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Duration of Usage and Farmer Reported Benefits of Conservation Tillage

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Abstract: This empirical paper investigates how duration of conservation tillage (CT) usage affects farmers' production cost, cash crop yields and economic returns. This paper was based on the analysis of responses from 708 surveys completed by South Dakota farmers in 2018. Our results suggest that it takes between five to ten years before CT is regarded as profitable by the majority of adopters. The likelihoods of adoption and positive outcomes are higher in areas with less precipitation. Adoption subsidies should account for agro-climatic characteristics and decrease with duration of usage. In areas with relatively high rainfall, monetary incentives may be required to encourage CT adoption. However, such inducements may only need to be offered for the first several years of adoption before the beneficial effects of CT render them unnecessary.

Keywords: conservation tillage, economic benefits, adoption and duration of usage, farmer survey

1. Introduction

Conservation tillage (CT) systems leave at least 30 percent of crop residue on the soil surface after planting or maintain a minimum of 1,000 pounds of small grain residue equivalent per acre during the wind erosion period (Pittelkow et al. 2015a, Carter 2017, NRCS 2011). This residue reduces soil erosion and water loss, and increases soil carbon storage and the resistance of the soil to extreme climatic variability (Clay et al., 2012, 2014). For example, it was estimated that increasing adoption of CT along with improved genetics increased soil carbon storage by 24% from 1985 to 2010, reduced wind and sheet erosion by 25% from 1982 to 2007, which in turn produced over 1 billion dollars as a return to soil management in South Dakota during the 2012 drought (Clay et al., 2012, 2014).

CT adoption increases from east to west across South Dakota (Clay et al. 2012). This geographic variation in no-tillage adoption is attributed to decreasing rainfall from east to west across the state. Ding et al. (2009) also found that CT adoption was higher in semi-arid than humid regions. However, Knowler and Bradshaw (2007) concluded that the circumstances under which farmers adopt conservation agriculture vary widely across studies with few common variables that are consistently associated with adoption. A review of the literature on adoption of Best Management Practices (including CT) found that access to and quality of information, financial capacity, and local networks of extension agents, and the involvement in farmers or watershed groups can also impact adoption (Baumgart-Getz et al. 2012). A more recent review also documented the importance of social networks and producer attitudes and awareness in conservation practice uptake (Prokopy et al. 2019).

Multi-year studies of CT demonstrate its significant benefits for soil and water quality as a result of reduced soil erosion and improved soil characteristics (Dumanski et al. 2006, Busari et al. 2015). Even though off-farm benefits of CT are well established, the evidence about the impacts of CT on yields and profitability are confounded by complex interactions among genetic improvements, soil variability, management, climatic changes, and equipment improvements (Chang et al., 2014; Canales et al. 2018). Critical to increasing the adoption of CT is the ability to better document the short- and long-term costs and benefits to adopting and maintaining this practice.

A review of the evidence in Kaval (2004) supports the assessment that no-tillage systems reduce costs and increase, but not necessarily stabilize, yields when compared to conventional tillage systems. Nonetheless, the comparisons depend on whether the data is gathered from farms or research experiment stations, the time period, and other factors such as the type of crop and geographic region. Because of the difficulties in gathering farm-level data on costs (and yields) there are few studies that empirically evaluate the profitability of CT. Focusing on corn, soybeans, and wheat cropping systems, Valentin et al. (2004) reported that soil conservation practices that included reduced tillage had a minimal impact on profitability. Using data from a seven-year study, Archer and Reicosky (2009) reported that no-tillage and strip-tillage may be economically viable alternatives to conventional tillage systems for corn and soybean production in the northern Corn Belt. Wade et al. (2016) showed that soil characteristics and crop rotation are important determinants of the adoption decision and that adoption costs are highly heterogeneous across farmers. Savings in labor and machinery costs associated with adoption of CT can be offset by higher expenditures on controlling weeds chemically due to increased herbicide requirement, or lower yields due to increase of diseases as a result of retention of moisture by crop residue. However, there is little evidence about how long-term changes in tillage management impact soil health, soil water holding capacity, and water infiltration that may only be realized during periods of extreme climate events (Clay et al., 2014). Quantifying these benefits is directly related to the length of time that the CT system has been used on the farm.

We hypothesize that CT users of longer terms experience a more positive outcome than a recent adopter because of (i) improvements in soil quality and better management skills as a result of longer CT usage or (ii) adopter-specific factors. The goal of this paper is to identify how duration of usage of CT affects farmers' perceptions about its effects on costs, yields, and profits using data from a representative sample of farmers in SD. Such information could help inform the development of targeted policies to increase adoption rates and diffusion of CT across wider areas. To our knowledge, this is the first study to jointly estimate the determinants of the duration of usage and adopters' perceptions about the effects of CT on production costs and output at the farm level. Ramsey et al. (2016) studied the effects of having some or no experience with several conservation practices, including CT, on farmer risk perceptions but do not consider the effects of duration of usage. Fuglie and Kascak (2001) applied a duration model to a large sample of US farms to identify several factors that explain diffusion of conservation practices. They reported that, controlling for geographic region, greater levels of education, farm size, and land quality increased the speed of CT diffusion. As discussed in Canales et al. (2018), the more recent studies use limited dependent variable models to explain farmers' adoption of tillage systems. The present study focuses on a population within the northern Great Plains climate transition zone that has significant variation in soil moisture and temperature across the region. Native vegetation range from tall grass prairie in eastern South Dakota to a short grass prairie in western South Dakota.

2. Review of empirical evidence about economic effects of conservation tillage

In this section, the pertinent theoretical considerations and empirical evidence about cost, yield, and profit responses of adoption of CT and the effects of duration of usage are reviewed.

Incremental cost

Theoretically, production costs can increase or decrease following adoption of CT (Hodde 2016). Decreased costs can result from a reduction in the number of field equipment passes over the field which lowers expenditures on labor, machinery, and fuel. Yet, expenditures on pesticides and other chemical inputs can increase if additional crop residue increases the prevalence of pests and diseases. Empirical studies comparing production costs under CT to those under other tillage systems find that the changes in production costs can be positive or negative but are typically small.

Although CT should reduce machinery needs for pre-planting operations, machinery costs overall do not necessarily decrease (Uri 1999, Zenter et al. 2002). While a reduction in trips across the field with CT decreases fuel and maintenance costs, CT may also require specialized implements (e.g. no-tillage grain drills, air seeders) and adjustments to planter and fertilizer application equipment (Epplin et al. 2005, Williams et al. 2009). Lee and Stewart (1985) argued that adjustment costs associated with machinery investment may make CT adoption difficult for small farms. A five-year study comparing the production costs on farms practicing continuous no-till on all acreage and farms that practiced some level of tillage concluded that, without controlling for farm- or farmer-specific characteristics, the overall expenditure on machinery was greater on no-till farms (Ibendahl 2016). The incremental expenditures on machinery due to adoption of CT may also change as technology improves and becomes more widely adopted. In fact, there is some evidence that suggests that the quality and availability of specialized farm implements required for CT increased over time (Boyle 2006).

On the other hand, many studies report significant savings in labor costs achieved by CT users. For example, Weersink et al. (1992) found that labor costs for no-tillage and ridge tillage corn-soybean farmers in southern Ontario were reduced by 60% when compared with conventional tillage systems. Using machinery management data, Dickey et al. (1992) reached a similar estimate by calculating the typical labor requirements for various tillage systems for corn and soybeans in Nebraska. Significantly lower labor requirements ranging between 20% and 30% were also reported in Chase and Duffy (1991) for Iowa corn-soybean crops, in Harper (1996) for Pennsylvania corn production, and in Johnson et al. (1986) for Kansas wheat rotations. More recently, Parvin and Martin (2005) reported that no-tillage reduced tractor hours per acre by 49% and labor hours per acre by 43%, and that savings increased as a result of machinery improvements.

The review of Uri (1999) finds that although CT can increase fertilizer use during the initial adoption period, continuous CT tends to reduce fertilizer use over time through its cumulative beneficial effects on soil. More recent studies based on larger data sets suggest that CT may reduce application rates for some types of fertilizer. For example, Wu and Babcock (1998) reported that CT reduces Nitrogen (N) use but has no effect on Potash (P). In a carefully documented chronological case study in SD, a reduction in both N and P fertilizer inputs over time occurred concurrently with significant yield gains (Anderson, 2016). In addition, CT can increase weed pressure and herbicide use. Although pest management can be affected by tillage system, Fuglie (1999) reported that tillage had a minimal effect on pesticide use.

As with adoption of any new technology, users of CT may become more efficient and productive as they intergrate the system into their farm. Nowak and Korsching (1985) suggested that education helps CT practitioners implement CT in their circumstances. Although much of the evidence regarding the different dimensions of learning about CT is anecdotal, the lack of farm management experience during transition to CT is frequently cited as one of the barriers to adoption (Bossange et al 2016). For example, long-term users of CT in SD report that the effectiveness of strip-tillage is influenced by the farm operator’s skills in managing factors such as the amount moisture in the soil, field slope, placement of seeds and fertilizer, timing of field operations, and skills in residue and weed management (Pocock 2007).

To recap, CT may decrease expenditures on labor and fuel, but its effect on expenditures of chemical fertilizers and pesticides is not certain. There is also some evidence that the cost savings are more likely to offset the additional expenditures as duration of usage increases due to gradual improvements in soil quality and better management skills.

Yield

Agronomic studies identify several pathways through which CT can affect soil productivity and yield probability distribution (Uri 1999, Karlen et al. 1994).[1] Productivity can increase as a result of increases in soil organic matter and microbial activity in upper soil horizons or layers (Diaz-Zorita et al. 2004), or decrease due to cooler and wetter soils that can delay planting and emergence (Rusinamhodzi et al. 2011). Empirical studies show that the effect of CT on yields depend on crop variety, crop rotation, soil properties, land slope, climatic conditions, and duration of usage (Palm et al. 2014). A meta-analysis of a large number of studies comparing no-till to conventional tillage suggests that no-tillage decreases corn yields by 7% to 12% and wheat yields by 2% to 5% (Pittelkow et al. 2015b). However, corn yield reductions were less likely in a corn-soybean rotation than a continuous corn production (Vyn and Raimbault 1993, West et al. 1996).

For continuous corn cropping systems, Pittelkow et al. (2015b) identified duration of usage, residue management, and aridity among the three most important factors determining the effect of CT on yield. They concluded that, corn yield decreased during early years in a dry environment and that the negative effects of CT were greater in cooler climates and/or areas with high precipitation (*Ibid*.) Derpsch et al. (2014) suggested that farm management experience that is gained with sustained long-term use may also influence the effects of adoption.

[1] An excellent account of the history of tillage can be found at https://extension.umn.edu/soil-management-and-health/history-tillage-and-tillage-research#post-dirty-thirties-1151262

Over time, differences between conventional management and CT can decrease and, under favorable conditions, profits under CT can be similar to those under conventional tillage methods (Toliver et al. 2012, Ogle et al. 2012). In those circumstances reduced yields and profits during the early years of adoption are offset by the subsequent increases in yields and profitability as a result of accumulation of soil nutrients and organic matter and improvements in the soil structure as well as better implementation of CT practices (Grandy et al. 2006). Uri (1999) concluded that improved soil characteristics associated with the continuous use of conservation tillage take at least 10 years to fully realize their positive impact on yield.[2]

3. Empirical Model

Farmers often choose the tillage system that maximizes the expected utility of income and land stewardship activities. Note that when carrying out empirical analysis on duration of usage and outcomes of conservation tillage, the endogeneity issue could potentially arise due to omitted variables that are correlated with both adoption timing and adoption outcomes. Among omitted variables in our sample are farm-level soil characteristics such as soil erodibility. As one of the primary benefits of CT stems from soil erosion control, the initial level of soil erosion affects the choice of the tillage system and productivity, and expenditures on additional measures to control soil erosion. There are also unobserved characteristics such as attitudes to risk and time preferences that affect farm management practices and income but are not included among regressors. Furthermore, farmers who do not experience benefits from CT practice are less likely to continue the practice, which could be an additional source of endogeneity. In our analysis, we excluded the group of discontinued farmers to eliminate this potentially important source of endogeneity.

[2] The short-term beneficial effects of CT on yields in the Great Plains stem from the reduction of soil erosion and water conservation (Anderson 2016). The case study in Anderson (2016) analyzes the changes in corn yields across time in a no-till cropping system in central SD and links the effects of different conservation practices on yield to agronomic factors and changing growing conditions.

The effects of duration of usage on CT usage outcomes was estimated using a recursive, simultaneous ordered probit model (Greene 2012):

(1) $$T_i^* = \alpha' \mathbf{x}_{1,i} + \varepsilon_i ,$$

(2) $$y_{k,i}^* = \beta_k' \mathbf{x}_{2,i} + \sum_{j=1}^{4} \gamma_{k,j} 1[T_i = j] + u_{k,i} ,$$

where *k*=1,2,3 indexes CT usage outcomes, which are cost, yield, and profit in our paper. We estimate three different models, one for each outcome. Here T_i^* is a latent variable that determines whether farmer i adopts CT, and in the case of adoption, the observed time of adoption, $y_{k,i}^*$ is latent variable that determines farmer i's reported changes in production costs, yields, and profits induced by adoption, and $\mathbf{x}_{1,i}$ and $\mathbf{x}_{2,i}$ are the sets of exogenous regressors. As pointed by Mourifie and Meango (2014), identification in bivariate ordered probit models generally relies on an exclusion restriction, that is, the exclusion of one or more variables that appear in the duration equation (1) from an outcome equation (2). In this paper, we use farmers' environmental attitudes as our exclusion variable. Specifically, we assume that a farmer who reports greater concerns about the impacts of farming practices on the environment and has a greater sense of responsibility for land stewardship is more likely to adopt CT (see Prokopy et al., 2019). However, these attitudinal characteristics should be unrelated to the perceived effects of CT on costs, yields, and profits. Our assumption behind the exclusion restriction was that the attitudinal factors affect outcomes only through their impact on the duration of usage.

The observed time of adoption $j =$ 0, 1, 2, 3, 4 corresponds to different adoption categories according to the duration of usage, with 0 = 'not adopted', 1 = 'less than 3 years', 2 = '3 to 5 years', 3 = ' 6 to 10 years', and 4 = 'more than 10 years'. The observed time of adoption T_i is related to its corresponding latent variable T_i^* through the function $T_i = j$ if $C_j \le T_i^* \le C_{j+1}$, where C_j is the threshold level that define adoption category specified by T_i, and $C_0 = -\infty$, $C_5 = +\infty$. The indicator function $1[T_i = j]$ is equal to 1 if $T_i = j$ and 0 otherwise. Similarly, the observed outcome variable $y_{k,i}$ corresponds to farmer i's rating about outcome k, which relates to its corresponding latent variable $y^*_{k,i}$ through the function $y_{k,i} = 1$ if $y^*_{k,i} \geq 0$ and $y_{k,i} = 0$ otherwise.

We adopted the same assumptions as in Greene (2012) and assumed that the error terms $(\varepsilon_i, u_{k,i})$ follow a bivariate normal distribution with zero mean, unit variance and a correlation of ρ_k.

$$\begin{pmatrix} \varepsilon_i \\ u_{k,i} \end{pmatrix} | \, \mathrm{x}_1, \mathrm{x}_2 \overset{i.i.d.}{\sim} N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho_k \\ \rho_k & 1 \end{pmatrix}\right],$$

where ρ_k measures the tetrachoric correlation between T_i and $y_{k,i}$. As shown in Greene (2012), full information maximum likelihood estimation of this model accounts for the endogeneity of the duration of adoption. Note that that the correlation parameter ρ_k measures the extent of endogeneity of T_i^* in determining $y^*_{k,i}$. It is not just a measure of the correlation between the discrete variables in the model since the duration of usage appears on the right-hand side of the outcome equations (2). Correlation between the reduced form equation (1) and structural equation (2) is also captured by parameters $\gamma_{k,j}$ (Filippine et al. 2018).

The endogeneity due to correlated errors of ε_i and $u_{k,i}$ can be determined by testing for the significance of ρ_k $(k = 1, 2, 3)$. The correlation coefficients correcting for selection bias in duration of CT usage (in the reduced form equation (1)) for the cost, yield and profit outcomes respectively are estimated as $\rho_1 =$ 0.086, $\rho_2 =$ - 0.278, $\rho_3 =$ - 0.337, all of which, however, are not significant at the 5% level based on likelihood ratio test. The correlation between errors in equations (1) and (2) serves as a control for selection bias (endogenous choice of the time of adoption). As indicated by the *p*-values of these correlation coefficients, endogeneity of duration of usage may not play an important role in the analysis of the effects of duration on outcomes. The estimation results when equations (1) and (2) are estimated separately are qualitatively similar.

Therefore, separate estimations of equation (1), an ordered probit model, and (2), three probit models are carried out using the probit package and ordered probit package in STATA software (version 15.0, StataCorp LLC, College Station, Texas, USA). For each explanatory variable, marginal effect is calculated for each observation in the sample, and then averaged across all the observations.

4. Data description

The data used in this study were elicited as part of the 2018 South Dakota Commodity Crop Producer Survey administered by an interdisciplinary team of researchers at South Dakota State University from January to March 2018. The survey was conducted in collaboration with the South Dakota Corn Utilization Council with the objective to collect data on farm operators' views and usage of farming practices and to better understand how agricultural producers in South Dakota are managing their farmland. In addition to the questions used in our analysis, the survey contained questions about sources of information and knowledge about soil and water conservation practices (conservation tillage, cover crops, diversified crop rotation, and integrated crop and livestock systems), perceived benefits and challenges in adoption of conservation practices, and attitudes to community, land, and environment. The survey targeted managers of farming operations in Central and Eastern portions of South Dakota where the production of corn and soybeans are dominant. The 3,000 farming operations were selected using proportionate stratified-random sampling according to number of farming operations in the study counties from a list of 10,000 farming operations that had participated in Farm Service Agency (FSA) programs in 2016.

The participants were contacted in four rounds using a modified version of the tailored design method (Dillman et al. 2014). First, the participants were contacted by letter with a link to answer the questionnaire online and information about the survey. One-half were randomly selected to receive a $2 bill incentive in order to test the efficacy of the incentive in increasing response rates with this population (Glas et al. 2019). Those who did not respond in the first round were then mailed the paper questionnaires with addressed and stamped return envelopes, followed by a reminder postcard two weeks later, and then a second paper copy of the survey and envelopes two weeks after that. Out of a total of 3,000 farming operations selected to participate in the survey, excluding operations that stopped farming or rented out all of their land, 708 questionnaires (including those filled out online and by mail) were collected with the resultant response rate of 30%.

On a number of key factors, survey respondents were comparable to data from the 2017 United States Department of Agriculture Census of Agriculture. Among these, the average age of SD farmers in the Census was 56.2 and for survey respondents it was 56.6. The average number of acres operated was 1,150, slightly lower than the Census average of 1,397. The average market value of agricultural products sold in 2017 in the Census (not including government payments) was $324,397, while in the survey the average was 3.51 (3=$100,000- 249,000; 4= $250,000- 499,000), which was comparable to the Census average.

Respondents provided information about their current and past usage of several soil conservation practices including CT. While several examples of CT practices such as no-tillage, strip-tillage or mulch-tillage, were provided to the respondents, we relied on respondents to determine whether they practice CT. Although no questions were asked about how the share of land under a particular conservation practice changed over time, farmers reported the total number of years using CT and whether they discontinued the practice. Of the 596 respondents who answered the CT adoption status question, only 19 respondents (3.19%) reported discontinuation of CT. Due to endogeneity considerations, dis-adopters were excluded from the modeling analysis.

Table 1 shows that while 44.3% of the respondents have used CT for more than 10 years, 14.1%, 10.6% and 6.7% of respondents used CT for between 6 and 10 years, between 3 and 5 years, and within the recent 3 years respectively. This indicates that while the adoption rate of CT grew during the past ten years, the rate of growth has gradually declined. The overall adoption rate of CT in our sample was 75.7%, comparable to the average CT adoption rate for the 36 counties targeted in our survey, which according to the 2017 Agriculture Census was 71.2%.

Farmers also rated changes in production costs, yields, and profits following adoption by choosing one of the five categories, namely - 2 = “reduced by >15%”, - 1 = “reduced by 5%-15%”, 0 = “very little change (within 5%)”, 1 = “increased by 5%-15%”, and - 2 = “increased by >15%”. An average rating of changes in total production cost, cash crop yield, and profitability after CT adoption, either based on adopters’ experience, or based on non-adopters’ perception, are provided for each adoption category (Table 2). An average value of greater or less than zero means an increase or a decrease or respectively, in the corresponding item after CT adoption.

For outcomes on total production cost, cash crop yield and profitability, Table 2 also presents the proportions of respondents in each of these three categories, namely 1) decrease, which consists of two categories, ‘reduced by 5%-15%’ and ‘reduced by >15%’; 2) same, which refers to the ‘very little change (within 5%)’ category; and 3) increase, which consists of two categories, ‘increased by 5%-15%’ and ‘increased by >15%’. Table 2 results indicate that more than one third of the recent adopters with less than 3 years of usage have already achieved a positive outcome in terms of production cost and profitability. In addition, when usage duration increases, the percentage of farmers who experienced CT benefits as indicated by reduced cost, increased yield and increased profitability gradually increase. Long-term users are more likely to experience positive outcomes resultant from CT usage. The Duncan's multiple range test on average ratings of changes in total cost suggests that even non-adopters perceive cost savings as a benefit from CT adoption, and their perceptions are not statistically different from the experiences of adopters with less than ten years of usage. This implies that cost benefits of CT such as reduced pre-planting operations and saved labor costs can be easily comprehended by non-adopters as well.

Compared with the cost saving advantage of CT, it takes a longer period for producers to experience the benefits of CT on cash crop yield. For example, among adopters with between 3 and 5 years of experience, 47.3% had a positive experience in cost savings, while only 33.8% experienced an increase in cash crop yield. After the initial five years of adoption, more than 50% of producers experienced the increase in cash crop yield. This finding indicates that generally it will take more than 5 years for the yield benefits of CT to manifest, since soil characteristics gradually improves over time and better implementation of CT practice comes through trials and errors.

A description of all the variables included in the model as well as the six statements used to elicit the producers' environmental attitudes appear in Table 3. Respondents were asked several questions related to their attitudes about land stewardship and environment measured on a 5-point Likert scale. One such question elicited the strength of respondents' beliefs that advances in agricultural technologies may offset the adverse effects of soil erosion on yields and productivity. Farmers also reported how strongly they were concerned about fossil fuels use, their willingness to use bio-based fuel, responsible usage of fertilizer application, perceived responsibility for soil erosion, and effects of crop residue management on soil health. Farmers' agreement ratings towards the six statements in Table 3 range from 1 = 'strongly disagree', 2 = 'disagree', 3 = 'agree', and 4 = 'strongly agree'. Following Sulemana and James (2014), an attitudinal factor index (AFI) that reflects the level of the respondent's concerns about the environmental consequences of farming was created. AFI is defined as an average of measures of attitudes to environment, land stewardship, and conservation (the formula appears in Table 3). Concerns about the environmental consequences of agriculture may impact adoption of best management practices in certain contexts (Floress et al. 2017). Note that stronger disagreement with the statement 1 and stronger agreements with statements 2 to 6 indicate greater concerns towards the environment, therefore in constructing AFI we assign a negative sign to S_1 but positive signs to S_2 through S_6. In this way, a higher AFI value stands for greater environment concerns.

A set of questions about operation characteristics included gross annual sales, share of owned land, and the percentage of off-farm income. We use annual gross revenue as a measure of farm size rather than acreage. It is worthwhile to observe that while there was a wide range of soil types, textures, and qualities within the geographic area, one of the most pronounced agronomic differences was average precipitation which ranged from 460 mm/year in central SD to 590 mm/year in the eastern part of the state (NRCS 2017, NASS 2018). Therefore, we also used 30-year May to September precipitation data at the county average level, generated from Parameter-elevation Regressions on Independent Slopes Model (PRISM). The survey also collected data on farmers' demographics including the number of years of being a primary decision-maker, the highest level of education, and whether the respondent studied agricultural sciences in college.

Summary statistics of the explanatory variables included in the ordered probit model (usage duration for CT) or probit models (CT outcomes) are provided in Table 4. Note that in the ordered probit model, we included different categories of gross sales, off-farm income, and education as binary dummy variables. For example, Table 4 findings suggest that 15.2%, 18.8%, 23.9%, 15.2%, and 10.4% of respondents belonged to the categories of $50,000 – 99,999, $100,000 – 249,999, $250,000 – 499,999, $500,000 – 999,999 and $1 million or more, respectively, while the rest of respondents belonged to the less than $50,000 category. In the three CT outcome models, in addition to the aforementioned binary variables, we also included the different categories of usage duration variables as binary dummy variables. Note that the percentage of respondents in each usage duration category resembles that of Table 1, with only slight differences that can be attributable to the exclusion of dis-adopters from the CT outcome models. Table 4 shows that the average operation period was 27 years and average share of owned land was 56.3%, and that 18.2% of respondents had completed an agricultural major or minor in college. Thirty-year average precipitation in inches, between May and September, ranges from 13.279 to 19.359, illustrating that there is considerable precipitation differences within the studied region.

5. Results and Discussion

The focus of this study was to determine the relationship between the duration of usage and farmer reported benefits resulting from implementation of CT. Since the estimated coefficients for equation (1) were difficult to interpret, we also reported the estimated marginal effects for the exogenous variables on adoption duration (Table 5), and the effects of duration of usage and exogenous factors on farm reported outcomes from CT usage (Tables 6).

Factors affecting Duration of CT adoption

Table 5 displays the ordered probit modeling results for CT adoption duration. The values of likelihood ratio $\chi^2(18)$ of 108.63 for the duration model indicates a significant improvement over the intercept only model. Operation years indicate the length of survey respondents' farm management experience. As farm management experience increases by one year, respondents are 0.5% more likely to have used CT for more than 10 years. This makes intuitional sense since normally CT usage years should be shorter than the number of operation years if the farm operator made the adoption decision. Based on our survey responses, however, duration of usage can exceed the respondent's number of years of farm management experience. For example, in our sample there are 82 respondents with less than ten years of experience as a primary farm operation decision-maker. Among those 18 (22%) reported using CT for more than 10 years, which indicates that they were not original adopters.

Ceteris Paribus, farmers expressing greater environmental concerns are more likely to be long-term users with CT usage experiences of at least 10 years, while less likely to be non-adopters or recent adopters (<5 years). Previous literature also found environmental attitudes as well as land stewardship motivation are among the variables positively associated with the adoption of agricultural conservation practices (Prokopy et al, 2019; Chouinard et al., 2008). Furthermore, long-term CT users are more likely to farm in the central part of the state with relatively low precipitation level, operate farms with gross sales more than $100,000, and have longer farm management experience. These results are consistent with the results in Fuglie and Kascac (2001) and Wade and Claasen (2017), that differences in natural resource characteristics (as captured by precipitation), farm size (gross annual sales), and farm management experience influence the time of adoption. In addition, we found those with a high proportion of off-farm income (81 - 100%) are 14.4% more likely to be long-term users (>10 years). This is similar to the findings of Fernandez-Cornejo et al. (2007), who found higher off-farm income contributed to the adoption of timesaving practices such as conservation tillage.

The other farm management variables and demographic characteristics such as share of owned land, education, and agricultural studies generally have expected signs but are not significant at the 10% level.

Factors affecting Benefits induced by CT adoption

The same explanatory variables for the adoption duration model, as discussed in the previous section, are also included in the analysis of the effects of duration of usage on CT induced on-farm benefits. Here we adopted a conservative definition of a successful outcome: an outcome was successful only if the respondents report an improvement of at least 5% as a result of adoption. Under this definition a response in the "very little change (within 5%)" category is counted as an unsuccessful outcome. Therefore, total cost reduction is equal to 1 if respondents rated their total cost as either 'reduced by >15%' or 'reduced by 5% - 15%', and 0 otherwise, while yield increase and profit increase take the value of 1 if producers chose 'increased by 5% - 15%' or 'increased by >15%', and 0 otherwise.

The estimated marginal effects of usage duration on farmer ratings are consistent across all three outcomes (cost, yield, profit). When controlling for the other factors, Table 6 indicates that the most recent adopters (< 3 years) have experienced a profit increase at 10% significance level when compared to non-adopters. Compared to non-adopters, adopters with between 3 and 5 years of usage are 22.1% more likely to rate a positive outcome in profit increase, and 18.0% and 18.9% more likely to perceive benefits in cost reduction and yield increase respectively. As adoption years increase, producers are more likely to report benefits in all three outcomes. For example, compared to non-adopters, those who used CT for less than 3 years, 3 to 5 years, 6 to 10 years and more than 10 years are 18.7%, 22.1%, 33.5% and 35.1% respectively, more likely to rate a positive effect on profitability. The effects of usage duration on CT benefits in Table 6 is consistent with the hypothesis that the soil health benefits of CT and their impact on soil productivity accumulate over time. For example, the benefits of reductions in soil erosion, increases in soil organic matter, and greater water infiltration and retention all accrue gradually over time.

Farms that receive less precipitation, usually those located towards the west of the studied region, were more likely to report beneficial on-farm effects following adoption while controlling for the duration of usage and other factors. When average precipitation over the past 30 years decreases by 1 inch, respondents are 5.4% more likely to experience yield increase, and 2.8% more likely to experience cost reduction as a result of CT implementation. The significant effect of precipitation on the yield outcome can be attributed to the water conservation benefits of CT (Ding et al 2009, Anderson 2016, Clay et al. 2014, Sanghun et al. 2014). By leaving at least 30 percent of crop residue on the soil surface, CT effectively reduces water evaporation. In addition, CT can increase water infiltration by nearly 50% compared to conventional tillage systems for soil types prevalent in SD (SDCD 2018). Within our studied region, compared with eastern SD, droughts are more common for central SD due to the semi-arid environmental characteristics (Clay et al., 2014). As a result, our survey results indicate that within our sampled region, CT adoption rates in central SD counties were in general greater than those for eastern SD (Figure 1). Similar to our findings, other studies also find the effect of tillage vs. no-till on crop yields is contingent on climate factors which influence expected returns of CT as well as its adoption rate (DeFelice et al., 2006; Ding et al., 2009; Toliver et al., 2012).

Depending on their farm scale, CT adopters also experienced different degrees of total cost reduction. For example, compared to farms with gross sales of less than $50,000, those with gross sales of 1 million or more are 21.7% more likely to experience reduction in total cost. In this regard, our results resemble that of Watkins et al. (2005), whose findings show that one of the greatest benefits of CT is its machinery ownership cost savings and that large farms benefit even more from such savings due to the economies of scale effect. Even though producers with higher share of off-farm income are more likely to adopt CT, when off-farm income percentages increase, producers are less likely to experience cost reductions. Compared to those with less than 20 percent of total income from off-farm employment, those with off-farm income between 81 to 100 percent are 20% less likely to experience reduction in total cost.

6. Conclusions

In this study we analyzed how the perceptions of the effects of the adoption of CT on production costs, yields, and profits change over time. Consistent with the previous literature we found that farm size, farm management experience, environmental attitudes and regional factors were important influencers of CT adoption. However, farm management variables such as gross sales, operator level of education, land ownership, and off-farm income were not statistically significant factors influencing outcomes. Our analysis showed that there was a strong relationship between the length of time that CT was adopted and farmers' perceptions of changes in cost, yields and profits. The proportion of respondents who believed that the economic on-farm effects of CT were positive varied across adopter categories. Of the non-adopters of CT, 72.2% and 83.2% respectively failed to perceive that CT's benefits in reducing costs and increasing yields. However, after less than 3 years of usage, more than one third of the recent adopters have achieved a positive outcome in terms of production cost and profitability. This means that for many producers, economic benefits of CT can manifest in a relatively short period. Outreach efforts to disseminate the timing of economic benefits in this manner could help interested producers make more informed decisions which will further promote CT practice.

Our analysis also indicates that government subsidies may only need to be offered during the first several years of adoption before the beneficial effects of CT render them unnecessary (Reimer et al. 2013, Reimer and Prokopy 2014). In fact, the Environmental Quality Incentives Program (EQIP) puts some restrictions on the period of time during which farmers can receive financial assistance to implement CT. Started as a cost-share subsidy program, the payment rates are currently fixed and do not vary geographically within a state. Notably, contracted producers who meet the requirements receive no more than three payments over the duration of a single

EQIP contract (National Resources Conservation Services 2018). However, there is also a provision that, after the contract expires, a producer can apply for subsequent new EQIP contracts to continue the practice on the same land, as long as it will generate conservation benefits.

In addition to duration of usage, precipitation was another significant determinant of perceived outcomes of adoption. Our results indicate that the yield benefits of CT could take longer to manifest in areas with high precipitation, which could have caused lower adoption rates of CT in these areas. The important role of CT in reversing land degradation and promoting sustainable agriculture justifies the provision of monetary subsidies to promote CT adoption, especially for farms located in areas with relatively high precipitation. However, even for regions where CT causes a decline in yields, CT may still have an economic advantage due to the lower costs. Therefore, more experiments could be carried out, especially in regions with relatively more precipitation, to examine the relative yield and economic benefits of CT in both the short- and long-term to provide producers with valuable information and guidance.

While our empirical results show that perceptions of profitability of adopting CT become more positive over time, we do not have enough information to further analyze the sources of the benefits of CT. More case studies on specific cost, profit, or cash crop yield on a per acre basis before and after implementation of CT in any local areas could be carried out to provide farmers with more detailed benchmark information on utilizing CT to maximize the farm profitability. In addition, a more detailed data set that includes information about soil health indicators, crop mix, field-level yield measurements, input use, and connections among neighbors could shed more light on the relative importance of agro-climatic conditions, social networks and management expertise in determining the short-term and long-term effects of CT. Furthermore, it would be useful to distinguish continuous CT adoption and alternate CT adoption, and evaluate the short- and long-term economic benefits of the two practices in different regions.

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Table 1: Distribution of CT adoption status

CT adoption status	Frequency	Percentage
Non-adopter	126	21.1%
< 3 years	40	6.7%
3 - 5 years	63	10.6%
6 -10 years	84	14.1%
> 10 years	264	44.3%
Dis-adopters	19	3.2%
Overall	596	100.0%

Table 2: Producer perceptions on total production cost, cash crop yield and profitability, by category

Type	Total Production Cost				Cash Crop Yield				Profitability			
	Decrease	Same	Increase	Average	Decrease	Same	Increase	Average	Decrease	Same	Increase	Average
Non-adopter	27.8%	53.9%	18.3%	-0.139[a]	24.4%	58.8%	16.8%	-0.134[a]	15.7%	62.0%	22.3%	0.050 [a]
< 3 years	35.6%	48.9%	15.6%	-0.222[a]	22.2%	48.9%	28.9%	0.133[b]	13.3%	51.1%	35.6%	0.267 [ab]
3 - 5 years	47.3%	29.7%	23.0%	-0.270[a]	12.2%	54.1%	33.8%	0.216[bc]	8.1%	47.3%	44.6%	0.378 [b]
6 -10 years	56.7%	25.6%	17.8%	-0.433[ab]	13.6%	35.2%	51.1%	0.443[c]	4.5%	38.2%	57.3%	0.625 [c]
> 10 years	59.6%	27.8%	12.6%	-0.626[b]	12.3%	37.3%	50.4%	0.485[c]	7.6%	31.8%	60.6%	0.640 [c]
Overall	49.6%	34.5%	16.0%	-0.427	15.6%	44.4%	40.0%	0.453	9.3%	42.3%	48.5%	0.294

Note: The two perception categories ‘reduced by 5%-15%’ and ‘reduced by >15%’ are combined into the category ‘lower’, the perception category ‘very little change (within 5%)’ is referred to as ‘same’, while the two perception categories ‘increased by 5%-15%’ and ‘increased by >15%’ are combined into the category ‘higher’. The average value is computed using - 2 = ‘reduced by 5%-15%’, -1 = ‘reduced by >15%’, 0 = ‘very little change (within 5%)’, 1 = ‘increased by 5%-15%’, and 2 = ‘increased by >15%’. Superscripts denote the results of Duncan’s multiple range test, where the variables not sharing the same letter in the group label are significantly different at the 5% significance level.

Table 3. Description of variables used in the modeling analysis

Variable	Description
Duration of usage	Years of usage for conservation tillage, categories are ‘never used’, ‘less than 3’, ‘3 - 5’, ‘6 - 10’, ’10 +’ and ‘discontinued usage’
Operation years	Number of years as a primary decision-maker for the operation
Gross sales	Gross sales in a typical year, categories are ‘less than $50,000’, ‘$50,000 – 99,999’, ‘$100,000- 249,999’, ‘$250,000- 499,999’, ‘$500,000- 999,999’, and ‘$1 million or more’.
Off-farm income	Percentage of total household income from off-farm employment, categories are ‘less than 20%’, ‘20-40%’, ‘41-60%’, ‘61-80%’, and ‘81% or more’.
Share of owned land	Percentage of land owned by farm operator.
Education	Highest level of school completed, comprised of ‘less than high school’, ‘high school’, ‘some college/technical school’, ‘college degree’, and ‘post-graduate degree’.
Agricultural studies	Whether an agricultural major or minor was completed in college.
Precipitation	Precipitation between May and September, 30-year average in inches, at the county level.
Attitudinal Factor Index	Average agreement ratings towards six statements: $\frac{1}{6}(5-S_1+\sum_{i=2}^{6} S_i)$
Statement 1 (S_1)	‘Technical advances in seeds, fertilizers, and pesticides can offset the adverse effects of soil erosion on productivity.’
Statement 2 (S_2)	‘I am concerned with how much fuel I use for farming.’
Statement 3 (S_3)	‘I would be willing to use a bio-based fuel.’
Statement 4 (S_4)	‘Chemical carry over is a concern for me.’
Statement 5 (S_5)	‘Farmers have a responsibility to use farm practices known to cause minimal soil erosion.’
Statement 6 (S_6)	‘Bailing stover or straw harms soil development.’

Table 4. Summary statistics for explanatory variables used in the regression models.

Variable	N	Mean	Std. Dev.	Min.	Max.
Duration of usage (< 3 years)	577	0.069	0.254	0	1
Duration of usage (3 - 5 years)	577	0.109	0.312	0	1
Duration of usage (6 – 10 years)	577	0.146	0.353	0	1
Duration of usage (> 10 years)	577	0.458	0.499	0	1
Environmental attitudes	542	2.853	0.327	1.833	3.833
Operation years	558	27.038	15.938	0	70
Gross Sales (50,000-99,999)	547	0.152	0.359	0	1
Gross Sales (100,000-249,999)	547	0.188	0.391	0	1
Gross Sales (250,000-499,999)	547	0.239	0.427	0	1
Gross Sales (500,000-999,999)	547	0.152	0.359	0	1
Gross Sales (1 million or more)	547	0.104	0.306	0	1
Off-farm income (20%-40%)	556	0.160	0.367	0	1
Off-farm income (41%-60%)	556	0.128	0.334	0	1
Off-farm income (61%-80%)	556	0.063	0.243	0	1
Off-farm income (81%-100%)	556	0.151	0.358	0	1
Share of owned land	543	0.563	0.359	0	1
Education (high school)	570	0.258	0.438	0	1
Education (some college)	570	0.349	0.477	0	1
Education (college degree)	570	0.314	0.465	0	1
Education (postgraduate degree)	570	0.054	0.227	0	1
Agricultural studies	614	0.182	0.386	0	1
Precipitation	614	16.523	1.505	13.279	19.359

Table 5. Ordered probit model results for adoption duration

		Marginal Effect (ME)				
Variable	Coefficient	Non-adopter	< 3 years	3 – 5 years	6 – 10 years	> 10 years
Environmental attitudes	0.800***	-0.198***	-0.034***	-0.033***	-0.005	0.270***
Operation years	0.014***	-0.004***	-0.001***	-0.001***	-0.000***	0.005***
Gross Sales (50,000-99,999)	0.326	-0.105	-0.009	-0.002	0.015	0.102
Gross Sales (100,000-249,999)	0.543***	-0.166**	-0.019**	-0.010	0.017	0.177***
Gross Sales (250,000-499,999)	0.690***	-0.202***	-0.026***	-0.017**	0.016	0.230***
Gross Sales (500,000-999,999)	0.837***	-0.234***	-0.034***	-0.026**	0.011	0.283***
Gross Sales (1 million or more)	1.005***	-0.265***	-0.043***	-0.038***	0.003	0.343***
Off-farm income (20%-40%)	0.122	-0.031	-0.005	-0.005	-0.000	0.041
Off-farm income (41%-60%)	0.183	-0.045	-0.008	-0.008	-0.001	0.062
Off-farm income (61%-80%)	-0.298	0.085	0.010	0.007*	-0.006	-0.096
Off-farm income (81%-100%)	0.424**	-0.096***	-0.019**	-0.021**	-0.008	0.144**
Share of owned land	-0.072	0.018	0.003	0.003	0.000	-0.024
Education (high school)	0.070	-0.019	-0.003	-0.002	0.000	0.023
Education (some college)	0.163	-0.042	-0.007	-0.006	-0.000	0.055
Education (college degree)	0.146	-0.038	-0.006	-0.005	-0.000	0.049
Education (postgraduate degree)	0.175	-0.045	-0.007	-0.007	-0.000	0.059
Agricultural studies	0.290	-0.072	-0.012	-0.012	-0.002	0.098
Precipitation	-0.176***	0.044***	0.008***	0.007***	0.001	-0.059***
Observation Number	451					
Likelihood ratio (LR) χ^2 (18)	108.63	Prob > LR χ^2 (18) = 0.000				

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

Table 6. Probit regression results on total cost change, yield change and profit change

Variable	Total Cost Reduction		Yield Increase		Profit Increase	
	Coeffi.	ME	Coeffi.	ME	Coeffi.	ME
Duration of usage (< 3 years)	0.413	0.147	0.468	0.147	0.536*	0.187*
Duration of usage (3 - 5 years)	0.503**	0.180**	0.584**	0.189**	0.627***	0.221***
Duration of usage (6 – 10 years)	0.710***	0.257***	0.935***	0.321***	0.925***	0.335***
Duration of usage (> 10 years)	0.671***	0.243***	0.884***	0.302***	0.968***	0.351***
Operation years	0.003	0.001	0.002	0.001	-0.000	-0.000
Gross Sales (50,000-99,999)	0.269	0.096	-0.220	-0.076	0.111	0.040
Gross Sales (100,000-249,999)	0.366	0.132	-0.091	-0.032	0.121	0.043
Gross Sales (250,000-499,999)	0.465*	0.168*	-0.057	-0.020	0.150	0.056
Gross Sales (500,000-999,999)	0.218	0.078	0.193	0.069	0.353	0.126
Gross Sales (1 million or more)	0.599**	0.217**	0.427	0.152	0.500*	0.178*
Off-farm income (20%-40%)	-0.015	-0.006	0.249	0.086	0.053	0.019
Off-farm income (41%-60%)	-0.281	-0.102	0.252	0.088	-0.139	-0.049
Off-farm income (61%-80%)	-0.111	-0.040	0.127	0.043	-0.189	-0.067
Off-farm income (81%-100%)	-0.564***	-0.200**	-0.027	-0.009	-0.221	-0.078
Share of owned land	0.109	-0.039	0.021	0.007	0.356*	0.125*
Education (high school)	0.380	0.134	0.032	0.011	0.785	0.264*
Education (some college)	0.238	0.083	0.165	0.057	0.630	0.209
Education (college degree)	0.419	0.148	0.016	0.006	0.791	0.266*
Education (postgraduate degree)	0.613	0.217	0.298	0.104	0.989*	0.336*
Agricultural studies	0.126	0.045	-0.049	-0.017	0.147	0.052
Precipitation	-0.079*	-0.028*	-0.155***	-0.054***	-0.444	-0.016
Constant	0.164		1.449		-1.055	
Observation number	451		451		451	
Likelihood ratio (LR) χ^2 (21)	63.09		66.32		68.40	
Prob > LR χ^2 (21)	0.000		0.000		0.000	

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

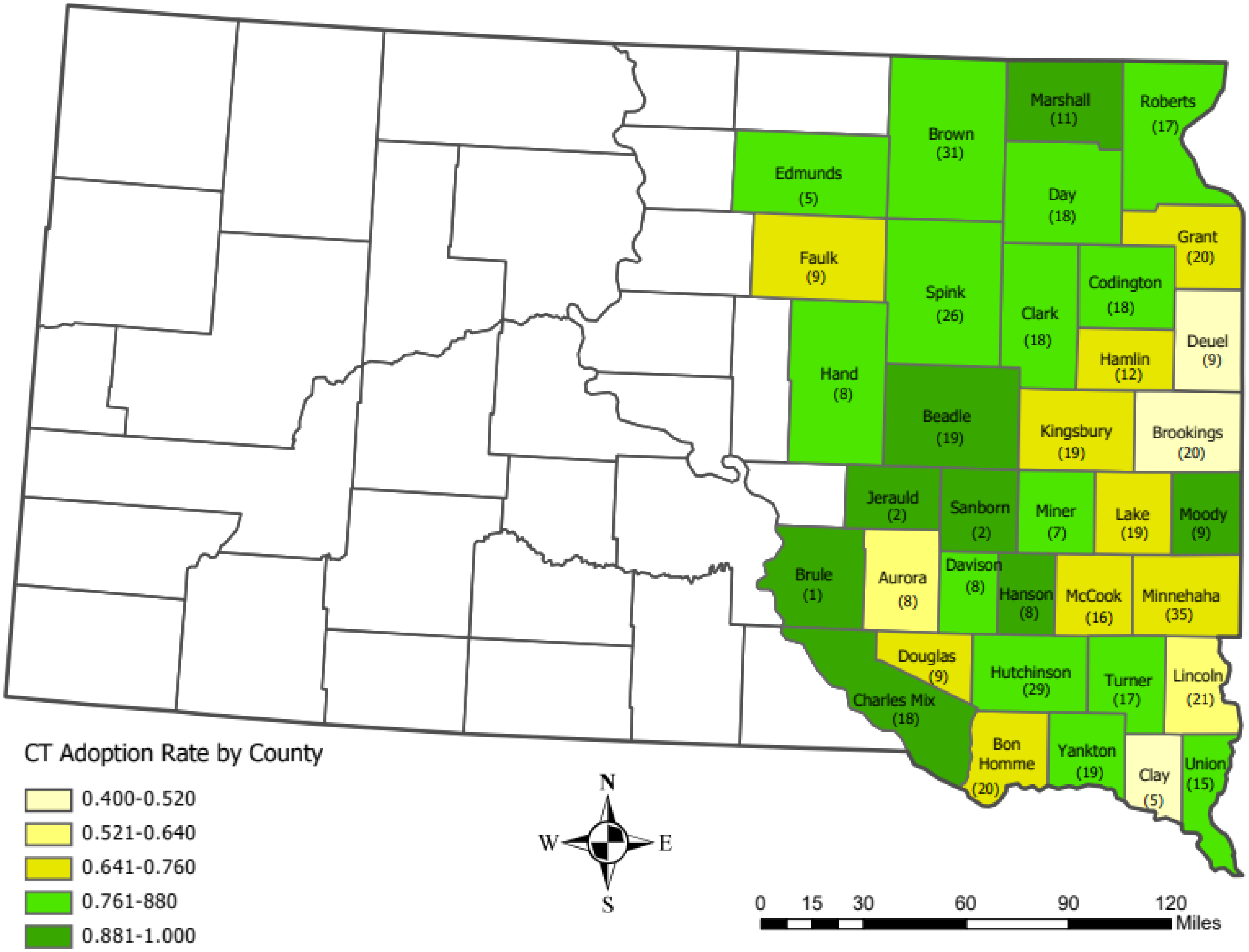

Figure 1: CT adoption rates by county with number of respondents indicated in brackets, based on 2018 South Dakota farmer survey.