2018), and is a commonly used sample source for survey research with agricultural producers (Ulrich-Schad *et al.*, 2022). In 2017, a total of 43,487 farm operators participated in FSA programs in South Dakota (Wang *et al.*, (2021b)). According to the 2017 Census of Agriculture, no-till, reduced tillage and cover crops were practiced on 7.66 million acres (38.64%), 4.30 million acres (21.70%) and 0.28 million acres (1.42%), respectively, out of 19.81 million croplands in South Dakota.

The survey participants were contacted up to four times: a letter with a link to answer the online questionnaire, a paper questionnaire with a stamped return envelope, a reminder postcard and a second replacement questionnaire with a stamped return envelope. As a pre-incentive, a $2 bill with the first letter was randomly assigned to one-half of the total respondents to test whether that would increase the response rate, which it did by a statistically significant margin (Avemegah *et al.*, 2021). The questionnaire had six sections (see Appendix A). The first and second sections included questions on farming decisions, farm management strategies and farming behavior. The third section consisted of questions related to benefits and challenges to the adoption of conservation practices, while section four included questions about the perceived change in costs and profits following conservation practice adoption. The fifth section included questions related to farming motivations or farmer's SOP, moral and social norms and environmental attitudes, and finally, the sixth section included the questions related to farm and farmer's socio-economic characteristics. This study used questions from all the sections except the fourth section.

Out of 3000 mailed questionnaires, a total of 708 respondents from 36 counties of eastern South Dakota returned the questionnaires. The adjusted survey response rate was 30% after those selected with incorrect addresses or no-longer farming status were excluded from the total. This is within the range (19.8–39.3%) of other recent studies that employed mail surveys of agricultural producers in the US Midwest (Wang *et al.*, 2017, 2019, 2020, 2021b, 2021a; Church *et al.*, 2020). Usually, high response rate is an indicator of data quality and can reduce the likelihood of nonresponse error (Dillman *et al.*, 2014). In addition, we compared our respondents' age and cropland acres operated with the USDA's 2017 Census of Agriculture, and found these key demographics of our respondents were comparable to the state-level demographics (see Avemegah *et al.*, 2021).

We used only 614 responses in this analysis because some respondents did not send their responses using the questionnaire with a printed unique ID or entered it incorrectly online which prevented us from locating their specific address and the associated weather data. Weather data such as precipitation and temperature were collected from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) dataset developed by PRISM Climate Group at Oregon State University. The PRISM utilizes point measurements of precipitation, temperature and other climatic factors to generate continuous, digital grid estimates of monthly, yearly and event-based climatic parameters (Daly *et al.*, 1994).

Data description

The survey questionnaire included five potential challenges associated with conservation tillage and 11 potential challenges associated with cover crops. We selected four challenges related to conservation tillage and five challenges related to cover crops as dependent variables for regression analysis based on their high levels of importance to farmers. The importance level of each potential challenge perceived by farmers was measured on a 4-point Likert scale where 1 = not important, 2 = slightly important, 3 = moderately important and 4 = very important. For model estimation purposes, we recoded the 4-point Likert scale to a 3-point Likert scale where 'not important' and 'slightly important' categories were combined as 1 (not or slightly important), 'moderately important' as 2 and 'very important' as 3 to balance the number of responses among different importance levels. In the discrete response variable, if the occurrence of an event is disproportionately high or low, the sample data become unbalanced and parameters estimated by regression analysis are affected. Thus, balanced data have lower variance of estimated parameters and better prediction capabilities than unbalanced data (Salas-Eljatib *et al.*, 2018).

The empirical model included six categories of independent variables, namely: farmer characteristics, farm characteristics, adoption duration, farmers' SOP, management strategies and climate factors (Table 1). The variables related to farmers' socio-economic characteristics were farmer age (*age*) and highest education level completed (*education*). Socio-economic factors could possibly affect farmers' perceived challenges associated with conservation practices because of their connection with awareness and farming experiences (Carlisle, 2016). For example, younger farmers might adopt conservation practices because they have longer farming horizons and see the potential of getting conservation benefits in the long term, while older farmers could be reluctant to accept innovations as they are more used to the long-standing farming traditions. The second category of variables was farm characteristics such as total acres of farmland (*acres*) and the proportion of owned farmland (*owned land*).

The third category of independent variables was adoption duration of conservation practices, which were measured on a 5-point scale (1 = <3 yr, 2 = 3–5 yr, 3 = 6–10 yr, 4 = 10+ yr and 5 = never used). When farmers have experience with conservation practices, it helps decrease the perceived challenges associated with their implementation (Dunn *et al.*, 2016). In South Dakota, conservation tillage has been practiced by farmers for decades, but the adoption of cover crops has not been widespread (NRCS, 2019). Working land conservation programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP) provide cost-share opportunities for 3–5 yr to adopt conservation practices on farmlands (Adhikari *et al.*, 2022). Considering these factors and the number of observations in each category, three binary variables related to the adoption duration of conservation tillage and cover crops were constructed and used as explanatory variables in the related regression models. On conservation tillage adoption duration, we have three variables, $\leqslant$*5 years*, *6 to 10 years* and *>10 years*, with non-adoption serving as a reference category. As cover crops are a relatively new practice, the three adoption duration variables for cover crops are shorter than those for conservation tillage, which are *<3 years, 3 to 5 years* and *>5 years*.

The fourth category of independent variables included farmers' SOP including the dimensions of *place attachment/identity, place dependence, social identity* and *economic dependence*. Principal component analysis (PCA) was used to identify underlying components of farmers' SOP regarding the land they farm. There were 16 different items originally included in the survey questionnaire which were derived from Eaton *et al.* (2019). Four

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Table 1. Description of the independent variables used in logistic regression analysis

Category	Variable	Description	*N*	Mean	s.d.
Farmer characteristics	Age	Age of respondent in years	555	56.816	14.089
	Education	Highest education level completed by a respondent (1 = Some college, technical school or higher, 0 = high school degree or lower)	570	0.718	0.451
Farm characteristics	Acres ($\times 10^2$)	Total acres of farmland	544	11.843	19.536
	Owned land	Proportion of owned farmland	503	59.072	33.885
Adoption duration (conservation tillage)	⩽5 yrs	Usage of conservation tillage (e.g., no-till, strip-till or mulch-till) (1 = 5 yr or less than 5 yr of use, 0 otherwise)	577	0.179	0.383
	6–10 yr	Usage of conservation tillage (e.g., no-till, strip-till or mulch-till) (1 = 6–10 yr of use, 0 otherwise)	577	0.146	0.353
	>10 yr	Usage of conservation tillage (e.g., no-till, strip-till or mulch-till) (1 = more than 10 yr of use, 0 otherwise)	577	0.458	0.499
	Non-adoption	Usage of conservation tillage (e.g., no-till, strip-till or mulch-till) (1 = no adoption of conservation tillage, 0 otherwise)	577	0.218	0.413
Adoption duration (cover crops)	<3 yr	Usage of cover crops (1 = less than 3 yr of use, 0 otherwise)	581	0.222	0.416
	3–5 yr	Usage of cover crops (1 = 3–5 yr of use, 0 otherwise)	581	0.112	0.315
	>5 yr	Usage of cover crops (1 = more than 5 yr of use, 0 otherwise)	581	0.141	0.348
	Non-adoption	Usage of cover crops (1 = no adoption of cover crops, 0 otherwise)	581	0.525	0.500
Sense of place	Place attachment/ identity	Farmers' attachment and identity in relation to farming (PCA index)	532	0	2.612
	Place dependence	Farmers' connection to the physical location they farm (PCA index)	532	0	1.264
	Social identity	Farmers' level of connection to other farmers (PCA index)	532	0	1.213
	Economic dependence	Farmers' level of economic dependence on farming (PCA index)	532	0	1.086
Farm management strategies	Business plan	1 if farmer agreed on 'I always have a written business plan for my farm operation', 0 if disagree	599	0.399	0.490
	Diversification	1 if farmer agreed on 'I am often looking for ways to diversify my farm operation', 0 otherwise	602	0.746	0.436
Weather characteristics	Precipitation	30-yr (1987–2017) average precipitation per crop growing season (May–September) in inches	614	16.432	1.487
	Temperature	30-yr (1987–2017) average temperature per crop growing season (May–September) in °C	614	18.905	0.737

components, selected based on greater than 1 eigenvalue criterion, explained 69.2% variation in the original data. Variables loaded under each component are presented in Table 2 with component 1 labeled as *place attachment/identity*, component 2 as *place dependence*, component 3 as *social identity* and component 4 as *economic dependence*. Factor scores were used as the measurements for each component. The fifth category of independent variables was related to farm management strategies such as 'I always have a written business plan for my farm operation' (*business plan*) and 'I am often looking for ways to diversify my farm operation' (*diversification*). Finally, independent variables related to climate factors were included, which are 30-yr average precipitation amount for crop growing season (*precipitation*), and 30-yr average temperature for crop growing season (*temperature*). The value of these climate variables was based on the county level. Climatic conditions greatly affect the need for and difficulty of establishing certain conservation practices on croplands (Ding *et al*., 2009; Arbuckle and Roesch-McNally, 2015).

Empirical model

Farmers were asked to provide ratings on the importance of the potential challenges associated with conservation practices to their farm operations. The stated responses for each potential challenge were specified as 3-point scale: not or slightly important, moderately important and very important. Given the ordered and discrete nature of the dependent variables, ordered logit models were constructed. The general form of the model in terms of the probability that an individual i chooses alternative m can be

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Table 2. PCA for SOP dimensions using varimax rotation method (n = 532, rho = 69.17%)

Component	Feeling/ motivation	Description	Mean	S.D.	Loading
Component 1 (place attachment/identity)	1	When I think of home, I think of land I farm	3.579	0.625	0.420
	2	I feel happiest when I am on the land I farm	3.594	0.602	0.436
	3	The land I farm is my favorite place to be	3.532	0.647	0.426
	4	The land I farm is an important part of who I am	3.598	0.626	0.376
	5	My personal history is closely tied to the land I farm	3.528	0.724	0.331
	6	Even if I were no longer farming, the land I farm will always be a part of who I am	3.513	0.704	0.339
	7	It is important to me that the land I farm stay in my family	3.575	0.678	0.236
Component 2 (place dependence)	8	If I could farm anywhere in the world, it would be the land I farm now	3.062	0.880	0.598
	9	Even though there might be better places to farm, I would rather farm in the area where I farm than anywhere else	3.211	0.782	0.605
	10	I would feel out of place farming anywhere else	2.883	0.875	0.503
Component 3 (social identity)	11	The friendships I have developed through farming activities in the area where I farm are important to me	3.472	0.645	0.472
	12	Farmers in the area where I farm generally have beliefs and values similar to mine	3.207	0.733	0.596
	13	I have a trusted network of people I talk with about farming in the area where I farm	3.199	0.717	0.615
Component 4 (Economic dependence)	14	There are not many job opportunities available to me other than farming	2.417	1.004	0.643
	15	The land I farm is important to my economic well-being	3.451	0.756	0.519
	16	The characteristics of the land I farm (soil type, topography, etc.) are largely responsible for my success as a farmer	3.098	0.770	0.507

Note: Farmers provided their ratings for feeling about the land they farm in 4-point Likert scale: 1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree and 4 = strongly agree.

presented as follows (Williams, 2006):

$$P(Y_i > j) = \frac{\exp(\alpha_j + X_i\beta)}{1 + [\exp(\alpha_j + X_i\beta)]} \quad j = 1, 2, \ldots, m{-}1 \tag{1}$$

In Equation (1), if $m = 3$ categories, then $j = 1$ represents category 1 *vs* category 2 and 3, $j = 2$ represents category 1 and 2 *vs* category 3. Similarly, Y_i is a dependent variable representing farmer perception about a potential challenge associated with the adoption of conservation tillage or cover crops. X_i is a vector of independent variables representing farm and farmer characteristics, adoption duration, SOP, farm management strategies and climate factors, which are explained in Table 1. The α_j is cut-off point (constant) for each logit and β is a vector of parameters.

The ordered logit model produces $m - 1$ set of binary logit models with different constants but a common slope vector β. Brant test can be used to test this equality of parameters assumption or parallel regression assumption (Brant, 1990). A generalized ordered logit model is recommended to avoid incorrect and misleading estimates when the Brant test rejects the null hypothesis of parallel regression (Williams, 2006). A generalized ordered logit model is also known as a partial proportional odds model and relaxes the parallel regression assumption for all or a specified subset of independent variables. Assuming only a subset of variables violates the parallel regression assumption, a generalized ordered logit model can be specified as below (Williams, 2006):

$$P(Y_i > j) = \frac{\exp(\alpha_j + X1_i\beta1 + X2_i\beta2 + X3_i\beta3_j)}{1 + [\exp(\alpha_j + X1_i\beta1 + X2_i\beta2 + X3_i\beta3_j)]} \quad j = 1, 2, \ldots, m{-}1 \tag{2}$$

where $\beta1$ and $\beta2$ are the vectors of parameters which do not violate parallel regression assumption and $\beta3_j$ is a vector of parameters which vary by cut-off points. $X1_i$ and $X2_i$ are subsets of independent variables which hold proportional odds assumptions, but $X3_i$ is a subset of independent variables whose parameters are allowed to differ by first (category 1 *vs* category 2 and 3) and second (category 1 and 2 *vs* category 3) logits. Categories 1, 2 and 3 are represented by farmer's stated importance level for each potential challenge toward conservation practice adoption, which are 'not or slightly important', 'moderately important' and 'very important'.

A total of four empirical models related to conservation tillage and five empirical models related to cover crops were estimated using an identical set of independent variables (Table 1). A user-written STATA command gologit2 was used to estimate a generalized ordered logit model (Williams, 2006). Odds ratios ($\exp\beta$) were computed to identify the magnitude of the association between independent variables and farmer's stated response with a potential challenge related to the adoption of conservation

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practices. In particular, the percentage change in probability (% Δodds) was computed by subtracting 1 from the odds ratio and then multiplying the resulted value by 100 (Stroman and Kreuter, 2016).

Results

Farm and farmer characteristics

We found the average age of the farmers participating in the survey was 57 yr old, with 71.8% completed some college or higher formal educational degree. The average participating farmer age is typical of farmers within South Dakota (U.S. Department of Agriculture, 2019). The participating farm operations had a total of 1184 acres on average as of 2017, with 59.1% of the acres owned and the rest rented (Table 1). Farmers participating in this survey on average had farms about three times larger than the average US farm, but smaller than South Dakota's average of 1443 acres as of 2017 (U.S. Department of Agriculture, 2019).

Conservation practice adoption and potential challenges

The adoption of conservation tillage on farmland was mainly constrained by biophysical conditions and opportunity costs. Biophysical conditions such as 'too much soil moisture' and 'delayed planting due to slow soil warming in spring' had mean values of 1.833 and 1.924 over the entire sample respectively on a 3-point scale indicating that these factors were important challenges for the implementation of conservation tillage (Table 3). Similarly, opportunity costs such as 'increased dependence on herbicide/fungicides' (1.916) and 'reduced crop yields' (1.878) were also important challenges for farmers regarding conservation tillage adoption in croplands.

Among the 577 farmers who indicated their experience of using conservation tillage, 45.8% had more than 10 yr of usage experience, while 21.8% reported that they had never adopted conservation tillage on their farmlands (Table 1). Compared to adopters, non-adopters of conservation tillage had slightly different perceptions on the potential challenges. They reported that adoption challenges related to opportunity costs were more important than biophysical conditions. Among the listed challenges, 'reduced crop yields' (1.956) and 'increased dependence on herbicide/fungicides' (1.948) were the two most important challenges for them. In contrast, farmers who had prior experiences in implementing conservation tillage expressed that 'delayed planting due to slow soil warming in spring' (1.933) and 'increased dependence on herbicide/fungicides' (1.908) were their most top concerns. Among the farmers who had prior experiences with conservation tillage, those who dis-adopted had greater concerns over all listed categories, with mean values for all listed challenges exceeding 2 on a 3-point scale.

In contrast to conservation tillage, South Dakota farmers had less experience with adopting cover crops on their farmlands. Of the total 581 respondents, a total of 52.5% of farmers had never adopted cover crops as conservation practice on farmlands, and only 14.1% of the farmers adopted this conservation practice for more than 5 yr (Table 1). Compared to the state average, the higher adoption rate of cover crops (48.5%) indicated by our survey likely suggest that producers who demonstrated interests in conservation practices were more likely to participate in our survey than those who did not (Wang *et al.*, 2021b).

Table 3. Description of the farmer perceived challenges toward conservation tillage and cover crops

Category	Variable	Description	Adopters			Non-adopters			Dis-adopters			Entire sample[a]		
			N	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.
Challenges related to conservation tillage														
Biophysical conditions	Y_1	Too much soil moisture	461	1.855	0.790	115	1.748	0.782	18	2.000	0.907	576	1.833	0.789
	Y_2	Delayed planting due to slow soil warming in spring	462	1.933	0.792	115	1.887	0.747	18	2.330	0.840	577	1.924	0.782
Opportunity costs	Y_3	Reduced crop yields	459	1.858	0.812	113	1.956	0.795	17	2.235	0.903	572	1.878	0.809
	Y_4	Increased dependence on herbicide/fungicides	458	1.908	0.754	115	1.948	0.747	17	2.059	0.827	573	1.916	0.753
Challenges related to cover crops														
Biophysical conditions	Y_5	Taking too much soil moisture	279	1.595	0.713	257	1.767	0.781	12	2.083	0.900	536	1.677	0.750
	Y_6	Difficulties in cover crop establishment	280	1.850	0.733	258	1.795	0.779	12	2.083	0.900	538	1.823	0.755
Opportunity costs	Y_7	Yield reduction in following cash crop	279	1.731	0.793	254	1.909	0.793	12	2.500	0.798	533	1.816	0.797
Resource constraints	Y_8	Narrow planting window	277	1.957	0.746	259	2.066	0.762	12	2.250	0.754	536	2.009	0.755
	Y_9	Lack of time/labor	276	1.771	0.774	258	1.996	0.806	12	1.833	0.835	534	1.880	0.797

[a]Adopters, non-adopters and dis-adopters do not add up the entire sample because adopters are defined as all who had previously used the practice, which include dis-adopters.

The types of challenges reported by farmers on the adoption of cover crops are biophysical conditions, opportunity costs and resource constraints. Based on farmers' responses over the entire sample, resource constraints such as 'narrow planting window' (2.009) and 'lack of time/labor' (1.880) were slightly more important to them than challenges related to opportunity costs ('yield reduction in following cash crop', 1.816) and biophysical conditions ('taking too much soil moisture', 1.677; 'difficulties in cover crop establishment', 1.823) (Table 3).

Among the challenges associated with cover crops, resource constraints such as 'narrow planting window' (2.066) and 'lack of time/labor' (1.996) were most important for farmers who never adopted cover crops on their farmlands. Compared to the adopters, non-adopters indicated greater importance for nearly all adoption challenges, except for the 'difficulties in cover crop establishment' challenge. Among the farmers who had previous experience with cover crops, those who dis-adopted the practice expressed higher concerns over all categories with 'yield reduction in the following cash crop' (2.500) being their top concern.

Factors affecting perceived challenges associated with conservation tillage

Brant test results indicated that two out of four models did not violate parallel regression assumption, and therefore, were estimated using ordered logistic regression (Table 4). The models that violated parallel regression assumption were the models with challenges of 'delayed planting' (Y_2), and 'reduced yield' (Y_3) as dependent variables, which were estimated using generalized ordered logistic regression. The likelihood ratio tests suggested that model fits for three out of four empirical models related to conservation tillage were significant at 1% level of significance (Table 4). Only the empirical model related to 'herbicide/fungicide dependence' (Y_4) was insignificant ($\chi^2 = 18.93$, $P = 0.22$) and therefore, not included in further interpretation.

Among farm and farmer characteristics, only farmer age (*age*) and proportion of owned farmland (*owned land*) had significant effects on perceived challenges on 'excessive soil moisture' (Y_1) and 'delayed planting' (Y_2), respectively (Table 4). For example, a year increase in age of farmer decreased the probability of perceiving 'excessive soil moisture' as an important challenge by 1.6%. Similarly, the proportion of owned farmland (*owned land*) was negatively associated with 'delayed planting' (Y_2) challenge.

Among SOP dimensions, farmer's social identity (*social identity*) was positively related to perceived challenges on 'excessive soil moisture' (Y_1) and 'delayed planting' (Y_2, Table 4). For example, an increase in social identity by a point factor score increased the perceived importance levels of challenges on 'delayed planting' and 'excessive soil moisture' by 22.6, and 29.4%, respectively. However, the effects of social identity on 'reduced yield' (Y_3) varied across different importance levels perceived by farmers. Economic dependence, as a dimension of farmers' SOP, was also positively associated with perceived importance levels for the following challenges: 'excessive soil moisture', 'delayed planting' and 'reduced yield' (Table 4). Regarding 'excessive soil moisture' challenge, for example, farmers indicating higher economic dependence (by a point factor) perceived a 25.4% increase in its level of importance. Likewise, regarding the 'delayed planting' and 'reduced yield' challenges, an increase in *economic dependence* by a point factor score was 27.4 and 33.6%, respectively, more likely to change the perception level from slightly/moderately important to very important category.

Farmers who had a business plan and those who adopted diversified farm management (*diversification*) perceived 'delayed planting' (Y_2) and 'reduced yield' (Y_3), respectively, as more important challenges. Climatic factor, average precipitation was positively associated with perceived challenges on 'excessive soil moisture' (Y_1) and 'delayed planting' (Y_2), yet its effects on 'reduced yield' (Y_3) varied depending on the importance level provided by farmers (Table 4). For example, an inch increase in average precipitation at the county level was associated with 19.8 and 25.4% increase in perceived importance on two challenges, 'excessive soil moisture' and 'delayed planting', respectively. Likewise, increase in average precipitation did not have a monotonous effect on the perceived challenge on 'reduced yield', with an inch increase in average precipitation at county level associated with 28.1% increase in the probability that a farmer would change his or her importance level from slightly important to moderately/very important category, yet a 15.7% decrease in the probability that a farmer would change his or her importance level from slightly/moderately important to the very important category.

The average temperature was significantly related to farmer perception about 'delayed planting' (Y_2) challenge (Table 4). A 1°C increase in average temperature at the county level was related to 36.9% decrease in probability that the farmer would change his or her perceived importance from slightly important to moderately/very important category. However, the effect of average temperature was positively related to the perception of farmers, who perceived 'delayed planting' as slightly/moderately important.

Factors affecting perceived challenges associated with cover crops

The model fits for all five empirical models related to cover crops were significant at 1% level of significance. Challenge models Y_5 and Y_6 were estimated using generalized ordered logistic regression, while the rest of the empirical models were estimated by employing the ordered logistic regression (Table 5). The choice between generalized ordered and ordered logit model was based on Brant test results at 5% level of significance.

The adoption duration of cover crops was negatively associated with perceiving 'soil moisture depletion' (Y_5) as an important challenge to adoption (Table 5). Compared to non-adopters, farmers who adopted cover crops for 'less than 3 years', '3 to 5 years' and 'more than 5 years' were 40.6, 40.6 and 54.1% less likely to view 'soil moisture depletion' as an important challenge. Dimensions of farmers' SOP such as economic dependence and place attachment/identity were positively associated with 'soil moisture depletion' (Y_5) and 'establishment difficulty' (Y_6) challenges, respectively. Having a written business plan for farm operation was negatively associated with farmer perception on 'establishment difficulty'. Similarly, another farm management strategy, *diversification* had a significant but varying effect on farmer perception about 'establishment difficulty' across the different perceived importance levels.

Size of farmland (*acres*) was also positively associated with perceived challenges related to biophysical conditions and the magnitude of effects was around 1% for a 100-acre change in farm size. Climatic factors such as average precipitation and temperature had significant effects on 'soil moisture depletion' (Y_5) challenge (Table 5). Specifically, for an inch of precipitation increase

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Table 4. Model estimates for the potential challenges associated with conservation tillage

		Excessive soil moisture (Y_1)		Delayed planting (Y_2)		Reduced yield (Y_3)		Herbicide/fungicide dependence (Y_4)	
Category	Variable	OR	S.E.	OR	S.E.	OR	S.E.	OR	S.E.
Farmer characteristics	Age	0.984**	0.008	0.988	0.008	0.993	0.008	0.996	0.008
	Education	1.331	0.286	1.371	0.297	0.950	0.204	0.808	0.172
Farm characteristics	Acres ($\times 10^2$)	0.994	0.005	0.994	0.005	0.992	0.006	0.997	0.005
	Owned land	0.995	0.003	0.993**	0.003	0.997	0.003	0.995	0.003
Adoption duration	⩽5 yr	1.499	0.472	1.239	0.383	0.872	0.270	0.782	0.240
	6–10 yr	1.559	0.492	1.291	0.400	0.870	0.274	0.691	0.213
	>10 yr	1.415	0.359	1.218	0.304	0.721[a]	0.195	0.766	0.192
Sense of place	Place attachment/identity	1.032	0.038	1.038	0.038	1.037	0.038	1.074**	0.039
	Place dependence	0.954	0.075	1.072	0.084	1.074	0.083	0.943	0.071
	Social identity	1.294***	0.110	1.226***	0.102	1.384***[a]	0.128	1.122	0.089
						0.824**[b]	0.081		
	Economic dependence	1.254***	0.112	1.075[a]	0.101	1.043[a]	0.102	1.121	0.097
				1.274***[b]	0.106	1.336***[b]	0.147		
Farm management strategies	Business plan	1.346	0.266	1.381*	0.272	1.140	0.225	0.829	0.162
	Diversification	0.904	0.206	0.891	0.202	1.487*	0.338	1.347	0.301
Weather characteristics	Precipitation	1.198***	0.083	1.254***	0.087	1.281***[a]	0.098	0.990	0.067
						0.843**[b]	0.064		
	Temperature	0.893	0.118	0.631***[a]	0.095	0.811	0.107	0.978	0.129
				1.445**[b]	0.225				
/cut1		−0.262	2.508	6.434	2.836	0.924	2.530	−2.098	2.478
/cut2		1.290	2.508	−2.237	2.981	1.954	2.592	−0.209	2.476
Brant test	Statistic	11.410		25.220		34.370		12.120	
	Prob > χ^2	0.723		0.047		0.003		0.670	
Observations		423		424		425		424	
Model fit statistics	Log likelihood	−432.577		−434.687		−434.905		−447.098	
	Likelihood ratio	45.220		57.160		52.620		18.930	
	Prob > χ^2	<0.001		<0.001		<0.001		0.217	

OR, odds ratio; S.E., standard error.
Superscript *a* refers to first logit (1 *vs* 2 and 3) and *b* refers to second logit (1 and 2 *vs* 3).
***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

at the county level, the probability that farmers change perceptions from slightly/moderately important to very important category with 'soil moisture depletion' decreased by 27.1%, while a degree increase in temperature increased such probability by 76.5%.

Another type of potential challenge associated with cover crop adoption was potential 'yield reduction' (Y_7). In comparison with those non-adopters, farmers who adopted cover crops for 'less than 3 years', '3 to 5 years' and 'more than 5 years' were 49.5, 41.8 and 50.5%, respectively, less likely to view 'yield reduction' as equally challenging (Table 5). On the other hand, farmers with higher *place attachment/identity* and *economic dependence* were 8.3 and 34.2% more likely to view 'yield reduction' as challenging (Table 5). Similarly, *temperature* was also positively associated with 'yield reduction' challenge.

Additionally, the resource constraints such as 'lack of time/labor' (Y_9) and 'narrow planting window' (Y_8) affect farmer's willingness to adopt cover crops. The adoption duration and *business plan* were negatively related to the perceived challenge on the resource constraints, while *place attachment/identity* and *economic dependence* were positively related to those constraints (Table 5). For example, farmers who adopted cover crops for '3 to 5 years' were 70.2 and 56% less likely to view 'lack of time/labor' and 'narrow planting window' as equally challenging when compared with non-adopters. In contrast, a point increase in factor score on *place attachment/identity* increased farmers' perceived importance level by 9 to 9.7% on both 'lack of time/labor' and 'narrow planting window' challenges (Table 5). Similarly, an increase in farmers' *economic dependence* by a point factor score was 30 and 31.3% more likely to increase the

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Table 5. Model estimates for the potential challenges associated with cover crops

		Soil moisture depletion (Y_5)		Establishment difficulty (Y_6)		Yield reduction (Y_7)		Narrow planting window (Y_8)		Lack of time/labor (Y_9)	
Category	Variable	OR	S.E.	OR	S.E.	OR	S.E.	OR	S.E.	OR	S.E.
Farmer characteristics	Age	1.004	0.009	1.023***[a]	0.009	1.007	0.009	1.002	0.008	1.006	0.008
				0.978**[b]	0.009						
	Education	0.769	0.169	1.144	0.246	0.735	0.160	1.245	0.269	1.185	0.258
Farm characteristics	Acres ($\times 10^2$)	1.011*	0.006	1.010**	0.005	1.004	0.005	1.011**	0.006	1.001	0.005
	Owned land	1.003	0.003	0.999	0.003	0.999	0.003	0.999	0.003	0.995	0.003
Adoption duration	<3 yr	0.594**	0.149	1.318	0.320	0.505***	0.127	0.979	0.241	0.919	0.222
	3–5 yr	0.594*	0.187	0.996	0.301	0.582*	0.177	0.440***	0.133	0.298***	0.093
	>5 yr	0.459***	0.138	1.015	0.286	0.495***	0.139	0.791	0.223	0.440***	0.127
Sense of place	Place attachment/ identity	1.025	0.041	1.093**	0.043	1.083**	0.042	1.097**	0.043	1.090**	0.042
	Place dependence	1.109	0.092	0.972	0.078	0.960	0.077	0.921	0.073	0.936	0.075
	Social identity	1.118	0.096	1.010[a]	0.089	1.089	0.090	1.017	0.082	0.994	0.080
				0.806**[b]	0.073						
	Economic dependence	1.219**	0.113	1.136	0.101	1.342***	0.122	1.313***	0.117	1.300***	0.117
Farm management strategies	Business plan	0.738	0.152	0.667**	0.135	0.833	0.166	0.638**	0.129	0.582***	0.117
	Diversification	1.096	0.263	1.658**[a]	0.423	1.342	0.315	0.904	0.217	1.041	0.243
				0.544**[b]	0.149						
Weather characteristics	Precipitation	0.949[a]	0.071	1.065	0.073	0.977	0.067	1.028	0.071	1.011	0.070
		0.729***[b]	0.082								
	Temperature	1.197[a]	0.178	0.955	0.129	1.403***	0.191	1.072	0.145	1.023	0.139
		1.765***[b]	0.323								
/cut1		−2.520	2.780	−1.391	2.576	5.638	2.562	0.570	2.546	−0.303	2.540
/cut2		−9.897	3.472	−1.472	2.601	7.188	2.573	2.670	2.550	1.389	2.541
Brant test	Statistic	27.730		24.700		8.910		16.530		14.400	
	Prob > χ^2	0.023		0.054		0.882		0.348		0.496	
Observations		408		409		406		407		406	
Model fit statistics	Log likelihood	−390.308		−418.851		−419.300		−416.494		−420.647	
	Likelihood ratio	48.200		35.580		36.160		34.160		43.960	
	Prob > χ^2	<0.001		<0.001		0.002		0.003		<0.001	

OR, odds ratio; S.E., standard error.
Superscript *a* refers to first logit (1 *vs* 2 and 3) and *b* refers to second logit (1 and 2 *vs* 3).
***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

perceived importance level on 'lack of time/labor' and 'narrow planting window' challenges, respectively.

Discussion

This study examined farmer perceptions on a number of challenges associated with conservation tillage and cover crops adoption. The primary conservation tillage benefits include input savings (e.g., nitrogen and phosphorus fertilizers) and improved soil health (Reimer *et al.*, 2012; Anderson, 2016). The majority of farmers faced challenges with conservation tillage practice, including excessive soil moisture, delayed planting of cash crops, reduced cash crop yields and increased dependence on herbicides and fungicides. In recent decades, there is an increasing climatic variation and the average annual precipitation is increasing in our study region (O'Brien *et al.*, 2020), which could further complicate the biophysical conditions and negatively affect the adoption of conservation tillage.

Planting of cover crops is important during the fallow period, such as the period between the fall harvest and spring planting, and years of prevented planting due to flooding or other climate driven problems to remove extra soil moisture and improve soil health (NRCS, 2019). In South Dakota, only less than 10% of farmers adopted cover crops as of 2017 (U.S. Department of Agriculture, 2019). Farmers ranked high seed costs, narrow planting window and lack of time/labor as topmost challenges associated with cover crops adoption. About half of the farmers paid between \$11 and \$20 per acre for their cover crop seeds in 2016–17 and this price range remained largely the same in 2019–20 (CTIC, 2020). The narrow planting window is a challenge, and is believed by some farmers to be essentially an economic concern ('…it is not worth the time'), while others suggested that managing the cover crops using 'whole system' approach could resolve the time constraint issue (Carlisle, 2016; Roesch-McNally *et al.*, 2018). Addressing these challenges will increase the adoption of cover crops which will subsequently improve biodiversity and climate resilience (Blesh and Wolf, 2014).

Our finding that 'reduced crop yield' is regarded as one of the most important barriers for both conservation tillage and cover crops suggests that maximized yield is a common goal among many farmers. Despite potential yield reduction, conservation tillage and cover cropping may benefit farmers through improved economic performance through decreased input costs, such as reduced labor, fuel, nitrogen fertilizer or pesticides requirements (Anderson, 2016; Mahama *et al.*, 2016; Singh *et al.*, 2021). Wang *et al.* (2021b) found that more farmers perceive a profit increase than a yield increase when asked about cover crops and conservation tillage. Therefore, helping farmers adjust their goals toward improving profit, rather than yield, may be a key strategy for promoting conservation tillage and cover cropping practices.

This study found that respondents with stronger social identities as farmers and more economic dependence on farming are more likely to rate conservation tillage challenges as more important. The underlying reason could be farmers more frequently talk about their challenges rather than addressing them under their existing social networks (Carlisle, 2016). Outreach programs could potentially utilize social networks (e.g., farmer associations, social media, etc.) to address farmer concerns toward conservation practices. As 87% of the croplands in South Dakota are operated by large-scale commercial farms of 1000+ acres (U.S. Department of Agriculture, 2019), education and demonstration efforts that target large-scale farms will likely have an amplified effect on increasing the number of acres under conservation tillage practices.

While conservation tillage helps preserve soil moisture in a semi-arid climate (Ding *et al.*, 2009), it could cause problems such as excessive soil moisture and slow soil warming in the crop planting season, therefore were viewed as major challenges by farmers located in regions with higher precipitation (Rusinamhodzi *et al.*, 2011; Reimer *et al.*, 2012). The climatic variation may be the key reason why the adoption of conservation tillage practices had strong spatial correlations among neighboring counties of Iowa, Nebraska and South Dakota (Ding *et al.*, 2009). To help relieve the excessive moisture challenges faced by conservation tillage users, promoting conservation tillage with cover crops in counties with higher precipitation potential are critical because this strategy helps improve biophysical conditions as well as reduce soil erosion caused by precipitation (Canales *et al.*, 2020).

It is interesting to notice that although adoption duration had little effect on the perceived challenges related to conservation tillage, it played a critical role in explaining perceived challenges related to cover crops. Our finding indicates that farmers who have used cover crops for longer periods are less likely to perceive challenges such as yield reduction and narrow planting window as important. This finding implies that farmers need longer planning horizons for cover crops to overcome the challenges and experience the benefits. Technical and financial assistance to cover crop adopters during the first few years of using the practice will help them learn how to better use this practice in their farming system (Church *et al.*, 2020). Providing cost-share to farmers, for example, helps them navigate the high cost associated with cover crops establishment. We also found that farmers who had business plans indicated fewer challenges with cover crops implementation. This is probably because farmers with business plans identify and implement actions in advance to mitigate challenges associated with cover crops. This highlights the need for outreach programs to assist farmers in understanding the importance of business plans (Mishra *et al.*, 2009).

Similar to conservation tillage challenges, perceived importance of cover crops challenges was contingent on dimensions of farmers' SOP. Specifically, cover crop challenges were perceived as more important by farmers with greater economic dependence and place attachment/identity. Our study found that farmers who were economically more dependent on farming would more likely perceive yield reduction, time/labor requirements and establishment difficulty as important challenges. Therefore, providing cost-share to such farmers could help change farmers' perception and adoption decisions. Our finding corroborates that of Arbuckle (2015) but contradicts with that of O'Connell *et al.* (2014), who found that economic costs linked with cover crops were not perceived as a barrier in North Carolina. The reason behind the contradicting results could be a different climatic condition of North Carolina and different crops grown compared to those of the Corn Belt states.

Some communities have mixed aesthetic perceptions of cover crops, some find them to be messy and unappealing (Carlisle, 2016). Mixed cover crop blends can have an irregular 'weedy' appearance that contrasts with the neat, weed-free rows that many prefer to see or have come to expect across the agricultural landscape. Therefore, for farmers with higher levels of place attachment/identity, the difficulty with cover crop adoption may

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arise from its perceived negative effect on their connections with the agricultural landscape. These findings imply that cover crop adoption may garner wider public support in the landscape with diverse land cover in terms of cropping patterns and natural ecosystems (i.e., grasslands and forest lands). In addition, programs that provide assistance in farmers' selection of cover crop species (e.g., ryegrass) that are compatible with the current farming system could also help reduce potential challenges faced by farmers.

Conclusions

The adoption of conservation agriculture such as conservation tillage and cover crops can help diversify farm level risks and promote on-farm biodiversity in the US Corn Belt. In this context, it is important to design appropriate strategies for increasing the adoption of conservation practices and promoting regenerative agriculture that protects and restores ecosystem services on more acres. This study provides insights on how farmers may overcome adoption barriers and integrate conservation practices in their farming system. A better understanding of farmers' perceived challenges associated with conservation practices is important as it could provide further directions for research and extension efforts to facilitate future adoption decisions. Farmers' primary challenges toward conservation tillage implementation include biophysical condition concerns such as excessive soil moisture and delayed planting, as well as opportunity cost concerns such as reduced cash crop yields, and increased dependence on herbicide and fungicides. We found that respondents with stronger social identities as farmers and greater economic dependence on farming were more likely to perceive greater challenges toward conservation tillage. These findings imply that conservation programs should consider social network utilization, economic subsidies or technical assistance to promote conservation tillage. Similarly, outreach programs that target large farm operations with detailed information on potential short-term opportunity costs (e.g., reduced crop yields) and long-term benefits (e.g., soil health) could promote conservation tillage implementation on more acres.

Regarding cover crops adoption, resource constraints (e.g., narrow planting window and lack of time/labor) were perceived by farmers as relatively more important than opportunity costs (e.g., yield reduction) and biophysical conditions (e.g., cover crop establishment and taking too much soil moisture). We found that the adoption duration of cover crops was negatively associated with cover crop challenges yet greater economic dependence on farming was positively associated with perceived challenges. These findings implied that financial subsidies may provide farmers incentives to experiment with cover crops and/or to expand cover crops usage acres on croplands.

Our paper has a few implications that could help guide the future policy and outreach efforts in promoting adoption of conservation practices such as conservation tillage and cover crops. First, to help farmers adopt the types of conservation practices that primarily improve profitability through reduced input costs, more outreach efforts could be utilized in emphasizing the importance of maximizing profit, rather than yield, on the sustainable management of the farm operation in the long term. Secondly, financial incentives could be more targeted toward farmers who have detailed plans for the adoption of cover crops, which cover specifics on how to address resource constraints in planting time, seeds, labor and equipment. Thirdly, outreach programs could be more influential in impacting farmer decisions by utilizing farmers' existing social networks (e.g., farmer associations) to share success stories of farmers who have managed their farms successfully under conservation practices. Finally, as joint adoption of conservation tillage and cover crops addresses some challenges such as excessive moisture challenge in high rainfall regions, future research and outreach efforts in promoting the complementary benefits of these two practices will help farmers make more educated decisions.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170523000042

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Conflict of interest. The authors declare that they have no conflict of interest.

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