Adoption of Cover Crops in Soybean Production

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Abstract

Using cover crops is beneficial not only for soil health but also for the environment, but many farmers have not adopted cover crops. We used a probit model with data on 1708 soybean producers from the 2012 USDA Agricultural Resource Management Survey to identify factors affecting adoption of cover crops. We found that perceptions of yield benefits were positively correlated with adoption, while concern about weeds was negatively correlated. Adoption varied by region. Educational efforts should focus on farmers' perceptions and concerns about using cover crops, such as timing of seeding cover crops, especially for farmers in colder regions.

Keywords: Adoption, Cover crops, Conservation, Phosphorous, Water quality

JEL codes: Q55, Q25, Q52

Introduction

Agricultural non-point sources are the leading contributor to water pollution in the U.S., but the problem can be reduced by adopting appropriate management practices (US EPA 2005). Cover crops can be a win-win solution because it can not only reduce nonpoint source pollutants (Carpenter et al. 1998) but also benefit crop yields (CTIC 2017). Specifically, cover crops are an effective practice for improving soil health, sequestering carbon, and reducing soil erosion and nutrient loss.

However, the practice was adopted on less than 13 percent of cropped farms in 2012 according to the Census of Agriculture (USDA 2014). A deeper understanding of cover crop adoption may be beneficial not only for farmers but also for environmental quality. The few studies on adoption of cover crops suffer from drawbacks such as limited geographic scope. The objective of this study was to identify the factors affecting adoption of cover crops using the 2012 USDA Agricultural Resource Management Survey (ARMS), a national survey of soybean producers, which allows regional comparisons. This data also allows us to examine the perceptions of benefits and barriers as well as farmers' actual behaviors.

We found that full-time farmers were more likely to use cover crops. Farmers having larger farms were more likely to adopt, but the effect was diminishing. Applying more fertilizer and using irrigation were associated with adoption of cover crops while treating more land for weeds had a negative effect. The first two factors (fertilizer and irrigation) may relate to perception of yield benefits while the latter (weeds) was related to a perceived adoption barrier. Farmers in the South were more likely to use cover crops than those in the Midwest while the northern Great Plains were less likely, which may be due to temperature conditions.

Background

Water quality issues caused by agricultural non-point sources are increasing. Nutrient losses, such as nitrogen (N) and phosphorus (P), from agricultural fields, causes problems. The nutrients move to surface water by runoff and could cause eutrophication (Carpenter 2005). In fact, N loss occurs through leaching, runoff or volatilization. Cover crops can reduce these losses by taking up the available N, and legume cover crops also enable N fixation from the atmosphere. Therefore, they can reduce nitrate (NO_3), a toxic nitrogen compound, leaching into groundwater (Strock, Porter and Russelle 2004; Tonitto, David and Drinkwater 2006). Dinnes et al. (2002) and Helmers and Castellano (2015) argue that there are temporal differences between water use by crops, precipitation patterns, and soil nitrate production in general (figures 1 and 2, which relate to Midwest conditions). Thus, cover crops can mitigate this issue by using excessive water and nutrients (Castellano and Hellmers 2015). Reduced amounts of NO_3 reduces gaseous losses, including nitrous oxide (N_2O), a greenhouse gas (Davidson et al. 2000). These reductions of available nitrogen also can reduce the losses by runoff.

[Insert figure 1 about here]

[Insert figure 2 about here]

P losses are generally caused by runoff and erosion because P is usually attached to soil particles (Devlin et al. 2002). Cover crops also can reduce soil erosion. Laloy and Bielders (2010) found that there were less soil loss and runoff in fields using cover crops than in those left untilled post-harvest. Specifically, using cover crops can reduce runoff of total P (Langdale, Leonard and Thomas 1985; Yoo, Touchton and Walker 1988). This is because cover crops reduce rainfall energy on soils due to stalk and leaf, and increase infiltration capacity and water storage ability by their roots. Therefore, cover crops can reduce nonpoint source pollutants from agriculture.

Soil organic matter or carbon is another important factor for productivity and, to farmers, one of well-known benefits of using cover crops (Kaspar and Singer 2011; Myers and Watts 2015; CTIC 2017). Mbuthia et al. (2015) conducted a long-term (31 years) cotton production study in Tennessee and found there was more total organic carbon under cover crop (legume) and no-till, as well as higher yields, than no cover crop and tilled fields.

In relation to climate change, carbon sequestration, enhanced infiltration, and reduced evaporation could be important benefits from using cover crops (Kaye and Quemada 2017). Sequestration of carbon transfers carbon dioxide, CO_2, in the atmosphere into the soil and is one way to increase soil organic matter. Using cover crops can increase carbon sequestration and may mitigate climate change (Lal 2004; Kaye and Quemada 2017). Heavy rainfall and drought could be increased by climate change (Lu et al. 2015; Kaye and Quemada 2017). Cover crops can reduce runoff by covering soil and reduce nutrient loss by uptake of residual nutrients (Strock et al. 2004; Steenwerth and Belina 2008). In a drought, cover crops can help retain soil moisture due to the mulch provided by cover crop residues (Kaye and Quemada 2017). Also certain crops with taproots, like radish, can increase infiltration, and thus enable the roots of cash crops to penetrate deeper (Chen and Weil 2011). However, farmers need to be careful with cover crop termination due to water use competition with cash crops (Alonso-Ayuso, Gabriel and Quemada 2014).

Conceptual Framework

Farmers will adopt cover crops if their expected utility, subject to their preferences, is maximized by doing so. Utility is a function of various factors including expected benefits and costs of adopting a practice versus not adopting. The factors affecting adoption can be divided into five categories: demographic factors, farm characteristics, adoption of related management practices or technologies, federal conservation program participation, and region. These categories and explanatory variables were based on literature related to adoption studies of technologies and best management practices. This literature is reviewed to develop testable hypotheses.

Among demographic factors, age is considered to affect adoption of new practices. Older farmers prefer less change in their practices due to a shorter planning horizon (Prokopy et al. 2008; McBride and Daberkow 2003; Soule, Tegene and Wiebe 2000). We hypothesize that younger farmers will have a higher likelihood of adoption. Education assumes a linkage between knowledge and adopting a practice and has had a positive effect on the likelihood of adoption (Rogers 2003; Mcbride and Greene 2013; Weber and McCann 2015; Schimmelpfennig and Ebel 2016). Bergtold, Duffy, and Hite (2008) used an education variable in their study of cover crops in Alabama, but it was not significant. Nevertheless, we expect that farmers with a higher education level are more likely to adopt cover crops. Information source is another important factor. Extension can provide information about benefits of practices for not only farmers but also the environment. Baumgart-Getz, Prokopy, and Floress (2012) found farmers participating in extension training were more likely to adopt best management practices[1]. In a cover crops adoption study, Arbuckle and Roesch-McNally (2015) used trust in extension as an explanatory variable, but it was not significant in Iowa. We included getting N fertilizer recommendations from the Extension Service as a factor and expect a positive relationship with the adoption of cover crops.

Off-farm employment could be a factor affecting the adoption decision. In the literature,

[1] No-till, cover crop, irrigation, precision agriculture, crop rotation, etc.

off-farm employment has shown mixed results since it can increase financial availability (Schimmelpfennig and Ebel 2016) or reduce time to consider and adopt new technology (Mcbride and Greene 2013). Gedikoglu, McCann, and Artz (2011) explained that off-farm employment may have a positive impact on a capital-intensive practice but a negative effect on a labor-intensive one. In a cover crop study, Bergtold, Duffy, and Hite (2008) used off-farm income (dummy variable), but it was not significant. This may be because cover crop non-users are concerned about labor/time costs (CTIC 2017). Thus, we included household off-farm work days and expect fewer off-farm work days makes it more likely to adopt the practice.

Farm characteristics also have been shown to affect adoption. Farm size is a possible adoption indicator. If farm size is large, then the farm could benefit from economies of scale. If there are fixed costs associated with a practice, average costs are lower relative to smaller farms. Also, farm size could be a proxy for profitability of the farms. On the other hand, according to CTIC (2017), one of the concerns about using cover crops for non-users was time/labor costs that could be an issue for larger farms. So, we used a quadratic form for farm size to capture the possibility of nonlinearity. In a cover crop study, Dunn et al. (2016) found farmers who have larger farms are more likely to plant more cover crops. So, we expect farmers operating larger farms will be more likely to adopt cover crops.

Land tenure determines whether farmers can make sustainable management plans and whether owners would receive the future benefits from planting cover crops (McBride and Daberkow 2003; Soule et al. 2000). In a cover crop adoption study, Bergtold, Duffy, and Hite (2008) found farmers renting more area were less likely to use cover crops. So, we include the percentage of acres owned of the total operated acres (owned plus rented) and expect that farmers with more owned acres are more likely to adopt cover crops.

Production diversity on a farm can may create synergies and thus be an indicator of adoption of cover crops. Farmers with livestock could get additional benefits from cover crops, like forage (Arbuckle and Roesch-McNally 2015; Singer, Nusser and Alf 2007). Specifically, we included a variable for having cattle and calves on their farm and expect those farmers to be more likely to adopt cover crops.

Additionally, CTIC (2017) asked questions about perceptions of benefits as well as concerns for using cover crops. Interestingly, there were common factors: whether the farmers use cover crops or not, yields, and use of inputs. Thus, we included yield goal and percentage of fertilized acres and land treated for weeds, insects or diseases. We have no prior expectation for these variables.

Soil health is important for productivity in agriculture. If their soil is classified as highly erodible by the Natural Resource Conservation Service, they need to use conservation practices in order to be eligible for government programs (Soule et al. 2000). One benefit that is well recognized by farmers using cover crops is less soil erosion because of improved soil structure (Myers and Watts 2015; O'Connell et al. 2015). However, McCann and Claassen (2016) identified a negative relationship between land identified as highly erodible and Conservation Stewardship Program (CSP) participation. They explained that farmers on highly erodible land must follow a written soil conservation plan to receive farm program payments, but the plan may not include CSP requirements including cover crops. Nevertheless, we hypothesize farmers having highly erodible soil are more likely to use cover crops.

Previous adoption of other management practices or technologies could be an indicator for adoption of cover crops. Adoption of conservation practices or technologies can be a proxy for environmental awareness (Schimmelpfennig and Ebel 2016; Weber and McCann 2015), and some practices may be complements or substitutes for each other. We include conservation tillage/no-till use, soil testing, crop rotation and manure use for practices, and using irrigation, variable application rate use, and having renewable energy production systems for technologies.

In a cover crops adoption study, Bergtold, Duffy, and Hite (2008) used conservation tillage, irrigation and the number of conservation practices, but only irrigation was significant and more irrigation increased adoption. We hypothesize farmers using these practices and technologies are more likely to adopt cover crops. To be specific, farmers using irrigation may increase soil water availability and reduce irrigation costs by adopting cover crops (Bergtold et al. 2012; Curell 2012). Traditional tillage tends to increase soil erosion and reduce soil infiltration, and thus increase water and nutrient runoff (Lal, Reicosky and Hanson 2007). Using conservation/no-tillage can reduce these issues, and they are helpful for reducing water pollution (Gebhardt et al. 1985).

In addition, farmers using soil tests can get detailed information about nutrients in their soil, and it could help farmers use less fertilizer than non-testers (Williamson 2011). Soil tests also provide information on organic matter in the soil, so these farmers would have information on soil health. Crop rotation has environmental benefits, such as managing soil nutrients and pests, and reducing soil erosion (Mohler and Johnson 2009) so we expect this would increase adoption. Manure studies have shown manure can be a substitute for fertilizer and it can help improve water quality, but only if managed well (Nunez and McCann 2008; Evanylo et al. 2008). In respect of nutrient management, cover crops could reduce nutrient runoff from manure. For technologies, Beckman and Xiarchos (2013) found farmers using conservation practices were more likely to be using renewable energy than the average farmer in California (NASS 2011). Using variable application rate could optimize and thus reduce the use of fertilizer (Ulrich-Schad et al. 2017). We thus expect adoption of cover crops to be highly among users of these two technologies

The federal government has some programs that might relate to adoption. Conservation programs subsidize farmers to help them use environmentally friendly agricultural practices. These programs include: Environmental Quality Incentives Program (EQIP), Conservation Stewardship Programs (CSP), Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), and Wetland Reserve Program (WRP). We expect farmers who have received funding from these programs will be more likely to adopt cover crops. Federal crop insurance might be another determinant of adoption. Crop insurance might have either a positive or negative effect on adoption of cover crops. In our model, we use a dummy variable for whether they enrolled in federal crop insurance as a proxy of risk-aversion. Kaye and Quemada (2017) argue that using cover crops can reduce risk from climate change, such as extreme rain and drought and other studies show cover crops are beneficial for the risk-averse farmer (Sarrantonio and Gallandt 2003; Lu et al. 2000). However, farmers who used cover crops had an issue with possibly losing eligibility for the insurance due to a tight deadline for cover crop termination (Marzen and Ballard 2016). Thus, risk-averse farmers may be reluctant to use cover crops.

Lastly, location could be a good predictor of cover crop adoption because rainfall and temperature around harvest are important for growing cover crops and achieving potential benefits. We used regional dummy variables with the Midwest as the base because it is the largest soybean producing region; we expect warmer regions are more likely to plant cover crops than colder ones (Wade, Claassen and Wallander 2015).

Methods and Data

Probit model

In this paper, we use a probit model to estimate the likelihood of adoption due to the dichotomous nature of the dependent variable. If a farmer adopts cover crops, then the independent variable is 1, otherwise (does not adopt) is 0. Then, the equation will be

$$y = X\beta + \varepsilon$$

where $X = (x_1, \cdots, x_k)$ is a transposed vector including independent variables, $\beta = (\beta_1, \cdots, \beta_k)'$ is a vector of coefficients, and ε_i is the error term with an assumption of a normal distribution, $N(0, \sigma_\varepsilon^2)$. The probability can be denoted as $p_i = P(Y = 1|X)$. The probit regression is

$$P(y = 1|X) = \Phi(X\beta + \varepsilon)$$

where $\Phi(\cdot)$ is the cumulative normal distribution.

$$P(y_{it} = 1|X_{it}) = \Phi(X_{it}\beta + v_i)$$

ARMS data

ARMS is a multiphase survey jointly conducted by the USDA Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS). The survey is designed based on 48 continental states' information to be representative and to support 15 key agricultural states. The survey consists of three phases. Phase 1 and 2 are conducted in the reference year, and phase 3 is conducted the following year. In phase 1, they are screening farmers who produce the targeted commodities (e.g., corn, soybeans, wheat, cotton, etc.) during the summer. In phase 2, in the fall and winter, they conduct the field-level survey by choosing randomly from farmers identified in phase 1 about inputs, management practices and costs for a specific field. In phase 3, in the spring of the following year, they collect data at the whole-farm level about returns and costs, and household characteristics. The phase 3 sample is randomly selected from phase 1 and also those who finished phase 2. Thus, the sample size of phase 3 is larger than phase 2. Lastly, the credibility of the gathered data is checked by ERS and NASS. In this study, the 2012 ARMS Soybean survey was used. A total of 2483 observations were collected from sixteen states; however, 1708 observations were available for the analysis of cover crop adoption due to non-response.

Results

Descriptive Statistics

Table 1 shows summary statistics for the ARMS data used in the regression. Approximately 17% (285 of 1708 respondents) reported adopting cover crops on their farm. The average age was around 56 and 56% of respondents had an education level more than or equal to a college degree. Twenty-one percent of respondents had more than 100 days of off-farm work. Only 1% of farmers said they followed N fertilizer recommendations from extension agents. The mean farm size was 1,770 acres, and on average, 39% of farmland was owned. About 12% of farmers identified their surveyed soybean field as highly erodible by NRCS. A third of farmers also had cattle and calves, and the average yield goal was 48 bushels/acre. Two-thirds of cropland was fertilized, 77% of land was treated for weeds, 32% was treated for insects, and 11% was treated for diseases.

For conservation practices and technologies, 20% of soybean farmers used a P soil test, and 26% of farmers used manure in 2012. Three-quarters of respondents used conservation or no tillage, and 81% of farmers planted different crops between 2011 and 2012. Eighteen percent of respondents used variable application rate and 23% of farmers used irrigation. Only 3% of respondents used renewable energy production systems.

In respect of Federal programs, 85% farmers enrolled in federal crop insurance. Among cost-sharing programs, farmers received $1/total farm acre from CRP, CREP or WRP payments and $1.58/total farm acre from EQIP or CSP contracts in 2012.

Lastly, a majority of the soybean farmers (53%) were from the Midwest region, which represents the largest soybean-growing region. Northern Plains was 23%, and Southern and Delta were 12%.

Probit Regression Results

We examined correlation coefficients for the explanatory variables and checked the variance inflation factor (VIF) to check for multicollinearity in the regression. The correlation coefficients were smaller than 0.52 in absolute values for all variable pairs, except squared size variables. There was no evidence of multicollinearity when examining the VIF because all variables had VIF values less than 2.1, except the squared term. The Chi-square indicated the model was significant ($p<0.001$). AIC was 1318.

Table 2 shows the probit regression results; more educated farmers were more likely to use cover crops, consistent with previous conservation practice adoption studies (Schimmelpfennig and Ebel 2016; Weber and McCann 2015; Mcbride and Greene 2013). Farmers having less than 100 days of off-farm work were more likely to adopt cover crops, consistent with Mcbride and Greene (2013) and Gedikoglu et al. (2011). Other significant results were that farmers having larger farms were more likely to adopt cover crops, but, the negative squared term indicates this effect was diminishing. It might imply that concerns regarding labor/time costs could be an issue on larger farms and off-farm work days. Farmers owning more of the farmed land were more likely to adopt cover crops, consistent with Bergtold et al. (2012). Ownership implies that farmers will be able to receive the long-term benefits of the practice.

Applying fertilizer to more acres was associated with adoption of cover crops while treating more land for weeds had a negative effect. Farmers using irrigation were more likely to plant cover crops, consistent with Bergtold et al. (2012). The fertilizer use and irrigation may be related to the perceived benefit of consistent yields; Venkateswarlu et al. (2007) found cover crops help maintain stable yield in a 10-year study. Also, farmers having trouble with weeds may have a barrier to using cover crops because of the concern about cover crops becoming weeds. Farmers having cattle were more likely to use cover crops, consistent with Arbuckle and Roesch-McNally (2015) and Singer et al. (2007). Those using manure were also more likely to use cover crops. Farmers using conservation tillage/ no-till, renewable energy systems or variable nutrient application rates were more likely to adopt. These practices and technologies may be related to farmers' environmental awareness and attitudes.

Those who have received more federal Environmental Quality Incentive Program or Conservation Stewardship Program payments were more likely to adopt the practice. Compared to the Midwest, farmers in the region including KY, NC TN, and VA were more likely to adopt cover crops while farmers in NE, SD, and ND were less likely to use it. One surprising result was that the region covering AR, LA, and MS was less likely to use cover crops than the Midwest, which partially contradicts Wade et al. (2015) and Dunn et al. (2016).

Conclusion

Reducing nonpoint source pollution from agriculture into water resources is important. Cover crops can be a solution that not only reduces nonpoint source pollutant but also improves soil health and provides other benefits, which can have positive effects on yields of cash crops. Thus, cover crops can be a win-win practice for farmers as well as the environment. Our results provide evidence that farmers do perceive it as a win-win practice but also that there are definite barriers to adoption.

Cover crops' adoption rate is still low, especially in colder regions because of the short window for seeding cover crops after harvest of cash crops. Thus, researchers have been working on cover crop interseeding (Wells et al. 2016). However, timing of seeding is important. If farmers seed cover crops too early, it could cause yield reductions due to competition for nutrients or water (Uchino et al. 2009). Weed control is another important concern.

Our findings suggest that extension agents and crop specialists should try to understand the specific concerns about using cover crops in their area, such as the possibility of cover crops becoming weeds, while stressing the benefits related to yields and long-term soil health.

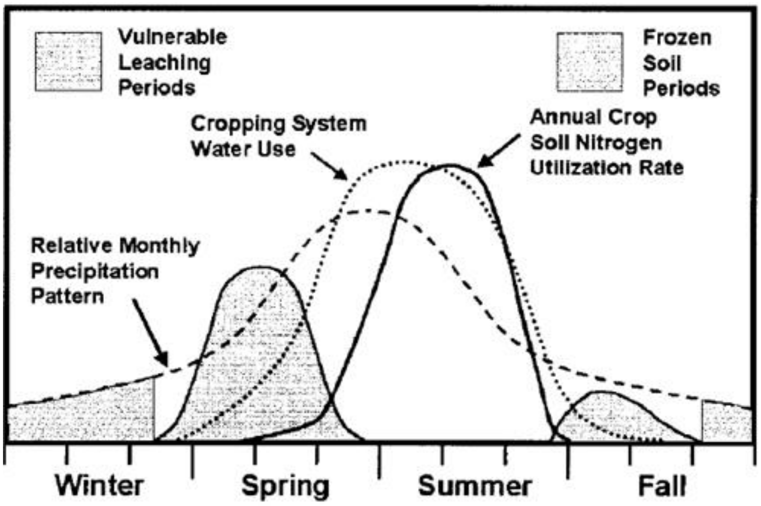

Figure 1. General Patterns of Precipitation, N Use Rate by Corn, Water Use

Source: Dinnes et al. 2002 (adapted from Power et al. 1998)

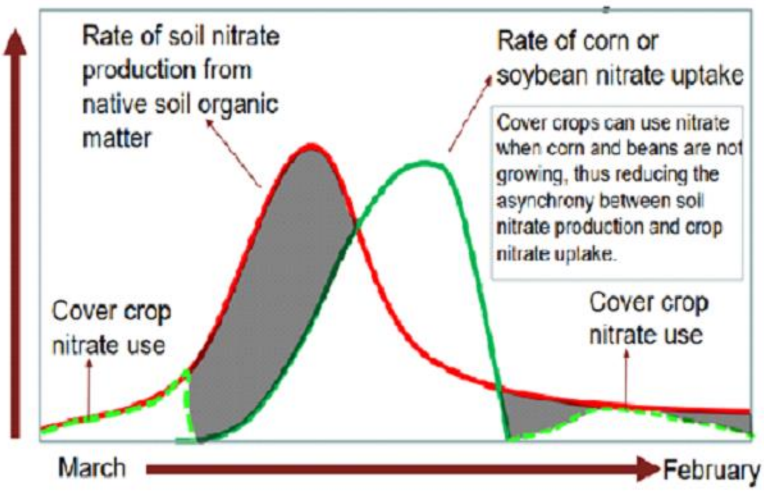

Figure 2. Time Difference Between Soil Nitrate Production and Crop Use

Source: Helmers and Castellano (2015)

Table 1. Summary statistics (N=1708)

Variable	*Mean*	*Std Dev*
Cover crop adoption	0.17	0.37
Age	56.04	11.56
Education (1:more than or equal to college; 0: less)	0.56	0.50
Operator off-farm days (1:more than 100d; 0:less than 100)	0.21	0.41
N fertilizer info from Extension (1:yes; 0:no)	0.01	0.09
Owned land (%)	0.39	0.34
Size (1,000 acres)	1.77	2.15
Cattle & calves (1:yes; 0:no)	0.33	0.47
Highly erodible (1:yes; 0:no)	0.12	0.33
Yield goal (BU/acre)	48.44	11.03
Cropland fertilized acres (%)	0.66	0.31
Land treated for weeds in crops and pasture (%)	0.77	0.30
Land treated for insects on hay or other crops (%)	0.32	0.37
Land treated for diseases in crops and orchards (%)	0.11	0.25
Federal crop insurance (1:enrolled; 0:not)	0.85	0.36
Renewable Energy Production Systems (1:yes; 0:no)	0.03	0.17
No-till/Conservation tillage (1:yes; 0:no)	0.74	0.44
Variable application rate for fertilizer and lime, or pesticide (1:yes; 0:no)	0.18	0.39
Manure (1:yes; 0:no)	0.26	0.44
Irrigation (1:yes; 0:no)	0.23	0.42
Rotation (1:yes; 0:no; Crop2011=not soybean)	0.81	0.39
Soil test (1:yes; 0:no)	0.20	0.40
CRP, CREP, WRP in 2012 ($/acre)	1.00	4.83
EQIP, CSP, CStP in 2012 ($/acre)	1.58	6.44
NASS1	0.12	0.32
NASS2	0.12	0.33
NASS3	0.53	0.50
NASS4	0.23	0.42

Note: NASS1 (Kentucky, North Carolina, Tennessee, Virginia), NASS2 (Arkansas, Louisiana, Mississippi), NASS3 (Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin), NASS4 (Kansas, Nebraska, North Dakota, South Dakota)

Table 2. Result of Probit Regression for Adoption of Cover Crops

Parameter	*Estimate*	*Standard Error*
Intercept	-1.811***	0.374
Age	-0.004	0.004
Education (1:more than or equal to college; 0: less)	0.144*	0.084
Operator off-farm days (1:more than 100d; 0:less than 100)	-0.244**	0.107
N fertilizer info from Extension (1:yes; 0:no)	0.211	0.373
Owned land (%)	0.260*	0.141
Size (1,000 acres)	0.096**	0.043
Square of size	-0.007**	0.003
Cattle & calves (1:yes; 0:no)	0.233**	0.098
Highly erodible (1:yes; 0:no)	-0.103	0.117
Yield goal (BU/acre)	0.000	0.004
Cropland fertilized acres (%)	0.579***	0.169
Land treated for weeds in crops and pasture (%)	-0.550**	0.174
Land treated for insects on hay or other crops (%)	0.071	0.135
Land treated for diseases in crops and orchards (%)	0.063	0.187
Federal crop insurance (1:enrolled; 0:not)	0.001	0.117
Renewable Energy Production Systems (1:yes; 0:no)	0.574**	0.200
No-till/Conservation tillage (1:yes; 0:no)	0.576***	0.115
Variable application rate for fertilizer and lime, or pesticide (1:yes; 0:no)	0.174*	0.100
Manure (1:yes; 0:no)	0.474***	0.095
Irrigation (1:yes; 0:no)	0.343**	0.111
Rotation (1:yes; 0:no; Crop2011=not soybean)	-0.037	0.122
Soil test (1:yes; 0:no)	0.038	0.099
CRP, CREP, WRP in 2012 ($/acre)	-0.001	0.011
EQIP, CSP, CStP in 2012 ($/acre)	0.023***	0.006
NASS1	0.542***	0.124
NASS2	-0.865***	0.212
NASS4	-0.479***	0.118
AIC	1318.535	
Obs.	1708	

Note: NASS1 (Kentucky, North Carolina, Tennessee, Virginia), NASS2 (Arkansas, Louisiana, Mississippi), NASS3 (Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin), NASS4 (Kansas, Nebraska, North Dakota, South Dakota)

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