Adoption of Cover Crops and Its Effect on Nitrogen Use by Farmers

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Abstract

With increasing environmental concerns, increasing population, changing tastes and preferences of consumers towards healthier foods, and with more food safety requirements, agronomic practices have changed gradually to provide not only food and fiber but also public goods and other beneficial services from agriculture. Cover cropping is one type of technology increasingly being adopted by producers of multifunctional agriculture. Cover crops provide a range of benefits, both private and public. In this paper we identify factors affecting farmers' choice to adopt cover crops. We examine the impact on nitrogen use from adopting cover crops and the resultant decrease in input costs. Using a two-stage approach that incorporates endogeneity of adoption in nitrogen management, we conclude that farmers adopting cover crop technologies, that increase production efficiency, tend to decrease nitrogen fertilizer use by 4.75%, as hypothesized by Smith (2002).

Keywords: cover crops, nitrogen usage, technology adoption,

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Introduction

As population has increased and technologies have changed over time, agricultural practices provide not only food and fiber to consumers but also certain practices can create environmental degradation, like land erosion, nitrogen leaching to water sources, other types of water pollution, and losses of CO_2 because of deforestation to convert forests to agricultural land (Tinker et al. 1996). And of course, climate change issues have become very important recently, with focus being directed at agriculture as a potential source for greenhouse gas mitigation through carbon sequestration, among others.

Agronomic practices that provide public goods and other beneficial services, as well as agricultural products, are referred to multicultural agriculture – a foundation for European model of agriculture and agricultural policy (Batie 2003). In recent years, the role of multifunctional agriculture has broadened to include meeting the needs of an increasing population and to provide sustainable practices that benefit and not degrade the environmental amenities society enjoys. Besides producing private (food and fiber) and industrial goods (bioenergy), agriculture can provide many public goods and services or externalities like land conservation, maintenance of landscape structure, biodiversity preservation , nutrient recycling and loss reduction, among others (Boody et al. 2005; Tapani and Jukka 2004).

Though the concept of multifunctional agriculture is very broad the major portion of it is adoption of various agricultural technologies among farmers. Different studies show that different technology adoptions can positively affect soil properties and harvest yields. For example, furrow disking reduces water consumption and improved yield and net returns (Nuti et al. 2009). Using such innovations led to both production and environmental benefits (Blazy et al.

2009). Farmers may be able to reduce risk exposure by trying new techniques on their more marginal lands, typically more steeply-sloped, relatively less productive parcels (at least initially) (Arellanes and Lee 2003). New technology practices adopted by agricultural producers can include good agrarian practices, irrigation scheduling, water saving, conservation tillage, organic farming, erosion reduction, nitrogen fertilization, plastic covered horticulture and cover cropping, among others (Bertuglia et al. 2006).

Cover cropping itself can be used for different purposes under different motivating conditions. Cover crops can positively affect soil properties and can improve crop development and yield. Much research has focused on how cover crops affect different attributes of soil and harvested yield. Cover crops can influence soil properties, crop yield and growth (both above and below ground biomass), in tomatoes, for example (Sainju et al. 2002). They also show that cover crops effect on soil carbon sequestration and microbial biomass and activities by providing additional residue carbon to soil (Sainju et al. 2007).

Cover crops can also decrease weed populations in lettuce (Ngouajio et al. 2002), legume cover crops can provide nitrogen to the next crop and reduce nitrogen requirements (Larson et al. 2001). Cover crop management has a significant effect on soil penetration resistance on several occasions, such as grazing of cover crops in grain cropping system that can increase economic return and diversify agricultural production system, not damaging the soil (Franzluebbers and Stuedemann 2008). Crops following cover crops show the most vigorous results (Bechini and Castoldi 2009). No tillage in combination with adapted cover crops and crop rotations result in reducing water runoff and consequently soil erosion, and winter cover crops result in significant yield increase of the following cash crops (Derpsch at all 1986). Cover crop mulching offers opportunities for smallholders by addressing soil fertility and weed management constraints (Erenstain 2003).

Another effect of cover crops is decreased nitrogen leaching rates of soil. Though some studies show that sometimes there is no statistically difference in yields between cover crop and non-cover crop treatments (Ritter et al. 1998), the majority of research indicates that cover crops help reduce nitrogen leaching. So Sainju et al. (2002) show that hairy vetch and crimson clover, both leguminous cover crops, fix Nitrogen (N) from the atmosphere. In another study, Sainju et al. (2007) show that cotton and sorghum yields and N uptake can be optimized and potential for soil erosion and N leaching can be reduced by using conservation tillage, such as no-till or strip till, in combination with a vetch/rye cover crop and 60-65 kg nitrogen ha^{-1}. Others show that cover crops reduce soil N_{min} content in autumn and in spring (Kramberger et al. 2000). Steenwerth and Belina (2004) describe how cover crops enhanced the soils' capacity for supporting greater microbial biomass nitrogen, potential nitrogen mineralization, and the microbiological function of nitrification and denitrification. Others have demonstrated that nitrate leaching was reduced by 40% in legume-based systems relative to conventional fertilizer-based system (Tonitto et al. 2005).

Empirical Model

In this paper, nitrogen fertilizer used by farmers who adopt cover crops and those who do not adopt cover crops is estimated. While nitrogen used by farmers is considered as left censored variable, adoption of cover crop is considered as an endogenous dummy variable. The resulting system is a Limited Dependent Variable (LDV) model defined by the amount of nitrogen used by farmers, with endogenous dummy variable that investigates whether the farmer adopts cover crops. Because the censoring precludes unique or sensible solutions for the reduced forms, a condition must be imposed in a system of censored dependent variables (Heckman, 2001). The structural form of the model is given by

$$Y_1^* = X'\beta + Y_2{}'\gamma + u_i$$

We assume that Y_1^* = Y_1^* is continuously observed such that

$$Y_1^* = X'\beta + Y_2{}'\gamma + u_i \quad if\ Y_1 > 0$$

$$Y_1^* = 0 \qquad\qquad\qquad\qquad if\ Y_1 \leq 0$$

Further endogeneity is introduced in the model if γ and u_i are correlated. Considering Y_2 is a dummy variable we estimate it using a Probit model to understand the probability of adoption such that

$$Y_2 \begin{cases} 1 = Z'\beta + v_i = Y_2^* \\ \quad\quad 0 \end{cases}$$

Where, Y_2 is a latent variable that is continuously observed. The errors follow the distribution

$$(v_i, u_i) \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{pmatrix} 1 & \rho\sigma_u \\ \rho\sigma_v & 1 \end{pmatrix}\right]$$

Thus Y_1 represents the amount of nitrogen used by farmers per acre and is censored at zero. The amount of nitrogen used is dependent on exogenous variables X and a dummy variable Y_2 representing the probability of adopting cover crops, which is potentially endogenous. Probability of adoption of cover crops is dependent on Z variables which are uncorrelated with error term ui. Endogeneity tests of acres of GM corn planted and hours worked off the farm are considered. We use the Smith Blundell test to determine exogeneity as proposed by Baum (1999) who computes a test for exogeneity based on the Smith and Blundell's test where, under the null hypothesis, the models are appropriately specified with all explanatory variables as exogenous. Under the alternative hypothesis, the suspected endogenous variables are expressed as linear projections of a set of instruments, and the residuals from the first-stage regressions are added to the model

Considerable literature has evolved in the use of limited dependent variable model with endogenous dummy variable. Amemiya (1974) considers a model in which all endogenous variables are truncated to zero, revealing certain necessary restrictions on the model and suggesting a method of estimation using the indirect least squares method. Nelson and Olson (1978) proposed a two-stage least squares procedure for Tobit analysis proving that the estimates are asymptotically normal. More recent studies have applied these models for specifying effects on adoption of technologies including Blundell and

Smith (1989) who compared estimates of marginal and marginal and new conditional maximum likelihood procedures. Goodwin and Mishra (2004) used the simultaneous equation framework to determine multiple job holdings and resulting effects on farming efficiency. A more detailed discussion on use of LDV with dummy endogenous model is presented by Angrist (2001)

As previous literature shows, cover crops provide beneficial effects, including reduced nitrogen leaching to soil and increased crop yields; benefiting both farmers and environment. Given that situation, our research has two objectives:

1) identify determinants of cover crop adoption, and
2) analyze how N management varies by farm relative to adoption or nonadoption of this technology.

Data and Methodology

A survey was administered to organic producers in seven states: Illinois, Indiana, Iowa, Ohio, Michigan, Minnesota, and Wisconsin. The results of our analysis are based on 233 observations of completed surveys from producers in those seven states. We further grouped these seven states into two ERS regions: Northern Crescent and Heartland. This was used as a dummy variable in the analysis. Table 1 contains definitions and summary statistics of the variables used for the econometric analysis.

The dependent variable in the probit model, cover crop adoption, is a discrete choice variable from the survey asking the farmers whether they currently used cover crops in their farming operation. If producers answered yes then they were asked what type of cover crops they used and how long they had used cover crops.

The dependent variable in the Tobit model was nitrogen usage buy the farmer in pounds per acre. The explanatory variables were divided into three categories: (i) demographic – ERS region, farmer's age, household income, education, experience, percent share of the off-farm work, type of farm's operation's organization; (ii) socio-economic – farm size, risk aversion, existence of cattle in the farm, importance of farmers relying on cover crops, using cooperative extension recommendations when making N management decisions, and organic fertilizer dealer recommendations when making N management decisions; (iii) agronomic – CRP payment, current commercial and legume N management practice changes, relative to 5 years ago.

Table 1. Definitions and summary statistics of producers included in the analysis.

	Variable	Description	Mean
1.	Cover_crop	Equal to '1' if cover crop incorporated in the corn yield, '0' otherwise.	0.538835
2.	Ncrecent	Equal to '1' if the farm is in Northern Crescent Region, '0' otherwise	0.472103
3.	Op_age	Farmer's age.	52.93396
4.	Hh_income	Total household income.	3.257732
5.	Isds_cov	Equal to '1' if importance of farmers relying on cover crops on decision making is low, '2' if moderate,'3'if high, and '4' if very high.	4.036649
6.	Isds_ext	Equal to '1' if importance of extension on decision making is low, '2' if moderate, '3'if high, and '4' if very high.	2.107345
7.	Isds_ode	Equal to '1' if importance of organic fertilizer dealers on decision making is low, '2' if moderate, '3'if high, and '4' if very high.	2.86631
8.	Op_educ	Farmer's highest level of education.	2.770642
9.	Farm_exp	Number of years of farming.	29.92453
10.	Sh_offarm	Percent share of the off-farm work for a year.	0.262035
11.	Totacres	Number of total acres of the farm.	933.9644
12.	Frm_org	Equal to '1' if farming operation is organized as family or individual, '2' if legal partnership and '3' if incorporated under state low.	1.279279
13.	Riskaver	Equal to '1' for the lowest 25% quartile of the distribution of risk aversion, '2', '3', and '4' for subsequent quartiles.	2.545064
14.	Livestoc	Equal to '1' if the farm has the livestock, '0' otherwise.	0.67382
15.	Crp_pmt	Equal to '1' if the farmer got CRP payment, '0' otherwise.	0.227468
16.	Nitrogen	Amount of nitrogen used per acre.	3.924398
17.	Tile_dra	Equal to '1' if the farm has artificial drainage, '0' otherwise.	0.298406
18.	Manure_c	Equal to '1' if manure was used, '0' otherwise.	0.577376
19.	Past_cn	Equal to '1' if less commercial N per acre, '2' if the same amount, '3' if more commercial N per acre was used by farmer than 5 years ago, and '4' if it doesn't apply to farmer's case.	3.00178
20.	Past_ln	Equal to '1' if less legume N per acre, '2' if the same amount, '3' if more legume N per acre was used by farmer than 5 years ago, and '4' if it doesn't apply to farmer's case.	2.394006
21.	Totfarm	Farm income	321394.4
22.	Sh_crop	Percentage share of the crop land	0.3270387
23.	Pcover	Predicted values of cover crop adoption form probit model	

A risk aversion variable was created to see how risk aversion affects cover crop adoption by the farmers. We created this variable by using the question about the farmer's knowledge about different attributes of farming. Then giving numerical values 0 to 4 to answers of the level of knowledge, we divided the distribution into four quartiles. By doing this, we assumed that the farmers who know most about different topics they are most risk averse.

Results and Discussion

Table 2 summarizes the probit model used to find out the factors affecting cover crops adoption by farmers. There is significant difference between two ERS regions, with ncrecent (the region variable), being negative and significant at 10% level. That means that the probability that the farmer will adopt cover crops is 38% less in Northern Crescent region than in Heartland region. The coefficient of total farm income is also negative and significant at 10% level as well. This illustrates the fact that if total farm income increases, a farmer is using technologies which tend to decrease the nitrogen level. The other negative and significant factor (at 10% level) is farming experience. This means if the farming experience increases by one year the probability that the farmer will adopt cover crop decreases by 0.11 – indicating that as producers age they are less likely to use this technology. All other demographic characteristics are non-significant in the model.

Among socio-economic variables, total-farm size and importance of farmers relying on cover crop decision-making are positive and significant at the 5%-level. Our results indicate that if the farm size increases by 100 acres, the probability of adopting cover crop increases by 2.25%. The and importance of farmers relying on cover crop decision-making is positive because the farmers are exchanging the information about their experiences, and the farmers who have already used cover crops, and had a positive experience over time, positively affect others attitudes about that technology. Importance of organic fertilizer dealers, in the cover crop decisions, is negative and significant at 10%-level. The fact that the importance of organic fertilizer dealers is negative can be interpreted by the fact that using cover crop decreases the demand for organic fertilizer so organic fertilizer dealers are not promoting cover crops promote and maybe even relegate the use of cover crops. CRP payment, the only agronomic variable in the model, is insignificant.

Table 2. Estimation results for Probit model of cover crop adoption

Cover_crop	Coefficient	Standard Error
ncrecent	-0.3870892*	0.2546041
op_age	0.1289766	0.0988613
agesq	-0.0008923	0.0010096
totfarm	-1.07e-06**	4.43e-07
op_educ	-.1001429	0.1285959
yrs_farm	-0.108025*	0.0626394
expsq	0.0018482*	0.001226
Totacres	0.000225**	0.0001005
Isds_cov	0.2831942**	0.1202109
Isds_ext	-0.1199586	0.1088286
Isds_ode	-0.1959407*	0.1060838
frm_org	0.1338505	0.1891036
riskaver	-0.1818991	0.1390599
livestoc	-0.0022218	0.2877578
crp_pmt	0.4235863	0.3073408
sh_offar	0.0009914	0.3432546
_cons	-2.490915	2.147731

The next step in our analysis is to find how predicted value of cover crops adoption is affecting nitrogen usage along with other variables. For this model we used predicted values of cover crop adoption from the previous model as an endogenous variable. Tobit model results (Table 3) and results of marginal effect analysis (Table 4) show that coefficient of predicted value of cover crop adoption is negative and significant at 10% level. This implies that if a farmer adopts cover crops, then nitrogen use decreases by 4.75%. Here again total farm income is negative and significant at 10% level, so that if farm income increases by $1 the nitrogen use decreases by 0.25%. Manure is the only other significant variable; negative and significant at 5%-level. This means that if the farmer uses manure, nitrogen usage by 3.47%.

Table 3. Estimation results for Tobit model of cover crop adoption

Nitrogen	Coefficient	Standard Error
Pcover	-892.9357*	489.0985
sh_crop	110.2172	458.0902
totfarm_	-.0000902*	.0000545
Riskaver	-91.01896	85.04202
Livestock	44.60294	185.6628
tile_dra	29.32435	184.2654
manure_c	-473.6775**	222.1237
past_cn	-307.07	214.9671
past_ln	-110.8518	179.3626
_cons	1006.553	876.5672
/sigma	296.1534	94.84945

Table 4. Marginal effects - Semi elasticities from Tobit model

Variable	dy/ex	Std. Err.	P>z
pcover	-475.329*	260.36	0.068
sh_crop	37.16865	154.48	0.81
totfarm_	-25.2677*	15.274	0.098
riskaver	-198.219	185.2	0.284
livestoc	30.72647	127.9	0.81
tile_dra	11.07809	69.611	0.874
manure_c	-347.364**	162.89	0.033
past_cn	-987.173	691.08	0.153
past_ln	-268.508	434.46	0.537

Conclusions

Previous literature showed that cover crops are helping to decrease soil erosion, increase biomass (under and above ground) of the plants and reduce nitrogen leakage, which in turn results in decrease in nitrogen fertilization. Various researchers have demonstrated those affects of cover crops through field studies, but we wanted to see first, which factors influence the cover crop adoption decision, and second, how cover crop adoption influences (decreases) nitrogen use by the farmers. We used a two-step model to find that relationship. The first step was the probit model in which we found the factors affecting cover crop adoption. In that first stage, ERS region, total farm income, farming experience, farm size, importance of farmers relying on cover crops, and organic fertilizer dealers turned out to be significant.

In the next step, using Tobit model, we tried to find how the cover crop adoption, along with other factors, affect nitrogen use by farmers. For this model we used predicted values of cover crop adoption from the previous (Probit) model as an endogenous variable. The results show that cover crop adoption is negative and significant, which means that there is significant evidence, that adoption of cover crops reduces nitrogen usage. This in turn may help reduce nitrogen leaking into waterways so that less nitrogen is present in water sources. The other significant variables in the Tobit analysis were total farm income and use of manure. However, in case of manure, there is not much of a reduction in overall nitrogen availability to the environment because manure itself contains nitrogen.

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