Journal of Agricultural and Resource Economics 44(2):404–421 ISSN 1068-5502

Soil Conservation Practice Adoption in the Northern Great Plains: Economic versus Stewardship Motivations

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By making adoption decisions on soil conservation practices, agricultural producers play a key role in reversing unintended consequences caused by soil degradation. This paper studies two soil conservation practices—diversified crop rotation (DCR) and integrated cropping and livestock system (ICLS)—using survey data collected from Nebraska, South Dakota, and North Dakota producers. We estimate a bivariate probit model to identify factors affecting adoption decisions. Farmers' requirements for monetary incentives and values on soil health were found to be important determinants of adoption behavior. Geographic location matters, as North Dakota had the highest DCR adoption rate yet the lowest ICLS adoption rate.

Key words: adoption behavior, diversified crop rotation (DCR), integrated cropping and livestock system (ICLS), monetary incentive, soil health

Introduction

Soil degradation has become a pressing global issue because of its adverse impacts on world food security, environment, and quality of life (Eswaran, Lal, and Reich, 2001; Lal, 2009; Rickson et al., 2015). It is estimated that the total annual cost of soil erosion from agriculture is $44 billion in United States alone and $400 billion worldwide (Eswaran, Lal, and Reich, 2001). Farm management practices such as conventional tillage, monoculture systems, and unbalanced fertilizer use can directly damage soil health by causing long-term depletion of soil organic matter and decreased soil productivity on the degraded soil.

Additional fertilizer input or improved seed varieties may often mask the effect of soil degradation on yield (Rickson et al., 2015). When other effects such as land location and agronomic practices were controlled for, Schumacher et al. (1994) found relative yield loss for erosion class 3 averaged from 8%–17% in the north-central United States. Panagos et al. (2018) modeled soil erosion rates under different climatic and land-use conditions and estimated an annual loss of approximately 0.43% crop productivity for 12 million hectares of agricultural area in the European Union that suffer from severe erosion. In addition to declined crop productivity, soil erosion has also led to unintended off-farm consequences such as water quality impairment in rivers and lakes (Uri, 1999).

This paper is based on a 2016 farmer survey conducted in North Dakota, South Dakota, and Nebraska, where soil degradation has become a concern for cultivated land use (Turner et al., 2018).

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This article is based upon research work that is financially supported by United States Department of Agriculture-NIFA, Coordinated Agricultural Projects (CAP) under award number 2016-6800424768.

Review coordinated by Richard T. Woodward.

In recent years, an expansion of row crops comprised largely of corn and soybean occurred in the Dakotas (Wright and Wimberly, 2013; Reitsma et al., 2014; Lark, Meghan Salmon, and Gibbs, 2015; Wimberly et al., 2017). During the 2007–2012 peak conversion period, nearly 20% of grasslands in the Dakotas were converted to croplands (Wang et al., 2018). Recent soil erosion events have been observed in the Dakotas where row crop expansion occurred, and similar events have also been documented in Nebraska (Turner et al., 2018).

In the long term, the adoption of soil conservation practices is necessary to combat the negative consequences of soil degradation (Claassen et al., 2004). Therefore, farmers and ranchers play a key role in reversing the trend toward degradation, as it is ultimately their decision to adopt conservation practices based on their own unique situations. Factors underlying the adoption decisions can be summarized into several broad categories: (i) farmer demographic characteristics; (ii) farm biophysical and financial characteristics; and (iii) exogenous factors such as market prices and government program participation (Knowler and Bradshaw, 2007).

Aside from these external explanatory factors, there also exists a branch of literature that emphasizes how farmers' intrinsic preferences or motivations affect adoption behavior. Under profit maximization assumption, economic factors such as profitability of different practices, financial liquidity, and cost-sharing considerations play the most important role in farmers' conservation practice decisions (Cary and Wilkinson, 1997; Honlonkou, 2004; Lichtenberg, 2004). Therefore, adoption can be promoted by offering farmers financial incentives. The Environmental Quality Incentives Program (EQIP) is one such example of a program that aims to improve working farmland by providing up to 50% cost share to many conservation practices. Uri (1999) showed that cost-sharing programs play an important role in removing financial barriers and promote the widespread adoption of conservation tillage.

However, adoption decisions cannot be explained by economic factors alone (Lambert et al., 2007; Greiner and Gregg, 2011; Vitale et al., 2011; Arbuckle and Roesch-McNally, 2015). Chouinard et al. (2008) suggested that the profit motive and the stewardship motive jointly determine farmers' decisions. As a result, farmers with a strong focus on the stewardship dimension should be willing to trade off private profits for social goals, such as soil health improvement and environmental benefits (Kooten, Weisensel, and Chinthammit, 1990). For some farmers, goals such as land stewardship or farming as a lifestyle may outweigh profit maximization (Bergtold, Fewell, and Duffy, 2010; Brodt et al., 2004; Conservation Technology Information Center, 2013; Maybery, Crase, and Gullifer, 2005; Pannell et al., 2006; Peterson et al., 2012). Therefore, farmers with differing personal goals typically have different requirements for monetary incentives (Lynne, Shonkwiler, and Rola, 1988). For example, individuals who prioritize economic returns would require higher monetary incentives, while those who emphasize land stewardship might adopt conservation practices even without monetary incentives.

Subjective perceptions such as awareness of environmental problems and concern about implementation difficulty have been shown to have an influence on conservation practices (Lynne, Shonkwiler, and Rola, 1988; Mccann et al., 1997; Werner et al., 2017). Regarding the adoption of new agricultural technologies such as new crop varieties, Adesina and Baidu-Forson (1995) indicated that farmers' subjective perceptions on the new crop attributes were important determinants of adoption behavior. Similarly, Adesina and Zinnah (1993) found that farmers' perceptions of new practice attributes were frequently significant in explaining adoption decisions, while none of the farm- and farmer-specific characteristics were significant.

In the literature that analyzed factors affecting soil conservation practices, various practices have been studied, but the main focuses have been conservation tillage (Rahm and Huffman, 1984; Fuglie, 1999; Uri, 1999; Vitale et al., 2011; Wauters et al., 2010) and cover crops (Bergtold et al., 2012; Arbuckle and Roesch-McNally, 2015; Conservation Technology Information Center, 2017; Werner et al., 2017). Very few peer-reviewed articles have studied adoption status and factors that determine adoption decisions of diversified crop rotation (DCR) and integrated cropping and livestock system (ICLS).

This study identifies the effects of economic and environmental motives on DCR and ICLS adoption decisions. In addition to farm and farmer characteristics, we study farmers' perceptions of the importance of economic returns and soil health and how prioritizing different goals may affect farmers' adoption decisions. The data we use for model estimation were collected from our 2016 survey of 3,500 agricultural producers in North Dakota, South Dakota, and Nebraska. While crop and livestock production are major contributors to the economy in these states, to our knowledge no study has addressed determinants of producers' adoption of soil conservation practices in this region. Our paper intends to fill in such gaps.

Diversified Crop Rotation and Integrated Cropping and Livestock System

The development of modern technology with an emphasis on scale economies has been accompanied by a loss of crop diversity (DeFries, Foley, and Asner, 2004; Miller, 2003). In the U.S. Corn Belt, a majority of cropland is occupied only by corn and soybean, either in monocultures or simple rotation (Hatfield, McMullen, and Jones, 2009; Brown and Schulte, 2011; Johnston, 2014). In the 22 counties of eastern South Dakota, where no-till acres were less than 25%, the average ratio of farm acres as of 2013 was 1 acre of small grain to 28 acres of row crop, comprising almost exclusively corn and soybeans (U.S. Department of Agriculture, 2014). Such systems have caused increased insect problems, herbicide-resistant weeds, incidence of crop diseases, and reliance on fertilizers (Sulc and Franzluebbers, 2014).

In our study, DCR practice is defined as a set or variable rotation of three or more crops, in contrast to monoculture or two-crop rotations. In a field study carried out in Iowa from 2003 to 2011, Davis et al. (2012) showed that DCR increased crop yields and profits, reduced the need of agrichemical inputs, and suppressed weeds relative to conventional two-crop rotation. Specifically, they found that average yields of maize and soybean during the 2003–2011 period were 4% and 9% higher in the 3- or 4-year rotations compared to the traditional 2-year rotation. Meanwhile, N fertilizer application averaged 16 kg and 11 kg per hectare, respectively, in 3- and 4-year rotation, compared with 80 kg per hectare in 2-year rotation. Similarly, herbicide application rates averaged 0.26 kg and 0.20 kg active ingredient per hectare, respectively, in 3- and 4-year rotation, compared with 1.9 kg a.i. per hectare in 2-year rotation.

While transitioning from the traditional corn–soybean rotation to DCR, farmers may face new challenges such as lack of access to specialized planting equipment; shortages of local infrastructure for handling, processing, and storing; and a need to develop new marketing information for new crop varieties. Furthermore, crop insurance may not be readily available for some new crop varieties (Sustainable Agriculture Research and Education, 2004). To provide economic incentives for DCR adoption, the Environmental Quality Incentives Program (EQIP) lists conservation crop rotation as one of the subsidized practices. The Conservation Stewardship Program (CSP) also provides substantial supplemental payment for adopting or improving a resource-conserving crop rotation (RCCR), which must include at least one resource-conserving crop—such as perennial grass, legume, or small grain—in combination with a grass or legume. In 2016, CSP enrolled more than 50,000 acres of RCCR across the country. Of the states with the highest level of RCCR enrollment, South Dakota and North Dakota led the way with 25,997 and 10,371 acres, respectively (National Sustainable Agriculture Coalition, 2017).

Another conservation practice studied in this paper is ICLS, in which livestock graze on cropland as a part of the agricultural operation, with livestock and cropland under either the same or different ownership. Before World War II, crop and livestock production were often integrated on small farms in the United States (Rotz et al., 2005), but agricultural production has since become increasingly concentrated and specialized, leading to the spatial and temporal separation of crop and livestock production (Russelle, Entz, and Franzluebbers, 2007). According to Dimitri, Effland, and Conklin (2005), the average number of commodities produced per farm decreased from five in 1990 to less than two in 2002. While farmers have benefited from economies of scale, such specialization has resulted in many negative environmental consequences (Sulc and Tracy, 2007) such as depletion of soil organic matter (Tiessen, Stewart, and Bettany, 1982), increase in soil erosion (Karlen et al., 1994; Pimentel et al., 1995), and increase in greenhouse gas emissions (Lal et al., 1999).

ICLS is a soil conservation practice with benefits in cycling nutrients from the crop to livestock and then recycling manure back to the land. With excess nutrients from large livestock operations and high fertilizer usage from crop production systems, there has been a renewed interest in recoupling crop and livestock production (Russelle, Entz, and Franzluebbers, 2007; Sulc and Tracy, 2007; Lemaire et al., 2014; Sulc and Franzluebbers, 2014). By encouraging the establishment of perennial grass and legume forages, the practice of ICLS also promotes DCR (Russelle, Entz, and Franzluebbers, 2007; Sulc and Tracy, 2007).

Meanwhile, ICLS may also pose various challenges to farmers that could potentially inhibit adoption decisions. For example, the most common concern associated with ICLS adoption is soil compaction and consequent decreasing infiltration of water into soil (Hamza and Anderson, 2005; Tracy and Zhang, 2008), despite a few studies that have showed that an increase in soil compaction was not significant and had no effect on crop yields (Bell et al., 2011; Rakkar et al., 2017). Other concerns include high fencing installation cost, water access issues, and lack of labor and experience for livestock management (Gardner and Faulkner, 1991).

Conceptual Model

Suppose there are N producers in the region. The utility of farmer i $(i = 1, 2, \ldots N)$ who uses traditional production practice T can be described as

$$U_i(T) = profit_i(T) + w_i \times soil_i(T), \tag{1}$$

where $profit_i(T)$ is the monetary profit farmer i gains from traditional practice T, $soil_i(T)$ is the value of soil health farmer i derives from traditional practice T, and w_i is the relative weight given by farmer i to soil health, assuming the weight given to profit is 1. Note that in the utility function specified in equation (1), we assume that farmers get satisfaction from both increased profit and improved soil health. Besides utilities associated with monetary profit and soil health, a farmer may also derive utilities from factors such as neighborhood and society recognition, work–life balance, etc. We do not include these additional factors in our model as they are not the focus of this paper.

The utility of farmer i who adopts conservation production practices C is

$$U_i(C) = profit_i(C) + w_i \times soil_i(C) - \varepsilon_i(z_{i1}, \ldots, z_{in}), \tag{2}$$

where monetary profit and value of soil health derived from conservation practice are denoted as $profit_i(C)$ and $soil_i(C)$, respectively, and ε_i is the inertia toward the traditional practice, which characterizes an unwillingness to change attitude, or a bias toward the status quo. The inertia term can be a function of certain farmer and farm characteristics as well as farmer attitudes, $z_{i1}, \ldots, z_{in}$ (e.g., inertia toward the status quo will likely increase as age increases). Additionally, given the potential risks involved with the new practice, those who are more risk averse are also likely to have stronger inertia. We do not include an inertia term in equation (1) since inertia is simply 0 when the traditional practice, which is our baseline case, is used.

Farmer i will adopt soil conservation practice C if the utility from adoption is greater than the utility from traditional production practice (i.e., $U_i(C) > U_i(T)$), or

$$profit_i(C) + w_i \times soil_i(C) - \varepsilon_i > profit_i(T) + w_i \times soil_i(T), \tag{3}$$

where $\Delta profit_i \equiv profit_i(C) - profit_i(T)$ and $\Delta soil_i \equiv soil_i(C) - soil_i(T)$, which stand for producer expected difference between conservation practice and traditional practice regarding profitability and soil health value, respectively. Equation (3) can then be rewritten as

$$\Delta profit_i + w_i \times \Delta soil_i > \varepsilon_i. \tag{4}$$

From the economic perspective, the rule of adoption can be derived from equation (4) as

$$\Delta profit_i > \overline{\Delta profit_i} \equiv \varepsilon_i - w_i \times \Delta soil, \tag{5}$$

where $\overline{\Delta profit_i}$, referred to hereafter as the adoption premium, is the minimal profitability difference between conservation and traditional practice required by farm i for adoption to occur. Based on condition (5), producers with a stronger inertia, ε_i, will require a higher adoption premium, $\overline{\Delta profit_i}$. Therefore we propose:

HYPOTHESIS 1. *Ceteris paribus, farmers with a higher adoption premium, $\overline{\Delta profit_i}$, are less likely to adopt soil conservation practices.*

Therefore, when other factors remain unchanged, adoption is less likely to occur for farmers who have a stronger inertia, ε_i. From the soil health perspective, we can further obtain the adoption decision rule from equation (4) as

$$w_i > \overline{w_i} \equiv \frac{\varepsilon_i - \Delta profit_i}{\Delta soil_i}. \tag{6}$$

Similarly, $\overline{w_i}$ can be interpreted as the minimal relative weight on soil health required by farmer i for adoption to occur. With ε_i, $\Delta profit_i$, and $\Delta soil_i$ fixed, $\overline{w_i}$ can be treated as a fixed parameter. In the long term, suppose the perceived adoption benefits of soil health increase or the inertia toward existing practice decreases, then $\overline{w_i}$ will take a lower value. Since $\overline{w_i}$ is unchanged in the short term, condition (6) is more likely to be satisfied for farmers with a higher relative weight, w_i, on soil health. This leads to:

HYPOTHESIS 2. *Ceteris paribus, farmers who place higher relative weight on soil health, w_i, are more likely to adopt soil conservation practice.*

Hypothesis 2 implies that producers who have stronger stewardship motivation (and thus prioritize the role of soil health) are more likely to adopt the conservation practice.

Survey Description

Our survey was conducted in Nebraska, South Dakota, and North Dakota, where crop and livestock production are major contributors to the regional economy. Corn and soybean are the dominant crops in the eastern region along the margin of the Corn Belt, while grassland becomes the major land use in the western region (Figure 1). The survey questionnaire consisted of several sections about the type of agricultural operation, livestock grazing practices on croplands, rotational cropping practices, farming information sources, and demographic information.

The mail survey was conducted using the Dillman (1978) method. The collection period was from mid-June to late July 2016 and involved a postcard preinstruction, two mailings of the survey questionnaire, and two reminder/thank you letters. In total, 3,500 surveys were mailed to agricultural producers from these states. Addresses were obtained from free online sources such as federal farm subsidy databases, the White Pages, and Manta. A high proportion of addresses in these publicly available data sources were outdated, resulting in 323 ineligible surveys. Of the 3,177 eligible survey sample, 672 were completed and returned, for a 21.2% response rate. The timing of the survey might be a factor that affect survey response rate, as June and July are among the busiest season for most agricultural producers in the region. The same survey conducted in winter might generate a higher response rate.

Due to a relatively small sample size, cropland acres and average nonirrigated crop yields were used to evaluate the representativeness of respondents' farms in these states. Based on U.S. Department of Agriculture 2012 Census of Agricultre data, farm-level cropland acres averaged

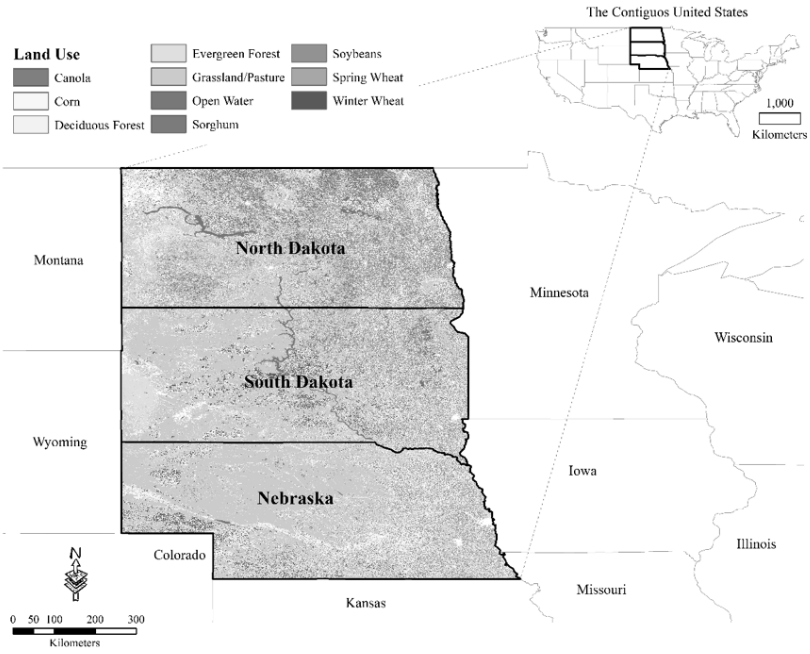

Figure 1. Main Land Uses in North Dakota, South Dakota, and Nebraska, 2016

534, 725, and 989 in Nebraska, South Dakota, and North Dakota, respectively.[1] Total crop acres in our paper refers to the total number of acres used for crop production, including corn, soybeans, wheat, sunflowers, and alfalfa. Similar to 2012 census data, our survey findings also showed North Dakota farms have more cropland acres on average compared to South Dakota and Nebraska farms. However, as total crop acres averaged 821, 948, and 2,265 in Nebraska, South Dakota, and North Dakota, respectively, our survey respondents had, on average, more cropland acres compared to the state average in 2012.

On average, survey respondents from Nebraska, South Dakota, and North Dakota reported nonirrigated corn yields of 143, 145, and 134 bushels/acre, respectively, and nonirrigated soybean yields of 54, 48, and 38 bushels/acre. Based on NASS Quick Stats, nonirrigated yields for corn averaged 147, 145, and 126 bushels, while those for soybeans averaged 55, 42, and 33 in Nebraska, South Dakota, and North Dakota, respectively.[2] Overall, survey-reported average nonirrigation yields are in consistent with the state averages, indicating farm conditions of our survey respondents are reflective of state average conditions.

Data Description

As this survey covers three states, we choose to include dummy variables for South Dakota and North Dakota, which either take a value of 1 if respondents are located in the state specified or 0 if not. Table 1 indicates that 50.6% of respondents are from South Dakota, 19.2% are from North Dakota, and the rest are from Nebraska.

As indicated in Table 1, 37.4% of 672 respondents adopted DCR practice. Based on Duncan's (1955) multirange test, DCR adoption rates were significantly different for the three states (Table 2). North Dakota had the highest adoption rate (52.7%), followed by South Dakota (39.4%) and Nebraska (24.1%). ICLS, which also refers to grazing livestock on croplands, has a much higher

[1] Average farm cropland acres are calculated as total acres of cropland divided by total number of farms with cropland.

[2] State average nonirrigation yield for Nebraska was from 2016, while state average nonirrigation yields for South Dakota and North Dakota were from 2013, the most recent year available.

Table 1. Descriptive Statistics

Variable	N	Mean	Std. Dev.	Min.	Max.
DCR adoption	672	0.374	0.484	0	1
ICLS adoption	672	0.710	0.454	0	1
Adoption of both practices	672	0.283	0.450	0	1
Adoption premium, DCR	521	2.875	0.819	1	4
Adoption premium, ICLS	515	2.511	0.805	1	4
Soil ranking, DCR	672	2.652	1.128	1	4
Soil ranking, ICLS	672	2.763	1.113	1	4
Age	640	63.150	11.162	27	95
Gender	657	1.078	0.268	1	2
Education	672	0.665	0.472	0	1
Employment	613	0.780	0.415	0	1
Moving possibility	672	0.121	0.326	0	1
Crop acres ($\times 10^3$)	568	1.186	1.959	0	22
South Dakota	672	0.506	0.500	0	1
North Dakota	672	0.192	0.394	0	1

Table 2. Mean Values for the Variables for North Dakota, South Dakota, and Nebraska

Variable	North Dakota	South Dakota	Nebraska
DCR adoption	52.7%[a]	39.4%[b]	24.1%[c]
ICLS adoption	58.9%[a]	71.8%[b]	77.3%[b]
Adoption of both practices	28.7%[a]	33.2%[a]	19.7%[b]
Adoption premium, DCR	2.783[a]	2.860[a]	2.958[a]
Adoption premium, ICLS	2.500[a]	2.506[a]	2.525[a]
Soil ranking, DCR	2.643[a]	2.674[a]	2.621[a]
Soil ranking, ICLS	2.884[a]	2.753[a]	2.704[a]
Age	61.692[a]	62.540[a]	65.077[b]
Gender	1.063[a]	1.084[a]	1.075[a]
Education	3.608[a]	3.428[a]	3.406[a]
Employment source	1.642[a]	1.672[a]	1.676[a]
Moving possibility	0.101[a]	0.135[a]	0.108[a]
Crop acres ($\times 10^3$)	2.265[a]	0.948[b]	0.821[b]

Notes: Superscripts denote Duncan's multiple range test results, where the numbers with same letters imply no statistically significant difference exist between the average values in different groups.

average adoption rate of 71.0% in our studied region. In contrast to DCR practice, Table 2 shows that the ICLS adoption rate for North Dakota (58.9%) significantly lagged behind those for South Dakota (71.8%) and Nebraska (77.3%).[3] On average, 28.3% of producers adopted both conservation practices. The adoption rates were 28.7%, 33.2%, and 19.7% in North Dakota, South Dakota, and Nebraska, respectively, with adoption rate in Nebraska significantly lower than in the other two states (Table 2).

All survey respondents were provided with the same four options to choose from, namely whether they would consider adoption if it increased annual profitability by $1/acre, $10/acre, $50/acre, or $100/acre, respectively denoted as options 1, 2, 3, and 4. Our approach bears a close resemblance to the payment card approach used in contingent valuation (CV) studies, a popular technique that measures people's willingness to pay for public goods. Compared to the dichotomous approach, it requires fewer observations to obtain the same level of statistical precision (Mitchell

[3] We also asked producers to identify the type of ICLS adoption, whether it is "my own livestock on my own cropland," "my own livestock grazing on someone else's cropland," or "my own cropland grazed by some else's livestock." The majority of respondents graze their own livestock on their own cropland (73.3% of Nebraska producers, 85.8%of South Dakota producers, and 86.8% of North Dakota producers).

and Carson, 1989). In addition, it offers the respondent more context to choose from and avoids the possibility of protest responses (Mitchell and Carson, 1989; Meyerhoff and Liebe, 2010).

The average adoption premium required for DCR adoption was 2.875, equivalent to a monetary amount of $45/acre. The adoption premium required for ICLS adoption was much lower, averaging 2.511, with an equivalent monetary value of approximately $30/acre. The lower average premium required for ICLS is possibly due to lower perceived risks associated with ICLS compared to DCR practice.

Ranking of soil health importance on adoption decisions, or relative weight on soil health, is used as an indicator of farmers' stewardship or conservation motive. The survey asked participants to rank the three factors that most likely influence their DCR and ICLS decisions. Five options were provided: "increased production," "financial subsidies to offset expenses," "better soil health," "better water quality in the region," and "better information on cropping techniques." In case respondents did not rank soil health in the top three, an automatic ranking of 4 was imposed. As indicated by Table 1, average soil health ranking was 2.652 on average for DCR, which means producers considered soil health to be the second or third most important factor when making DCR adoption decisions. The average soil health ranking for ICLS was 2.763, lower than its counterpart for DCR, possibly due to the concern of soil compaction caused by livestock grazing.[4] Average adoption premium and soil health ranking show no significant differences among the three states, indicating that producers have comparable economic and stewardship motives across states.

Several survey questions solicited data on farm operator characteristics, including age, gender, and highest level of education. The average survey respondent in Nebraska, South Dakota, and North Dakota was 61.7, 62.5, and 65.1 years old, respectively. In addition, 92% of the 657 respondents were male, consistent with our expectation for overall farmer population. The highest level of education is treated as a binary variable in our model, denoted as 0 for those who have some high school or high school degree and 1 for those who have some college, college degree, or above. Table 1 results showed that 66.5% of our survey respondents had some college, college degree, or above.

Employment source was obtained as a variable that measures (i) farmer risk attitude, as literature suggests that farmers could use off-farm income as a buffer for higher risks involved in farming and therefore be more likely to adopt conservation practice and (ii) time spent on the farm, as a higher proportion of off-farm jobs potentially means less time involved with on-farm conservation practice. Overall, the effect of employment source on adoption decision is ambiguous. Employment source enters as a binary variable in our model, with 0 denoting farmers who are employed off-farm full-time or part-time and 1 denoting those who are employed full-time on the farm. We found that 78% of our respondents worked full-time on the farm.

The survey also inquired about the possibility of moving to a new place in the near future, conjecturing that the higher the likelihood, the less motivation farmers would have to conserve soil on their current farms. Two categories were used: 0 means no intention to move, and 1 means planning to move within the next 5 years. A majority of respondents showed an attachment to the land; only 12.1% of producers had intentions of moving within 5 years.

Empirical Model

As conservation practice adoption decisions are often made in conjunction, it is necessary to jointly analyze management decisions (Wu and Babcock, 1998). To account for potential correlation between adoption decisions, we chose a bivariate probit model to model farmer's DCR and ICLS adoption decisions. Previous studies have frequently used the bivariate probit model to model joint adoption decisions of two practices (Nkegbe, Shankar, and Ceddia, 2012; Adusumilli and Wang, 2018; Fisher, Holden, and Katengeza, 2017; Mutale, Kalinda, and Kuntashula, 2017). The

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[4] When asked the biggest challenge they face in ICLS adoption, 46.8% of producers chose no fencing on cropland and 38.6% listed soil compaction.

specification for the bivariate probit model in our case is given as

(7) $$y_{1i}^* = x_{1i}{}' \beta_1 + \varepsilon_{1i};\ y_{1i} = 1 \text{ if } y_{1i}^* > 0,\ \ y_{1i} = 0 \text{ if } y_{1i}^* \leq 0;$$

(8) $$y_{2i}^* = x_{2i}{}' \beta_2 + \varepsilon_{2i};\ y_{2i} = 1 \text{ if } y_{2i}^* > 0,\ y_{2i} = 0 \text{ if } y_{2i}^* \leq 0,$$

where y_{1i}^* and y_{2i}^* are latent variables representing hidden utility functions, which is the additional utility that farmer i receives from adopting conservation practices, or $U_i(C) - U_i(T)$, as depicted in our conceptual model. Specifically, y_{1i}^* is the utility gain from DCR adoption compared to monoculture or simple rotation and y_{2i}^* stands for the utility gain from ICLS adoption compared to separated crop and livestock production. Their observed counterparts are y_{1i}^* and y_{2i}^*, which are the observed adoption decisions for DCR and ICLS, respectively. The vectors of explanatory variables are $\boldsymbol{x}_{1i}$ and $\boldsymbol{x}_{2i}$. Error terms are denoted as ε_{1i} and ε_{2i}, with a bivariate normal distribution, $BVN(0,0,1,1,\rho)$, where ρ is the tetrachoric correlation between two latent variables, y_{1i}^* and y_{2i}^*.

The coefficient estimates, $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$, do not indicate the marginal effects of explanatory variables $\boldsymbol{x}_{1i}$ and $\boldsymbol{x}_{2i}$ on adoption decision probabilities. Rather, they measure how a unit change in an explanatory variable, holding other variables fixed, affects the expected values of the latent variables, $E(y_{1i}^*)$ and $E(y_{2i}^*)$ (e.g., $\partial E(y_{1i}^*)/\partial x_k = \beta_{1k}$). To compute the marginal effect of x_k on the expected adoption decisions, $E(y_{1i}^*)$ and $E(y_{2i}^*)$, we use the coefficient scaled by density function, $\phi_2(x_1, x_2, \rho)$ (Greene, 2012). There are two methods to calculate overall marginal effect. One is to compute the density at the sample mean of the data, and the second is to compute the density at each observation, then compute the mean of these individual effects to obtain the overall marginal effect (Greene, 2012). In this paper, we present results from the former approach, which in our case produces similar results as the marginal effects generated by the latter approach.

To test two hypotheses specified in the conceptual model, we estimate the bivariate probit model specified in equations (7) and (8). Explanatory variables include producer perception variables such as adoption premium required and perception of soil health importance on adoption decisions. We assume that producers who ranked soil health as the most influential factor have a higher relative weight on soil health, denoted as w_i in our conceptual model, than those who ranked soil health as the second most influential factor, and so on. A caveat here is that adoption of DCR and ICLS might enhance farmers' perception of soil health importance, which could potentially cause an endogeneity bias that warrants future research.

To explore possible demographic factors that may contribute to adoption decisions, we also include farmer and farm characteristics variables such as age, gender, education, employment source, possibility of moving in future, and total crop acres. In addition, we include two location variables, South Dakota and North Dakota, with Nebraska serving as the base, to see whether conservation practice adoption rates differ among the three states.

Results and Discussion

Duncan's Multiple Range Test

To test Hypotheses 1 and 2, we first compare the average DCR adoption rate for farmers in different adoption premium and stewardship motive groups, divided based on criteria: (i) adoption premiums required for DCR adoption and (ii) ranking of soil health importance on adoption decisions. Results in Table 3a lend support to both hypotheses.

Consistent with Hypothesis 1, if the producers' require adoption premium increases, then adoption rate declines at a steady rate. We performed Duncan's (1955) multiple range test to see whether there exists significant difference across groups. Table 3a presents adoption rates for different groups, where the same superscript letter means the values are not significantly different. When the required adoption premium for DCR practice increases from \$1/acre to \$100/acre,

Table 3a. DCR Adoption Rates, by Adoption Premium and Soil Health Priority

	Adoption Premium			Soil Health Priority	
Requirement	No. of Farmers	Adoption Rate	Ranking	No. of Farmers	Adoption Rate
$1	26	65.4%[a]	1st	126	51.6%[a]
$10	133	49.6%[ab]	2nd	207	46.4%[ab]
$50	242	43.8%[bc]	3rd	114	37.7%[b]
$100	120	29.2%[c]	Not ranked	225	20.9%[c]

Table 3b. ICLS Adoption Rate, by Adoption Premium and Soil Health Priority

	Adoption Premium			Soil Health Priority	
Requirement	No. of Farmers	Adoption Rate	Ranking	No. of Farmers	Adoption Rate
$1	43	90.7%[a]	1st	106	80.2%[a]
$10	225	89.3%[a]	2nd	196	80.6%[a]
$50	188	67.0%[b]	3rd	121	78.5%[a]
$100	59	44.1%[c]	Not ranked	249	55.8%[b]

Notes: Superscripts denote Duncan's multiple range test results, where the numbers with same letters imply that no statistically significant difference exists between the average values in different groups.

adoption rates for corresponding groups gradually decrease. For example, adoption rate of the $10/acre group shows a significantly higher adoption rate (49.6%) than the $100/acre group (29.2%).

A similar pattern exists regarding soil health priority ranking. Those who give soil health higher priorities are more likely to adopt. The average adoption rate for those who ranked soil health as the first priority is significantly higher than that for those who indicate soil health as their third priority. Those who did not list soil health as one of the first three priorities have significantly lower adoption rate compared to those who did, consistent with Hypothesis 2.

Table 3b presents ICLS adoption rates based on the same grouping criteria as Table 3a. Consistent with Hypothesis 1, the mean adoption rates for the producer groups who require $1/acre and $10/acre adoption premium are significantly higher than the producer group who require $50/acre, while the group requiring $100/acre has the lowest adoption rate. However, no significant difference exists for the groups that listed soil health as one of the top three priorities. The adoption rate is significantly lower for those who did not rank soil health as one of the top three priorities, consistent with Hypothesis 2.

Bivariate Probit Model

Table 4 presents bivariate probit model estimation results for DCR and ICLS adoption decisions, with both coefficients and the marginal effect for each explanatory variable estimated. As 317 observations have missing values for some variables, the model is estimated with 355 observations. Standard errors for the coefficients and significance levels were calculated after 200 bootstrap replications. A log likelihood test shows that the hypothesis that all coefficients in our model are equal to 0 can be rejected at the 1% significance level. A pseudo-R^2 of 0.56 also indicates a reasonable fit of the model.[5] The correlation coefficient (ρ) between the bivariate outcomes is 0.143 and not significant from 0, which means DCR and ILCS adoption decisions are not interrelated.

Results in Table 4 indicate that both adoption premium and soil ranking affect DCR adoption decisions at the 1% significance level, with signs consistent with Hypotheses 1 and 2. *Ceteris paribus*, a 1-unit increase in adoption premium decreases the probability of adoption by 10.1%. Similarly, when other conditions remain unchanged, a 1-unit increase in soil ranking decreases the probability of adoption by 7.4%. This means that DCR adoption is more likely to occur for those who require lower annual profitability increases from the new practice or for those who believe soil

[5] The pseudo-R^2 is calculated as $\rho = 1 - \ln L(M_{full}) / \ln L(M_{int})$, where $\ln L(M_{full})$ is the log likelihood of our specified model and $\ln L(M_{int})$ is the log likelihood of the model that contains only intercept variables.

Table 4. Bivariate Probit Model Estimates for DCR and ICLS Adoption (N = 355)

	Coefficient		Marginal Effect		Coefficient		Marginal Effect	
Independent Variable	**Estimates**	**P>|z|**	**Estimates**	**P>|z|**	**Estimates**	**P>|z|**	**Estimates**	**P>|z|**
Intercept	1.465	0.041			2.795	0.022		
	(0.718)				(1.218)			
Adoption premium	−0.268	0.008	−0.101	0.008	−0.662	0.000	−0.201	0.000
	(0.101)		(0.038)		(0.115)		(0.036)	
Soil ranking	−0.196	0.006	−0.074	0.006	−0.068	0.400	−0.021	0.398
	(0.071)		(0.027)		(0.081)		(0.024)	
Age	−0.014	0.081	−0.005	0.081	−0.005	0.523	−0.002	0.520
	(0.008)		(0.003)		(0.008)		(0.002)	
Gender	−0.376	0.257	−0.141	0.255	0.617	0.496	0.187	0.483
	(0.332)		(0.124)		(0.905)		(0.267)	
Education	0.063	0.693	0.024	0.692	−0.417	0.036	−0.118	0.022
	(0.161)		(0.060)		(0.199)		(0.052)	
Employment	0.172	0.371	0.064	0.362	−0.029	0.876	−0.009	0.876
	(0.193)		(0.070)		(0.187)		(0.056)	
Crop acres	0.100	0.018	0.038	0.018	−0.052	0.372	−0.016	0.373
	(0.042)		(0.016)		(0.058)		(0.018)	
Moving possibility	−0.558	0.031	−0.189	0.012	−0.203	0.402	−0.065	0.429
	(0.259)		(0.075)		(0.243)		(0.082)	
South Dakota	0.573	0.001	0.215	0.001	−0.128	0.533	−0.039	0.532
	(0.177)		(0.069)		(0.206)		(0.063)	
North Dakota	0.771	0.000	0.298	0.000	−0.398	0.097	−0.130	0.115
	(0.220)		(0.083)		(0.240)		(0.082)	

Notes: Numbers in parentheses are bootstrap standard errors. LR test of $\rho = 0$: Prob > $\chi^2 = 0.189$. Log likelihood = −373.47, Prob > $\chi^2 = 0.000$, and pseudo-$R^2 = 0.56$.

health are more likely to influence their adoption decisions. For ICLS adoption, adoption premium is significant at the 1% level, and the likelihood of adoption drops by 20.1% if required adoption premium increases by 1 unit. Soil ranking has the expected sign but is not significant, possibly because many survey respondents (38.6%) showed a concern for soil compaction as a consequence of ICLS adoption.

Therefore, adoption rate for conservative practices could be boosted if more producers developed an unbiased perception on the new practice's economic and soil health benefits. Potential methods include providing information and technical support through field tours, extension workshops, peer learning among farmers themselves, and government education programs (Carolan, 2006; Miller, Chin, and Zook, 2012).

In addition to adoption premium and soil ranking, three variables related to farmer and farm characteristics are significant in the DCR adoption model: age, moving possibility, and crop acres. As explained in the conceptual model section, variables such as age may increase inertia toward a traditional practice, as indicated by in equation (2), which will discourage the adoption of conservation practices. Empirical findings in Table 4 regarding DCR adoption are consistent with this assumption, in that the probability of adoption will be significantly reduced as age or moving possibility increase. In both cases, the time horizon for practicing DCR on the same farm operation decreases, which means less time to recoup the benefits from the investment (Lambert et al., 2007), made a similar observation). In alignment with moving possibility, Wilson (1997) also found that length of residency on the same land positively correlated with participation in agri-environmental schemes.

Crop acres also positively affected the DCR adoption decisions at the 5% significance level. Specifically, when crop acres increase by 1,000 acres, the probability of adoption increases by 3.8%. With lack of equipment being cited as a factor preventing the adoption of soil conservation practices (Snapp et al., 2005; Carlisle, 2016), a possible explanation for this finding is that larger farms are able to spread the initial equipment investment cost over more acres, which reduces the financial challenge of adoption (Napier, Tucker, and McCarter, 2000; Tosakana et al., 2010).

In contrast to its positive effect on DCR adoption, crop acres has no significant influence on ICLS adoption, which indicates that the effect of farm size differed depending on the specific conservation practice (Soule, Tegene, and Wiebe, 2000; Knowler and Bradshaw, 2007; Lambert et al., 2007). Among the included farmer and farm characteristics variables, education is the only significant explanatory variable for ICLS adoption. Specially, farmers who received some college education, college degree, or above are 11.8% less likely to adopt ICLS compared their peers with a high school degree or some high school education. This indicates that farmers with a higher level of education are more likely to be specialized in either crop or livestock production.

We also incorporated the location effect in our model to check the difference in adoption rates across our study region. Compared to Nebraska farmers, South Dakota and North Dakota farmers were 21.5% and 29.8% more likely, respectively, to adopt the DCR practice. DCR adoption rate in North Dakota was the highest among the three states, which indicates a gradual increase in DCR adoption rates when moving further north in the study region. However, the ICLS adoption rates in those three states were not statistically different.

Conclusion

Policy makers and researchers have promoted soil conservation practices to reverse the unintended soil trend toward degradation. To promote diffusion of conservation practices among farmers, many studies have identified factors that contribute to the adoption of soil conservation practices, but to date no variable has been recognized that has a significant effect on all adoption decisions in different regions (Knowler and Bradshaw, 2007).

This paper aimed to increase our understanding of adoption behaviors of two important soil conservation practices—diversified crop rotation and integrated cropping and livestock system—in the U.S. Northern Great Plains as well as various factors that affect adoption decisions. Our model estimation results indicate that factors that shorten the time horizon to work on the same farm, such as older age and the possibility of moving, significantly reduce the probability of DCR adoption. Crop acres contributed positively to DCR adoption yet had no significant effect on ICLS adoption. Overall, among external farmer and farm characteristics, we found no variable that had the same significant effects on both DCR and ICLS adoption, consistent with conclusions made by Knowler and Bradshaw (2007).

Some farmer perception variables were found to have a significant influence on the adoption decisions of both conservation practices. Specifically, we found that producers who require higher adoption premiums are less likely to adopt conservation practices. For example, farmers who perceive a conservation practice to have higher risk will likely require higher adoption premiums. Reducing perceived risks associated with conservation practices could be an effective method to lower required adoption premiums and increase adoption rate (Arbuckle and Roesch-McNally, 2015).

In addition, the stewardship motive, or the perception of soil health importance, also played a significant role in DCR adoption. Generally, those who listed soil health as a more influencing factor when considering adoption were more likely to adopt the conservation practices. Previous literature has also suggested that enhanced knowledge about the environmental, agronomic, and economic benefits of soil health practices positively affects adoption decisions (Singer, Nusser, and Alf, 2007; Miller, Chin, and Zook, 2012; National Wildlife Foundation, 2012).

Our findings suggest that future efforts to understand farmer conservation behavior should focus more on farmers' attitudes and perceptions of conservation practices. Compared to external farmer and farm characteristics, farmers' perceptions are more likely to influence adoption decisions on a universal basis (Adesina and Baidu-Forson, 1995). To diffuse soil conservation practices more effectively, besides government cost-share programs, future efforts could be made to (i) reduce adoption premiums by providing necessary education materials to lower perceived risks associated with conservation practices and (ii) enhance awareness of the importance of soil health in agricultural production and establish soil health benefits associated with soil conservation practices.

[First submitted April 2018; accepted for publication October 2018.]

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