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Assessing the joint adoption and complementarity between in-field conservation practices of Kansas farmers

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Abstract

Agricultural conservation systems consist of a myriad of conservation practices. The mix and intensity of conservation practices adopted can benefit farmers and affect the entire production system in addition to soil and water conservation. The purpose of this study is to examine and analyze farmer adoption of and complementarity between conservation practices from a joint and conditional probabilistic perspective using Kansas as a case study. We develop a modeling framework that can analyze and examine farmers' joint and conditional adoption decisions using a multinomial logistic regression model. This framework is used to estimate conditional probabilities of adopting conservation practices given adoption of other practices to better capture the complementarity between different conservation practices. These estimates allow for an assessment of linkages between adoption of different conservation practices and the socioeconomic factors that affect the likelihood of adopting conservation practices given other conservation practices have already been adopted on-farm. The results can help guide policy and outreach efforts to promote further intensification of adoption by farmers.

Keywords: Adoption, Complementarity, Conservation, Cover crops, Joint framework, Manure, No-tillage

Introduction

Conservation systems are able to improve both direct and indirect ecosystem services (Reicosky 2008). Direct services are improved by farmers working on agricultural lands, such as providing food and feedstock supplies. Indirect services are enhanced by using conservation systems in existing production systems, which can help to enhance life-fulfilling services (e.g., existence value and scientific discovery), stabilizing services (e.g., partial stabilization of climate and moderation of weather extremes), and preservation of options (e.g., maintenance of ecological components and systems needed for the future) (Chee 2004). Tilman et al. (2002) found that agricultural systems that do not enhance indirect ecosystem services can degrade soil quality, result in higher soil erosion rates and potentially require increased input use (e.g., fertilization, irrigation and energy) to offset declining soil productivity. In contrast, well-managed agricultural systems that

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enhance indirect ecosystem services through conservation can help to reduce soil erosion and improve soil quality, as well as improve crop yield and lower crop yield variability (Hanson et al. 2007; Reicosky 2008).

Agricultural conservation systems consist of a myriad of conservation practices, including conservation tillage, dynamic crop rotations, cover crops, use of legumes in rotation, use of manure as a part of a crop nutrient management plan, precision agriculture, integrated pest management and other conservation nutrient management practices. The applied economics literature has studied a large number of factors affecting the adoption of these conservation practices. Many studies have examined the adoption of single practices (e.g., Helms et al. 1987; Fuglie and Bosch 1995; Hamido and Kpomblekou-A 2009), while only a few others have examined the joint adoption or bundles of conservation practices (e.g., Wu and Babcock 1998; Bergtold and Molnar 2010). A limited number of studies have examined the stepwise or sequential adoption of conservation practices (e.g., Byerlee and de Polanco 1986; Khanna 2001; Leathers and Smale 1991).

Farmers can benefit from the mix and intensity of conservation practices adopted. Conservation practices affect the entire production system on-farm, and their interactions within the production system have an impact on soil and water conservation. Pierce (1985) found that conservation tillage affected the entire crop production system, including crop rotations, planting, equipment performance and so on. As a result, in order to take advantage of conservation practices, farmers must be able to make decisions taking into account the interrelated nature of conservation practices and other agricultural practices. In addition, farmers need to identify the set of local resource concerns (e.g., soil, water, air, plants and/or animals) and the corresponding set of complementary conservation practices (e.g., time, location and adoption) for a properly and well-developed conservation plan. Stinner and House (1989) emphasize that famers must use a "system approach" by collecting all the interrelated factors together when addressing conservation needs, which includes understanding the complementarity between conservation practices. Canales et al. (2020) find that taking account of complementarities between conservation practices can help to best determine the order of adoption, speed the rate of adoption of different conservation practices and help to intensify conservation efforts on-farm, providing greater environmental benefits. Moreover, social and economic factors that affect the adoption of conservation practices must be taken into account when developing conservation plans. For example, Ramsey et al. (2019) examined yield-risk perceptions of Kansas farmers on adoption and intensification of conservation practices finding mixed results; however, there was some indication that if a conservation practice can remove some yield risk, this may positively impact adoption and use. Pannell et al. (2006) reviewed a large number of socioeconomic factors that can influence adoption of conservation practices on-farm, including farm demographics, farm characteristics, cultural barriers, social networks, farmers' personalities, risk perceptions, economic well-being and land tenure, among others.

Understanding what has been mentioned above and knowing the significant role played by conservation practices and their interactions, the purpose of this study is to examine and analyze the adoption of conservation practices by farmers in Kansas from a joint perspective. More specifically this study examines farmers' joint decision to adopt

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alternative conservation practice bundles, examines the complementarity between the adoption of different conservation practices and assesses the socioeconomic and farm factors affecting adoption. The joint adoption framework is expanded to assess how complementarity between conservation practices can be assessed using cross-sectional data. The conservation practices considered here will be the use of conservation tillage, cover crops and use of manure as a fertilizer source.

The joint adoption (adopting multiple conservation practices during a specified time period) of a bundle or system of conservation practices is modeled using a multinomial logistic approach under a random utility framework. Model estimates are then used to estimate conditional probabilities of adopting conservation practices given the adoption of other practices that help to assess complementarity between conservation practices. These estimates allow for an assessment of the linkages between the adoption of different conservation practices, as well as the socioeconomic factors that affect the likelihood of adopting such conservation practices. Farmers may improve on-farm performance of conservation cropping systems through increasing the efficiency of the conservation practices adopted, as well as reducing risk and uncertainty given the useful and valuable background information from past choices.

Background
Cross-sectional methods used in the adoption literature
Many studies examine the adoption of single practices. Gould et al. (1989) used a single probit equation and two-limit tobit model to examine factors influencing producers' level of awareness of soil erosion; and found that farmers who worked off-farm had a lower probability of adopting conservation tillage because of a lack of information or commitment to the farm operation. Fuglie and Bosch (1995) employed a simultaneous equation model to study the impact of soil nitrogen testing and illustrated that farms with lower sales had a lower probability of adopting soil nitrogen tests. Uri (1997) used a two-stage decision model to estimate corn produced in the USA in 1987 using the Farm Costs and Returns Survey (FCRS) and found that cash grain enterprises chose conservation tillage more often than other types of farms. Soule et al. (2000) used a logistic adoption model with data from 941 US corn producers to study how land tenure affected conservation practice adoption and found that different types of lease arrangements influenced the adoption of conservation tillage by producers.

Others have examined the joint adoption of a set of conservation practices. Wu and Babcock (1998) applied a polychotomous-choice model to study the adoption of alternative management practices, including conservation tillage, crop rotation and soil N testing, on cropland. They found that farmers, not including small and limited-resource famers, were more likely to adopt conservation practices when they had a conservation plan. Bergtold and Molnar (2010) developed a polychotomous-choice selectivity model to examine factors affecting the adoption of conservation tillage, soil testing and crop rotations by small and limited resource farmers in the southeastern USA. They found that these farmers had adopted the selected practices on a very limited basis and that farmers adopted practices individually rather than in bundles. In addition, Bergtold and Molnar (2010) found that adoption patterns by small and limited resource farmers in the Southeast would adversely affect their eligibility for participation in the Conservation

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Security Program (CSP). The assessment of the joint adoption of conservation practices is relatively sparse in the applied literature. Other examples include: Dorfman (1996) modeled the joint adoption of different practices using a multinomial probit framework to understand the interactions between adopting different conservation practices; Cooper (2003) examined the adoption of bundles of best management practices by farmers and how incentive payments influenced their adoption; Lichtenberg (2004) studied the adoption and demand for conservation practices by farmers in Maryland and how conservation practices were packaged together; Genius et al. (2006) examined the adoption of organic farming practices in Greece; and Jara-Rojas et al. (2013) explored the adoption of soil and water conservation practices by producers in Chile.

Studies have examined the stepwise or sequential adoption of conservation practices, as well. Byerlee and de Polanco (1986) found that farmers preferred to adopt practices with the highest returns the earliest and showed that conservation system adoption is a dynamic and ongoing process. Leathers and Smale (1991) pointed out that the simultaneous adoption of bundles of conservation practices would be the most profitable long-term approach, but stepwise adoption might be a least cost option. Khanna (2001) used a bivariate probit model to analyze the sequential decision to adopt soil testing followed by variable rate technology to study the effect of adoption on nitrogen productivity.

This study builds on the literature by considering a methodological framework to expand on the methods examining the adoption of conservation practices (and technologies) using cross-sectional data. A multinomial modeling framework under a random utility approach is used to model the joint adoption of conservation practices. The framework is then used to examine the complementarity between practices using estimates of conditional probabilities of adopting conservation practices from the joint adoption model, which has not been thoroughly explored in the applied economics literature. To examine the proposed approach, we focus on the adoption of three conservation practices by crop farmers in Kansas: no-tillage, cover crops, and use of manure as a fertilizer source.

Conservation practices examined

No-tillage

No-tillage, also called zero tillage or direct drilling, is a method used to plant or grow crops or pasture from year to year without influencing the soil through tillage (USDA-NRCS 2013). No-tillage is planting crops into untilled soil by opening a proper slot in the soil with sufficient width and depth to obtain seed coverage (Derpsch and Friedrich 2009). This agricultural technique helps to reduce soil erosion by increasing water and organic matter retention, as well as cycling of nutrients in the soil. Another significant benefit of no-tillage is improvement in soil biological fertility, which makes soil more resilient (USDA-NRCS 2013). Lal (1976) found that no-tillage results in higher organic matter content and higher concentrations of nitrate-nitrogen under several crop rotations (e.g., maize–cowpeas and soybeans–soybeans), while runoff and erosion losses from use of no-tillage were minimal. Seta et al. (1993) conducted a study evaluating the effects of conventional tillage, chisel-plow tillage and no-tillage on the quality of runoff water near Lexington, KY. They found that no-tillage had the lowest mean runoff volume, mean sediment concentration and total soil losses. However, NO^-_3, NH^+_3,

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and PO^{3-}_4 in the runoff water from no-tillage were higher than the other two practices examined. Thus, net water quality impacts at a given spatial location may not be known. Tillage practices can have an impact on farm income and commodity production through cost savings and yield impacts (Bergtold et al. 2020). Over time there has been a large increase in no-tillage adoption in the USA from 38.9 million acres in 1994 to 62.4 million acres by 2004 to 104 million acres in 2017 (Horowitz et al. 2010; USDA-NASS 2017). Canales et al. (2018) found adoption of no-tillage in Kansas varied depending on crop species, but it was also more likely to be adopted by larger farms in terms of acreage and by more risk averse producers.

Cover crops

Cover crops are crops planted primarily to manage soil fertility, soil quality, water, weed pressures and biodiversity in an agroecosystem (Lu et al. 2000). Cover crops are defined as crops grown specifically for covering ground to avoid or eliminate soil erosion and loss of plant nutrients through leaching and runoff (Pieters and McKee 1938). Elwell and Stocking (1976) presented evidence showing that percent vegetative cover was the primary element determining erosion hazard from crops and grassland in Rhodesia. Everts (2002) found that hairy vetch and hairy vetch and rye cover crop mixtures increased fruit harvest numbers when compared to crop production on bare ground. In addition, cover crops may help to break disease cycles and reduce populations of bacterial and fungal diseases. Cover crops can also contribute to increasing availability of nitrogen to succeeding crops, improve soil structure and water infiltration, reduce surface soil temperature and water evaporation and increase soil productivity (Frye et al. 1988). Singer et al. (2011) employed a root zone water quality model to analyze the effect of cover crop on nitrogen (N) load in tile drainage in Iowa, and they found that a winter annual cover crop could reduce annual N loads to tile drains by approximately 20% in either 2-year or 3-year maize–soybean and maize–maize–soybean rotations. Adoption of cover crops is relatively low across the USA and returns from cover crops is heavily dependent upon management (Bergtold et al. 2019).

Use of manure

Manure is used as fertilizer on agricultural lands to contribute to the fertility of the soil by adding organic matter and nutrients that are trapped by bacteria in the soil. It also serves as a mechanism to add value to livestock waste and provides a way to help potentially restore soil fertility in nutrient deficient soils. Fronning et al. (2008) conducted a field experiment under a corn–soybean rotation with complete corn stover removal and found use of manure raised soil carbon (C) levels in the 0–5 and 0–25 cm soil profile and total soil organic C in the 0–25 cm profile by 25%. Manure was also found to significantly increase growth and yield parameters, as well as the final yields of vegetable maize (Amos et al. 2013). While manure may provide fertility and conservation benefits, nutrient management plans are needed (with proper crediting of nutrients) to make sure manure application does not lead to over application of nutrients and subsequent nutrient runoff (Keplinger and Hauck 2006). Costs of manure will vary considerably given source, nutrient quality and transport (e.g., Fleming et al. 1998; Keplinger and Hauck 2006).

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Data

The data used for this paper were obtained from a mail survey in 2011 examining Kansas agricultural crop producers' land use decisions. The survey contained 46 questions about how farmers make their land-use decision on a number of different topics, including goals of farming; conservation program participation; conservation practice adoption; irrigation use; biofuel crops; perceptions about crop prices, crop yield, and weather risk; insurance and crop marketing; and farm characteristics. Of interest for this study was a set of questions asking about conservation practice adoption for in-field practices used in crop production.

The survey targeted Kansas farmers with 50 or more acres of farmable land and over $10,000 in annual gross farm income in 2010. This sample helped to exclude hobby farmers and part-time producers. A contact list was obtained with approximately 23,000 farm contacts meeting these criteria from FarmMarketID (www.FarmMarket ID.com). For the survey sample, a random sample of 10,000 farmers was drawn from the FarmMarketID farmer contact list. The survey was sent to all respondents following the Dillman (2007) approach in late February 2011. A cover letter explaining the purpose of the survey, the research project, how survey results would be used and confidentiality was included, as well.

A total of 2317 surveys with usable data were received and 684 were returned as undeliverable or deemed non-applicable (e.g., farmer was deceased or retired), resulting in an approximate response rate of 25 percent. Due to missing data (either from questions not answered or entry of an implausible value), 2114 survey responses were usable for this analysis.

The survey data were complemented with publicly available soils and weather data at the county level. Soils data were obtained from the Soil Survey Geographic (SSURGO) database (Soil Survey Staff 2019). From this database, county averages of the kw-factor (which examines soil erosion potential); available water capacity (as a measure of potential soil water storage that is available to plants); and the standard deviation of slope (as a proxy of the variability of the terrain) were estimated by taking spatially weighted averages across soil polygons using the percent of area of arable land (based on land capability classes 1 to 6) represented by each soil polygon as the weighting factor for all 105 counties in Kansas. A potential limitation of county averages to capture land characteristics is that it will not necessarily represent a specific producer's farm or situation, but provides guidance on the impact of general trends in the landscape at the county level.

The only weather variable used was the Palmer Z Index. This index measures short-term drought on a monthly basis and is more suitable for examining drought situations for agricultural purposes than other similar drought indices (Karl 1986). Both the mean and standard deviation over a 10-year period for each county in Kansas were estimated. Weather variables were assigned to each respondent as the spatially weighted average of the associated county level averages or values using the percentage of their land operated in a given county as the weighting factor, following Caldas et al. (2014). Two regional dummy variables are included in the study to account for local differences between eastern, central and western Kansas related to crop and livestock intensity, cultural practices, infrastructure, markets and other unobserved factors. As you move from east to

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Table 1 Definition of Explanatory Variables and Summary Statistics ($n = 2114$)

	Variables	Mean	SD	Definition
Landscape attributes	KW Factor	0.30	0.10	Spatially weighted average over arable land of the K-W factor in the counties farmers operate
	Available water capacity	0.16	0.06	Spatially weighted average over arable land of available water capacity in the counties farmers operate
	Std slope	3.78	1.58	Standard deviation of slope within the counties farmers operate
Farm characteristics	Farm size	1150.41	6524.27	Total cropland acres operated in 2010
	Rental percentage	0.41	0.37	Share of farm acres rented
	Irrigation percent	0.05	0.21	Share of crop land irrigated
	Livestock	0.52	0.50	Cattle and/or hogs raised on farmers' operation in 2010 (1 = yes, 0 = no)
	EQIP and CSP	0.12	0.32	Farmer participates in Environmental Quality Incentives Program (EQIP) and/or Conservation Stewardship Program (CSP) in 2010 (1 = yes, 0 = no)
Farmer demographics and characteristics	Experience	35.85	15.04	Number of years the operator has been farming
	Risk avoider	0.40	0.49	Farmer describes themselves as a risk avoider (1 = yes, 0 = no)
	Off-farm employ	0.53	0.50	Farmers or their immediate families employed off the farm (1 = yes, 0 = no)
	Crop insurance	0.68	0.47	Farmers grow and insure their crop (1 = yes, 0 = no)
	Gender	0.95	0.23	Gender of farm operator (1 = male, 0 = female)
	College	0.34	0.47	Farm operator has earned a college degree (1 = yes, 0 = no)
Region	West	0.23	0.42	Agricultural reporting district 10, 20 or 30 (1 = west, 0 = other area)
	East	0.32	0.47	Agricultural reporting district 70, 80 or 90 (1 = east, 0 = other area)
Weather	Average PZ	0.52	0.11	Mean Palmer Z Drought over past 10 years
	Std PZ	2.04	0.13	Standard deviation of the Palmer Z Drought over past 10 years

The standard deviation of all binary variables is calculated as: $\sqrt{p(1-p)}$, where p is the mean of the binary variable.

west in Kanas crop mix changes due to lower average annual rainfall, greater livestock concentrations, higher rates of irrigation, and less densely populated areas.

Summary statistics for explanatory (independent) variables derived from the survey, as well as the soil and weather variables, are shown in Table 1. The table is broken down into five categories of variables that are considered in the joint adoption model examined: landscape attributes, farm characteristics, farmer demographics and characteristics; region; and weather. Fifty-two percent of survey respondents raised either cattle or hogs or both on their operation in 2010. Twelve percent of farmers in the survey were enrolled in the Environmental Quality Incentives Program (EQIP) and/or Conservation Stewardship Program (CSP), while less than half of survey respondents described themselves as being a risk-avoider. Fifty-three percent of survey respondents had a member of the household working off the farm, which was treated as "employment" in D'Souza's conservation practice adoption model (D'Souza et al. 1993). In general, off-farm income

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Table 2 Conservation plans (Bundles) adopted using no-tillage, cover crops and manure (*n* = 2114)

Management plan	In-field conservation practices			Percent of respondents using plan
	No-tillage (NT)	Cover crops (CC)	Manure (M)	
NT	X	–	–	52.27
CC	–	X	–	1.68
M	–	–	X	1.90
NC	X	X	–	4.19
NM	X	–	X	5.48
CM	–	X	X	0.09
NCM	X	X	X	0.99
NONE	–	–	–	33.41

can subsidize a proportion of any loss in farm income. With those "supplements," farmers may be encouraged to undertake riskier crop rotations and to adopt additional conservation practices. Thirty-four percent of farm operators in the survey had earned a college or higher degree.

Survey summary statistics were compared with those in the 2017 Agricultural Census (USDA-NASS 2017) for Kansas to examine the representativeness of the sample. Survey respondents have been farming on average 36 years, while the 2017 Agricultural Census (USDA-NASS 2017) indicates the number of years that farmers have been working on their present farm is about 25.7 years. This difference may be due to the nature of the designed questions and more limited survey sample. Table 1 shows that survey respondents do not only work on their family farm, but also on other farms and off-farm. Farms with more than 50 acres of crop land production and $10,000 in gross farm sales were surveyed, which eliminated a significant number of farms in Kansas. The 2017 Agricultural Census (USDA-NASS 2017) indicated that approximately 20 percent of primary operators of farms in Kansas are female. In contrast, only 5 percent of the survey respondents are female. This statistic has drastically increased since the timing of the survey in 2011. In 2012, this percentage was 11%. Moreover, survey respondents operate on average 1150 acres of cropland, while census figures indicate farms with over 50 acres of land operated about 980 acres (USDA-NASS 2017). Finally, 60% of farmers received income off the farm according to the 2017 Agricultural Census (USDA-NASS 2017), while 53% of farmers earn income off the farm in our 2011 survey sample. These differences from the 2017 Census are partially due to the survey being targeted to Kansas farmers with 50 or more acres of arable land and over $10,000 in annual gross farm income, as well as the time difference between survey data collection and the census comparison.

In this study, we model the joint adoption of conservation practice bundles. The conservation bundles are made up of up to three conservation practices adopted by farmers surveyed in Kansas: no-tillage, cover crops and use of manure as a fertilizer source. The use of manure was specifically described as occurring under a crop nutrient management plan where nutrients provided by the manure would be credited and taken account of. Those three conservation practices can form a total of eight conservation practice bundles that are listed in Table 2 with associated respondent adoption as a percentage. We refer to these bundles as conservation (management) plans or bundles in

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the paper. More than half of survey respondents adopted the no-tillage only plan (NT), while 33.41% of survey respondents adopted none of the conservation practice bundles listed in Table 2. These conservation practice bundles (management plans) serve as the dependent variable for the joint adoption model considered next.

Methodology

Theoretical foundations

This study develops a methodology for assessing the conditional adoption (complementarity) of alternative farm practices using a joint adoption framework. Suppose a farmer can choose from adopting r possible practices on the farm. These practices can form $M = 2^r$ conservation bundles or conservation management plans. Let $\delta_m, m = 0, 1, ..., M$, be a specific bundle, where δ_m is a $(R \times 1)$ vector of indicator variables, $Y_r, r = 1, ..., R$, equal to 1 if the rth practice is part of bundle m. Under the assumption of utility maximization, a farmer i derives utility from choosing bundle m with a given set of attributes/factors X_i that maximizes his or her utility u_{mi}. The utility for adopting bundle m can be represented as:

$$u_{mi} = U\left\{ E[R(X_i)]; Z_i; \beta_m \right\} \tag{1}$$

where $E[R(X_i)]$ is expected profit from adopting the given bundle of conservation practices, X_i is a vector of individual specific explanatory variables affecting the profitability of bundle m, Z_i is a vector of other variables that impact the utility for bundle m, and β_m is a vector of parameters specific to the utility received for adoption of bundle m. Farmers' decisions on adoption of conservation practices are often influenced and motivated by other factors rather than profit related factors under a utility framework (Skaggs et al. 1994). Thus, it is necessary to distinguish and separate those profit related variables, X_i, and nonprofit but utility related variables, Z_i, including farming experience, education and employment (Ervin and Ervin 1982; D'Souza et al. 1993), age and other demographics (Skaggs et al. 1994). A farmer will adopt bundle m if:

$$u_{mi} = max(u_{1i}, \ldots, u_{mi}, \ldots, u_{Mi}). \tag{2}$$

Empirical model

A researcher only observes the choice of plan or practice bundle adopted. Thus, the theoretical model represented by Eqs. (1) and (2) can be viewed in a random utility framework:

$$u_{mi} = V_m\left\{ E[R(X_i)]; Z_i; \beta_m \right\} + \varepsilon_{mi}$$

where V_m is the deterministic component of utility and ε_{mi} is the random or unobserved component of utility (Louviere et al. 2000).

Following the methods in Bergtold and Molnar (2010) and Wu and Babcock (1998), a polychotomous-choice selectivity model of joint adoption is employed. If the residuals, $\varepsilon_{mi}, m = 0, 1, ..., M$ are independently distributed with extreme value distribution (type 1), then the probability of a farmer choosing bundle m, δ_m, can be written as:

$$\pi_m = \Pr(I = m) = \frac{\exp(V_m[E(R(X_i)); Z_i; \beta_m)}{\sum_{s=0}^{M} \exp(V_s[E(R(X_i)); Z_i; \beta_s])}, \tag{3}$$

where I is a polychotomous index equal to m if bundle m is chosen. The adoption of a particular bundle of conservation practices is conditional on a number of explanatory factors, including experience, farm sales, land tenure, participation in conservation programs, farmer perceptions, use of insurance and a number of demographic variables.

For those farm characteristics, it is expected that farm size and rental percentage could have a positive effect on conservation practices. With larger farm size and more rented land, it is likely farmers will adopt conservation practices which provide net positive returns in the short term, but avoid or delay adopting conservation practices that are likely to only provide net positive returns over a longer time horizon. Farmers participating in EQIP and/or CSP can obtain financial incentives to adopt, as well as obtain more information and gain additional experience, increasing the probability of adopting conservation practices. Compared with risk-averse farmers, risk-neutral or risk-loving farmers may choose higher return crops or conservation practices regardless of time and regional constraints.

For farmer demographics and characteristics, we expect farmer experience, off-farm employment, crop insurance and farmers' education level could increase the likelihood of adopting conservation practices. The weather, region and landscape attributes will likely affect adopting conservation practices differently across the various management plans.

With the limited number of observations for conservation management plan bundles CM and NCM listed in Table 2, it is assumed that $P(I = CM) = 0$, and $P(I = NCM) = 0$ (i.e., the probability of adopting these bundles is equal to zero), such that they will have no direct effect on the estimation of the model. Given the limited number of observations, the effects of the explanatory variables on the adoption of these management plans cannot be reliably identified. To not bias results, the observations with these associated conservation management plans are removed from the dataset, leaving 2091 observations for estimation of the model. While there are limited observations for other management plans, there does exist at least a 2:1 ratio of observations to parameters for each of the remaining conservation management plans (bundles) in the empirical model, providing enough degrees of freedom for estimation.

Marginal effects and measures of practice complementarity

Following Eq. (3) a multinomial logistic model is used to estimate the joint adoption of bundles of conservation practices or management plans. The model estimates the probability of adopting a bundle given a set of explanatory factors, but allows one to estimate the marginal probability of adopting a single practice and conditional probability of adopting a practice given other practice adoption. Marginal effects can be derived for all of these types of probabilities.

It is difficult to interpret the meaning of coefficients in the multinomial logistic model. The marginal effects of explanatory variables on the probability of adopting a

bundle of practices provide a measure to assess the impact of specific explanatory factors. The marginal effects provide both a sign and magnitude for the marginal change in an explanatory variable on the probability of adoption. The marginal effect for a given explanatory variable,x_k, is given by (Greene 2012):

$$\frac{\partial \pi_m}{\partial x_k} = \pi_m \left[\beta_{m,k} - \sum_{s=0}^{M} \pi_s \beta_{s,k} \right] \tag{4}$$

It should be noted that the sign of the marginal effect may not follow the sign of $\beta_{m,k}$ for $m = 0, 1,..., M$.

Wu and Babcock (1998) emphasize that the unconditional marginal probability of adopting a practice or single element of a conservation bundle sequence may be of interest. The marginal probability of adopting a single practice can be derived from the joint modeling framework as:

$$P_s = \sum_{m \varepsilon \{\delta_m : Y_s = 1\}} \pi_m \tag{5}$$

where s is the index for the single practice of interest and Y_S is an indicator variable equal to 1 when practice s is included in bundle m. The associated marginal effects for the marginal probabilities can be expressed as (Wu and Babcock 1998):

$$\frac{\partial P_s}{\partial x_k} = \sum_{m \varepsilon \{\delta_m : Y_s = 1\}} \frac{\partial \pi_m}{\partial x_k} \tag{6}$$

Joint probabilities of adopting two or more practices can be derived, as well. For example, the probability that a farmer jointly adopts two conservation practices is:

$$P_{rs} = \sum_{m \varepsilon \{\delta_m : Y_r = 1, Y_s = 1\}} \pi_m, \tag{7}$$

which can be useful when examining complementarity between conservation practices. The associated marginal effect for the bivariate probability given by Eq. (7) is:

$$\frac{\partial P_{rs}}{\partial X_k} = \sum_{m \varepsilon \{\delta_m : Y_r = 1, Y_s = 1\}} \frac{\partial \pi_m}{\partial X_k} \tag{8}$$

The joint adoption or multinomial model estimated allows for the estimation of conditional probabilities, which can be interpreted here as a measure of complementarity between two practices. For example, one could estimate the adoption of cover crops, given the no-tillage adoption decision. Given the cross-sectional nature of the data though, it should be cautioned that the conditional probabilities should not be interpreted as sequential adoption. The use as a measure of complementarity may assist in examining what factors affect farmers' choices to intensify conservation efforts on-farm in order to help develop outreach strategies and incentive mechanisms. Using this framework, the adoption of practice s given practice r can be represented as:

$$P_{s|r} = \frac{P_{sr}}{P_r} \tag{9}$$

where the marginal and bivariate probabilities are given by Eq. (5) and (7). Equation (9) may be interpreted as a measure of complementarity that ranges from 0 to 1. The larger the value of the conditional probability given by Eq. (9) the more likely two conservation practices will be adopted together over time, which may be simultaneous or sequential. Of additional interest is the estimation of marginal effects of the explanatory variables for the conditional probabilities assessed. These marginal effects allow for the examination of how different agronomic, economic, ecological and social factors may impact the complementarity between two given practices. These can be obtained by differentiating the conditional probability with respect to an explanatory variable of interest (k):

$$\frac{\partial P_{s|r}}{\partial X_k} = \frac{\frac{\partial P_{sr}}{\partial X_k} * P_r - P_{sr} * \frac{\partial P_r}{\partial X_k}}{P_r^2} \tag{10}$$

where the associated marginal effects for the marginal and bivariate probabilities are given by Eqs. (6) and (8). It should be emphasized that all the marginal effects estimated can be done using the joint probabilities and marginal effects estimated using the joint multinomial logistic model given by Eqs. (3) and (4). That is, the joint framework inherently captures the complementarities (dependencies) between adopting different practices.

To test for the significance of marginal effects, asymptotic estimates of the standard errors are required. Given the complexity of some of the equations of the marginal effects above, the method of Krinsky and Robb (1986) is utilized to estimate the asymptotic standard errors for the calculation of asymptotic z-statistics (see Greene 2012, as well). All marginal effects were calculated as partial averages following Greene (2012).

Result and discussion

For this study, the empirical joint multinomial model is estimated using NLOGIT 4.0. MATLAB is then used to estimate marginal effects and associated asymptotic standard errors. Parameter estimates for the model are provided in the "Appendix." The McFadden Pseudo R-square for the regression model is equal to 0.0823. We tested to assess if the independence of irrelevant alternatives (IIA) assumption is violated using the Hausman and Small and Hsiao tests (Freese and Long 2001; Hausman and McFadden 1984; Small and Hsiao 1985). Test results indicate no departures from the IIA assumption. Marginal effects and associated asymptotic statistics from the multinomial model for the adoption of different conservation bundles are estimated and presented in Table 3.[1] It should be emphasized that the base category in the model is NONE (or no conservation practices adopted) and the empirical model does not include the plans (bundles) of

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[1] While parameter estimates for the "None" bundle or conservation plan (M), where no conservation practices are adopted, has no estimated parameters (i.e., a required normalization of the model for estimation), the probability of adopting this bundle is equal to $\left[1 + \sum_{s=1}^{M-1} \exp(V_s\left[E(R(\boldsymbol{X_i})); \boldsymbol{Z}_i; \boldsymbol{\beta}_s\right]\right]$, so marginal effects for this conservation bundle are estimable.

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Table 3 Marginal effects for the adoption of different conservation practices/bundles

Variables	None	No-tillage only	Cover crops only	Use of manure only	No-tillage and cover crops	No-tillage and use of manure
KW factor	0.895** (0.397)	− 1.328*** (3.09)	0.314** (0.139)	− 0.107 (0.132)	− 0.039 (0.192)	0.266 (0.205)
Available water content	− 1.749** (0.721)	2.652*** (0.781)	− 0.707** (0.271)	0.137 (0.235)	0.169 (0.348)	− 0.502 (0.371)
Std slope	0.0046 (0.0069)	0.0021 (0.0075)	0.0032* (0.0018)	− 0.0053* (0.0026)	− 0.0032 (0.0034)	− 0.0014 (0.0036)
Farm size	− 0.00009*** (0.00001)	0.00008*** (0.00001)	0.00000 0.00000	− 0.00001 (0.00000)	0.00000 (0.00000)	0.00001*** (0.00000)
Rental percentage	− 0.108*** (0.028)	0.096*** (0.030)	− 0.022** (0.0095)	− 0.012 (0.0090)	0.026* (0.013)	0.021 (0.014)
Irrigation percent	− 0.010 (0.068)	0.118 (0.076)	− 0.091 (0.064)	0.011 (0.017)	− 0.065 (0.049)	0.037 (0.031)
EQIP and CSP	− 0.110*** (0.030)	0.049 (0.034)	0.013 (0.014)	− 0.012* (0.0072)	0.038** (0.018)	0.023 (0.017)
Experience	0.0016** (0.0007)	− 0.00061 (0.00077)	− 0.00014 (0.00018)	− 0.00006 (0.00023)	− 0.00001 (0.00033)	− 0.00079** (0.00038)
Risk avoider	0.012 (0.020)	0.012 (0.021)	− 0.0045 (0.0054)	0.0084 (0.0065)	− 0.018** (0.0088)	− 0.0096 (0.010)
Off-farm employ	− 0.050** (0.021)	0.055** (0.023)	− 0.0097* (0.0058)	− 0.0032 (0.0066)	0.0098 (0.0095)	− 0.0021 (0.011)
Crop insurance	− 0.013 (0.022)	0.046* (0.023)	− 0.0099 (0.0069)	− 0.0029 (0.0065)	− 0.0047 (0.010)	− 0.015 (0.012)
Gender	− 0.078* (0.049)	0.170*** (0.050)	− 0.015 (0.017)	0.0099 (0.011)	− 0.041 (0.030)	− 0.046 (0.033)
College	− 0.063** 0.021	0.050** (0.023)	− 0.010* (0.0053)	0.014* (0.0073)	0.0013 (0.0096)	0.0084 (0.011)
Livestock	0.019 (0.020)	− 0.080*** (0.022)	− 0.0064 (0.0056)	0.032*** (0.0065)	− 0.0013 (0.0094)	0.037*** (0.010)
West	− 0.015 (0.029)	− 0.0072 (0.032)	− 0.0072 (0.0069)	0.0016 (0.0094)	− 0.012 (0.012)	0.040** (0.020)
East	− 0.053** (0.024)	0.066** (0.027)	− 0.027*** (0.0082)	− 0.0018 (0.0077)	− 0.020** (0.010)	0.035** (0.016)
Average PZ	0.137 (0.111)	− 0.173 (0.119)	− 0.083** (0.035)	0.051 (0.041)	0.040 (0.057)	0.028 (0.052)
Std PZ	− 0.094 (0.104)	0.222* (0.112)	0.038 (0.033)	− 0.040 (0.032)	− 0.061 (0.052)	− 0.065 (0.055)
Model fit statistics						
Log likelihood						− 2180.80
McFadden pseudo R^2						0.084
Number of observations						2091

Standard errors are presented in parentheses

***, **, * indicate statistical significance at 1%, 5% and 10% level, respectively. Marginal effects are estimated as partial average effects following Greene (2012)

CM and NCM, given a lack of observations (i.e., degrees of freedom) needed to estimate parameters for these bundles, as previously discussed. The corresponding observations for these two bundles were dropped.

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Table 4 Estimated marginal effects for the unconditional and conditional adoption of no-tillage, cover crops and manure

Variables	Unconditional practice adoption			Conditional adoption	
	No-tillage	Cover crops	Use of manure	Cover crops given no-tillage adopted	Use of manure given no-tillage adopted
KW factor	− 1.246*** (0.446)	0.427 (0.305)	0.067 (0.263)	0.048 (0.274)	0.515* (0.313)
Available water content	2.635*** (0.815)	− 0.900 (0.587)	− 0.202 (0.474)	0.014 (0.496)	− 1.002* (0.569)
Std slope	− 0.0028 (0.0076)	0.0024 (0.0044)	− 0.0080* (0.0049)	− 0.0040 (0.0052)	− 0.0019 (0.0053)
Farm size	0.00010*** (0.000014)	− 0.0000019 (0.0000080)	0.0000013 (0.0000065)	− 0.0000035 (0.0000053)	0.00000029 (0.0000011)
Rental percentage	0.157*** (0.034)	− 0.012 (0.024)	0.0060 (0.019)	0.021 (0.016)	0.013 (0.020)
Irrigation percentage	0.118 (0.094)	− 0.184 (0.123)	0.048 (0.037)	− 0.093 (0.071)	0.041 (0.045)
EQIP and CSP	0.124*** (0.038)	0.041** (0.019)	0.00062 (0.023)	0.030* (0.017)	0.017 (0.019)
Experience	− 0.0014* (0.00076)	− 0.00023 (0.00043)	− 0.00077* (0.00048)	0.00011 (0.00046)	− 0.00096* (0.00058)
Risk avoider	− 0.015 (0.022)	− 0.022* (0.013)	0.0015 (0.013)	− 0.024* (0.014)	− 0.012 (0.016)
Off_Farm employ	0.068*** (0.023)	− 0.0065 (0.014)	− 0.0044 (0.013)	0.0074 (0.014)	− 0.011 (0.015)
Crop insurance	0.030 (0.023)	− 0.017 (0.013)	− 0.015 (0.013)	− 0.0085 (0.014)	− 0.024 (0.016)
Gender	0.102** (0.052)	− 0.043* (0.023)	− 0.017 (0.033)	− 0.051** (0.026)	− 0.067** (0.031)
College	0.068*** (0.024)	− 0.016 (0.015)	0.024* (0.013)	− 0.0034 (0.013)	0.0048 (0.015)
Livestock	− 0.055** (0.024)	− 0.012 (0.013)	0.081*** (0.019)	0.0022 (0.013)	0.061*** (0.018)
West	0.021 (0.033)	− 0.021 (0.018)	0.032* (0.019)	− 0.019 (0.020)	0.047** (0.022)
East	0.098*** (0.029)	− 0.064*** (0.022)	0.028* (0.017)	− 0.036** (0.018)	0.036* (0.020)
Average PZ	− 0.100 (0.123)	− 0.094 (0.079)	0.089 (0.074)	0.062 (0.080)	0.055 (0.076)
Std PZ	0.102 (0.116)	0.011 (0.073)	− 0.106 (0.067)	− 0.088 (0.073)	− 0.108 (0.082)

Standard errors are presented in parentheses

***,**,* indicates statistical significance at 1%, 5% and 10% level, respectively. Marginal effects are estimated as partial average effects following Greene (2012). The number of observations was 2091

In this section of the paper, we first examine the bundles of practices and what factors influence producers to adopt bundles with multiple conservation practices versus one or no practices. The remaining sections further examine the complementarities between practices using the estimated bivariate and conditional probabilities of conservation practice adoption discussed above. Estimated marginal effects of the explanatory variables for the different estimates of the probabilities of adopting

conservation plans and practices along with the associated asymptotic standard errors are provided in Table 4.

Conservation practice bundle (management plan) adoption

Examining the marginal effects in Table 3 of different explanatory factors on the adoption of conservation practice bundles shows how different factors impact the adoption of different bundles of conservation practices by producers. As shown in Table 2, approximately 89% of producers adopted only one conservation practice or none. Fifty-three percent only adopted no-tillage, while 33% adopted no conservation practices. Examining the factors impacting adoption of no conservation practices in Table 3, higher erosion potential on their land and more farm experience increased the marginal likelihood of adopting no conservation practices. It could be that marginal lands with high erosion potential are more likely to be retired (e.g., put in the Conservation Reserve Program or similar program) by a farmer or landowner rather than remain in production (Konyar and Osborn 1990). Experience may be directly related to the age of the farmer, indicating that older farmers or those with much more experience are less likely to adopt conservation practices (Pannell et al. 2006). Significant factors, both statistically and substantively, influencing producers to adopt one or more conservation practices and not the "None" bundle included farm size, participating in EQIP or CSP, being employed off farm, and having a college degree. As farm size increases, the likelihood of adopting conservation practices may increase due to the ability of the farmer to spread out equipment costs over a larger area of land and absorb any potential yield impacts due to spatial variability in practice performance across the farm landscape. Pannell and Classen (2020) review the agricultural adoption literature related to agricultural policy and examine the additionality of conservation programs, finding that conservation programs do play a significant role in promoting conservation practice adoption, especially for practices such as cover crops. The possibility of taking advantage of a conservation program's benefits has the ability of reducing the costs of adoption, increasing the adoption of some bundles of conservation practices. In addition, farm size, having a college education and off farm employment, all increase the likelihood of adopting some type of conservation on-farm (Dorfman 1996).

A number of practices promoted the adoption of only a single practice, with no-tillage only being the most commonly adopted conservation bundle with one practice. Cover crops and use of manure were adopted as the only conservation practice by less than 2 percent of producers. Factors of interest that significantly influenced the adoption of only a single conservation practice included off-farm employment and use of crop insurance, as well as soil and weather conditions. Off-farm employment increased the probability of only adopting no-tillage by 5.0%. Off-farm employment can subsidize a proportion of the potential loss in farm income to encourage Kansas farmers to adopt no-tillage (Pannell et al. 2006). In addition, adoption of no-tillage may reduce labor requirements, freeing up time for additional off-farm employment.

However, for some conservation practices, like cover crops, adoption may increase time requirements the producer may not have if working off-farm (Bergtold et al. 2019). The impact on crop yields of conservation practice adoption will vary and be place specific. The availability of crop insurance that may protect against potential yield effects from adoption may improve the likelihood of adoption if practices are approved by the institution providing the insurance, which has been a contentious issue for cover crop adoption (Canales et al. 2018; Bergtold et al. 2019). In addition, land tenure plays a role on the adoption of conservation practices (Pannell et al. 2006). Adoption of conservation practices that may only provide benefits over the longer term, which can include cover crops, may be less likely to be adopted by producers (Soule et al. 2000). A higher percentage of rented acreage increased adoption of no-tillage only, while reducing adoption of cover crops only. Benefits from no-tillage, especially cost savings, are likely to be realized in the short term, while for cover crops, costs are incurred in the short term, with benefits potentially being experienced in the longer term (Bergtold et al. 2019).

Local soil and weather factors will influence adoption. Increased risk of soil erosion reduced the marginal likelihood of adopting only no-tillage, while it marginally increased the likelihood of adoption of cover crops only. Furthermore, greater available water capacity in the soil increased the adoption of no-tillage only, while reducing the adoption of cover crops only. Adopting cover crops only is likely to occur with greater probability on higher sloped lands, while use of manure only is less likely to occur. Areas prone to drought are less likely to plant cover crops only, while being more likely to adopt no-tillage only. Each of these conservation practices has its own benefits and challenges that are context specific (Bergtold et al. 2019; Canales et al. 2018; Pannell et al. 2006). As seen, some factors had the opposite effects on given conservation practice bundles with only one practice, suggesting that producers who only adopted a single practice may have perceived that combining this with one of the other two practices being considered would have been too costly or have a potentially negative impact on their operation.

The factors impacting the adoption of one or more conservation practices begin to provide some insight into the factors that shape farmers' adoption decision about adopting multiple conservation practices. It should be emphasized that less than 11 percent of the farmers surveyed adopted more than one of the conservation practices examined. A number of statistically significant factors positively impacted the marginal probability of adopting more than one conservation practice. Participation in the EQIP or CSP increased the likelihood of adopting no-tillage and cover crops by 3.8%, which has been evidenced in the literature (e.g., Bergtold and Molnar 2010). As previously mentioned, the potential different impacts of these practices and significant challenges to adopting cover crops make incentive-based voluntary conservation programs a significant factor in promoting adoption of conservation practices, especially more than one (Bergtold and Molnar 2010; Pannell and Claassen 2020). The presence of livestock on-farm or being close to a feedlot or large livestock operation (e.g., in western Kansas) increased the likelihood of adopting the no-tillage and manure conservation practice bundle by

3.7 and 4.0 percent, respectively. Fuglie and Bosch (1995) mention that raising livestock could provide an incentive for producers to seek guidance on managing manure application for both farming land and pastures. In contrast, more farmer experience reduced the likelihood of jointly adopting no-tillage and manure (NM) and being a risk-avoider reduced the likelihood of adopting no-tillage and cover crops (NC).

Conditional adoption of conservation practices and complementarity

In this study, we proposed using the joint adoption framework to look at the conditional probabilities to provide a measure of complementarity between adopting conservation practices using cross-sectional data. This knowledge may be helpful in determining how to incentivize or promote adoption of additional conservation practices. In addition, the approach allows for a greater ability to utilize the information present in cross-sectional data in adoption studies. The conditional probabilities examined here were chosen based on the adoption patterns found in the survey. For example, it would be less likely that cover crops would be adopted as a conservation practice without adoption of no-tillage. In addition, it may make more management sense to adopt no-tillage prior to the adoption of cover crops, given cover crops increase the amount of residue on the soil surface and can significantly increase management intensity (Canales et al. 2020). Thus, we examine two conditional probabilities here: (i) adoption of cover crops conditional on no-tillage adoption and (ii) adoption of manure use as a fertilizer source conditional on no-tillage adoption. From this study, the estimated mean conditional probability of adopting cover crops given no-tillage has been adopted is 5.7%, while the mean conditional probability of adopting the use of manure as a fertilizer given no-tillage has been adopted is 8.2%. The positive probabilities indicate a small but positive complementarity between cover crops and manure with no-tillage.

The estimated marginal effects of the conditional probabilities given the explanatory variables in the study are provided in Table 4. Based on marginal effect estimates, conservation program participation positively impacts the complementarity between cover crops and no-tillage adoption. That is, participation in EQIP and/or CSP enhances the chances of adopting cover crops, given no-tillage adoption behavior. This result is not unexpected as past literature has shown the additionality of incentive-based conservation programs on cover crop adoption (Pannell and Claassen 2020). In addition, farmers may see the practices as more complementary or in a systems framework context from active participation in conservation programs and exposure to technical assistance provided by the programs. Statistically significant factors that reduce complementarity between these practices (or the likelihood that they will both be adopted) include risk aversion and geography (e.g., being located in eastern Kansas). Farmers who are risk averse are less likely to intensify conservation efforts and conservation practice effectiveness and suitability, especially cover crops, will vary by location (Bergtold et al. 2019).

Different factors impacted the complementarity between use of manure and no-tillage. Significant factors that increase complementarity include soil erosion, raising or presence of livestock on or near the farm, and geography. As discussed earlier, experience

with livestock on-farm, may provide the needed experience and knowledge for handling of manure for application to cropland and pastures. In addition, being in proximity to larger concentrations of livestock improves the likelihood of adoption of manure usage on-farm (Serebrennikov et al. 2020). The significant and positive marginal effect of the soil erosion factor and the significant, but negative effect of the marginal effect of available water capacity of the soil may be related to the potential effects of manure application on improving soil health, while at the same time representing a potential source of nonpoint source pollution (Peng et al. 2016; Rees et al. 2011). Factors that reduced the complementarity between use of manure and no-tillage adoption included greater farm experience and being a risk avoider. As discussed earlier, greater experience is likely highly correlated with farmer age and risk averse farmers are less likely to intensify conservation efforts on-farm.

The estimates provided here may be useful for policymakers interested in encouraging farmers who have already adopted certain practices, by promoting the complementarities between these practices, enhancing overall environmental benefits of conservation programs. For example, an integrated crop and livestock farm operation that has already adopted no-tillage may consider adopting use of manure on their crop fields if provided the right information and they are educated about the potential conservation benefits of manure application to their crop fields. In addition, no-tillage farmers in proximity to livestock operations could be targeted for a concerted effort to promote crop nutrient management and manure practice adoption.

Unconditional adoption of no-tillage, cover crops and manure application
While much of the article is focused on conservation practice complementarity, understanding the unconditional adoption of single conservation practices is still important. Such analyses are still useful and needed as adoption is often piecemeal or done sequentially over time (Bergtold and Molnar 2010; Khanna 2001). In this section, we briefly examine the unconditional adoption of the three conservation practices examined in the study. The unconditional probability of adopting a practice is approximately 59% for no-tillage (NT); 8.1% for cover crops (CC); and 9.2% for use of manure (M), respectively. These probability results are quite different from what was presented in Table 2, which eliminates the internal and external influences among those conservation plans and practices. Marginal effects of explanatory factors for the probability of adopting the selected conservation practices are reported in Table 4.

For the unconditional adoption of no-tillage, increased available water capacity, farm size, farm experience, amount of land rented, off-farm employment, gender, college education, and residing in eastern KS (relative to central Kansas) increased the likelihood of adopting no-tillage. Erosion potential, farmer experience and raising livestock on-farm decreased the likelihood of adopting this practice. Many of the signs follow those for the management bundle of no-tillage only in Table 3. Results suggest again that education and conservation programs can be effective tools at promoting adoption (Pannell et al. 2006). Those promoting adoption of no-tillage practices needs to understand

that adoption and use of no-tillage and other conservation tillage will vary by geography, cropping system, farm enterprise mix and farmer situation, as evidenced by the myriad of factors marginally impacting adoption (Canales et al. 2018).

The factors influencing the unconditional adoption of cover crops are very similar to those in Table 3 for the conservation bundle with cover crops only. As previously seen, participation in an incentive-based conservation program, such as EQIP or CSP, increases adoption marginally by 4.1%, while risk averse farmers are less likely to adopt by 2.2%. In addition, given that cover crop suitability is geographically dependent, farmers in eastern KS are less likely to adopt cover crops relative to farmers in the central part of the state.

The unconditional adoption of the use of manure as a fertilizer source is impacted by a number of explanatory factors. Having a college education, raising livestock and residing in eastern or western KS increased the likelihood of adopting this conservation practice. The reasoning for the significance of these factors follows prior discussion. The only factor that negatively impacted adoption of manure use was farmer experience. Many of the factors examined and found significant here are supported in the literature (Pannell et al. 2006; Pannell and Claasen 2020; Bergtold et al. 2019).

Policy and adoption implications

Results show the conservation practices examined in this study (no-tillage, cover crops, and use of manure) are definitely complementary to each other. Canales et al. (2020) indicate that by taking advantage of the complementarities between practices, farmers will likely adopt conservation practices over time at a quicker rate. For farmers who had already adopted no-tillage, Canales et al. (2020) found that the time to adoption of cover crops was reduced by up to 70 percent, enhancing the environmental impacts of the adoption of this practice over time. A number of factors influence adoption of multiple conservation practices, including conservation program participation and geography. Getting farmers to participate in incentive-based conservation programs, such as the EQIP and CSP, enhances the likelihood of adopting multiple conservation practices (likely over time). It is important that policymakers take account of practice complementarities to further enhance the additionality of programs, helping to intensify conservation adoption and environmental stewardship across the landscape (Pannell and Classen 2020). Estimates for additionality from studies of incentive programs for cover crops are as high as 98 percent (Fleming et al. 2018). Policymakers and agencies, such as the US Department of Agriculture, may be able to take advantage of practice complementarities by designing programs that build on sequential adoption of practices that have complementarities to have greater environmental impacts and participation. Another factor to consider is that policymaking, extension and outreach efforts that take advantage of practice complementarities to promote conservation adoption need to take into account geography and the context in which adoption is taking place. For example, extension and outreach professionals could target outreach and programmatic efforts for the adoption

and application of manure use and technologies toward integrated livestock-producers and areas with higher concentrations of livestock production (e.g., feedlots).

Conclusion

Conservation practices significantly affect the whole production system on-farm, as well as soil and water conservation. In order to provide more useful guidance and assistance, extension professionals, producers and policymakers should recognize and take advantage of the complementarities in adoption between conservation practices. Such complementarities can be utilized to better enhance the additionality of conservation programs, enhance environmental stewardship across agricultural landscapes and improve economic and environmental conditions at the farm level. The purpose of this study was to examine conservation practice adoption by Kansas farmers from a joint perspective, analyze the adoption of conservation practices, examine how socio-economic and farm factors affect adoption of multiple conservation practices and examine the complementarities between adoption of different conservation practices. Using a cross-sectional dataset, we model the joint adoption of conservation practices using a multinomial modeling framework and then utilize this framework to estimate conditional probabilities of adopting conservation practices as a methodology to explore complementarities between conservation practices. We find that a myriad of factors impact adoption of individual and bundles of conservation practices. There exists heterogeneity across what factors impact adoption of different conservation practices and bundles on farms across the landscape. Soil characteristics and geography can significantly influence adoption, as well as farm characteristics, such as farm size and integration of livestock, and conservation program enrollment. In addition, we find small but positive complementarities between conservation practices that could influence sequential adoption of these practices, as well as factors that can influence the complementary relationships.

The research conducted was limited by the use of cross-sectional data. It provided a deep analysis for one point in time; however, future research in this area ideally should include a panel dataset that covers multiple years. The current methods are unable to unpack the potential sequential nature and temporal dynamics of the adoption process over time. The use of conservation practices typically will require up to several years for producers to assess, trial, overcome challenges and successfully integrate the practice into their current cropping system. While the framework provided here provides a way to better exploit cross-sectional adoption studies, more dynamic longitudinal approaches are needed to fully understand the complexities and intricacies of the adoption process itself, including the complementarities between conservation practices in a conservation cropping system.

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Appendix

See Table 5.

Table 5 Parameter estimates for the multinomial logistic model of conservation practices

Variables	No-tillage only	Cover crops only	Use of manure only	No-tillage and cover crops	No-tillage and use of manure
Constant	− 2.003** (0.971)	− 2.503 (4.073)	− 1.247 (3.001)	− 0.273 (2.352)	− 0.504 (2.014)
KW factor	− 5.850*** (2.087)	17.827** (8.826)	− 8.417 (7.090)	− 4.282 (4.887)	1.406 (4.210)
Available water content	11.634*** (3.801)	− 40.898** (16.91)	12.720 (12.704)	10.621 (8.888)	− 2.349 (7.639)
Std slope	− 0.013 (0.036)	0.198* (0.116)	− 0.291** (0.137)	− 0.091 (0.090)	− 0.044 (0.073)
Farm size	0.00047*** (0.000069)	− 0.0000083 (0.00029)	− 0.000043 (0.00025)	0.00041*** (0.00011)	0.00047*** (0.000070)
Rental percentage	0.590*** (0.149)	− 1.131* (0.609)	− 0.282 (0.486)	1.006*** (0.329)	0.803*** (0.294)
Irrigation percentage	0.309 (0.324)	− 5.898 (4.162)	0.665 (0.922)	− 1.402 (1.194)	0.761 (0.637)
EQIP and CSP	0.533*** (0.185)	1.018* (0.586)	− 0.466 (0.752)	1.123*** (0.313)	0.805*** (0.293)
Experience	− 0.0068* (0.0037)	− 0.014 (0.012)	− 0.0083 (0.012)	− 0.0060 (0.0084)	− 0.020*** (0.0077)
Risk avoider	− 0.021 (0.104)	− 0.331 (0.377)	0.380 (0.330)	− 0.487** (0.246)	− 0.221 (0.216)
Off−farm employ	0.286*** (0.109)	− 0.498 (0.399)	− 0.0016 (0.348)	0.413* (0.248)	0.146 (0.216)
Crop insurance	0.140 (0.113)	− 0.545 (0.388)	− 0.105 (0.340)	− 0.053 (0.251)	− 0.209 (0.222)
Gender	0.629** (0.248)	− 0.527 (0.665)	0.882 (1.040)	− 0.434 (0.447)	− 0.367 (0.423)
College	0.324*** 0.114	− 0.579 (0.460)	0.853** (0.338)	0.266 (0.244)	0.387* (0.217)
Livestock	− 0.224** (0.107)	− 0.472 (0.377)	2.039*** (0.497)	− 0.105 (0.241)	0.628*** (0.228)
West	0.042 (0.156)	− 0.468 (0.534)	0.145 (0.487)	− 0.254 (0.351)	0.668** (0.302)
East	0.339** (0.133)	− 1.960*** (0.663)	0.109 (0.435)	− 0.294 (0.306)	0.797*** (0.272)
Average PZ	− 0.778 (0.579)	− 5.824*** (2.186)	2.257 (2.191)	0.471 (1.439)	0.074 (1.076)
Std PZ	0.737 (0.543)	2.744 (2.170)	− 1.807 (1.685)	− 1.080 (1.304)	− 0.886 (1.126)
Fit statistics					
Log likelihood					− 2180.80
McFadded pseudo R^2					0.084
Number of observations					2091

Standard errors are presented in parentheses

***,**,* indicate statistical significant at 1%, 5% and 10% level, respectively

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