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Original Research Article

Analysis of soil management and water conservation practices adoption among crop and pasture farmers in humid-south of the United States

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ABSTRACT

Nutrient management, water quality protection, and irrigation efficiency top the list of on-farm resource concerns indicating a need to address them through conservation strategies. A suite of Best Management Practices (BMPs) has been identified and recommended, through several outlets, to farmers to ameliorate these concerns. This research examines the adoption of strategies that ameliorate the resource concerns as a joint decision, using a bivariate model. Data from the 2016 Nutrient Management Survey, conducted by the Louisiana Master Farmer Program, are used to examine the factors affecting adoption of these conservation practices. A bivariate probit regression found significant results for explanatory variables and emphasize the effect of perception regarding the role of on-farm practices, ownership of land, participation in conservation programs in the past, and producers educational attainment on the likelihood of adopting the conservation practices. Implications for policy development and educational programs are discussed.

1. Introduction

Central to the strategy of understanding the need to transform intensive agricultural production practices in the face of growing demand on natural resources, increasing population and changing climate is the knowledge of Best Management Practices (BMPs). Federal and state policies and research by land-grant universities in nations across the world continue to emphasize nutrient stewardship as an opportunity for agricultural producers to minimize environmental and economic impairments of water quality deterioration (Mango, Makate, Tamene, Mponela, & Ndengu, 2017; Salassi, Zansler, & Giesler, 2002). Several BMPs are evaluated and promoted by land-grant universities and conservation agencies to address nutrient management issues and water conservation in agricultural production (Adusumilli, Davis, & Fromme, 2016; Bautista, Waller, & Roanhorse, 2010; Yuan & Bingner, 2002). Recommended BMPs intend to minimize the impact on soil and water resources as well as reduce the unreasonable economic burden on the producers, and improve overall production contributing to food security (Zanella et al., 2015). Consensus exists among researchers and policymakers that some voluntary adoption of management practices aimed at improving water quality occurs on most farms; however, seldom reported and/or documented. Nevertheless, both producers and agencies have been aware of the need to adopt specific BMPs in order to minimize the potential negative effects on the environment that could result from agricultural activities.

Farmer's[1] perspective on BMPs adoption, the effect of BMPs on environmental consequences, and the role of farm production practices on environmental sustainability can depend on expected costs and benefits and on several factors that differ among potential adopters (Adusumilli, Lee, Rister, & Lacewell, 2014; Baumgart-Getz, Prokopy, & Floress, 2012).[2] Understanding issues related to BMPs adoption that expand and optimize irrigation water use,

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[1] According to United States Department of Agriculture, a farmer or farm operator is either an owner or tenant or a partner who runs the farm and makes day-to-day management decisions.

[2] An "adopter" is defined as one who used at least one of the recommended BMPs on some parts of his/her land.

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mitigate threats to water resources, and provide an assessment of economic risk to producers will allow citizens and other critical stakeholders in addressing resource management issues and balance future agricultural production needs in the face of anticipated constraints to agricultural production.

Very few studies have modeled the determinants of farm-level decisions to conserve water and soil simultaneously (Jara-Rojas, Bravo-Ureta, & Díaz, 2012). Most of the literature treats adoption of soil conservation and water efficiency practices as separate decisions (Kim, Gillespie, & Paudel, 2005); however, farmers often adopt practices that have the advantage of complementarity and substitutability (Lee, 2005). According to Natural Resources Conservation Service, several practices provide both soil conservation and water quality and quantity benefits. Adoption of interrelated conservation practices is more complex as it presents a long-term strategy, beyond short-term economic gains, to conserve natural resources (Caswell, Fuglie, Ingram, Jans, & Kascak, 2001). Hence, ignoring the complementarity might underestimate or overestimate the influence of factors on decision-making regarding adoption of practices (Teklewold, Kassie, & Shiferaw, 2013). A joint estimation could allow accounting for reality often faced by farmers in adopting practices and technology. Moreover, previous research suggested that relevant factors associated with adoption of practices can have a high degree of locations specificity (Wandel & Smithers, 2000), hence, it is important to have a localized understanding of the factors that influence adoption of practices which provide soil conservation and irrigation water efficiency.

The objective of the paper is to contribute to the literature on natural resource conservation by analyzing the factors that influence simultaneous adoption of soil conservation and water efficiency practices using a bivariate modeling approach. The results could help understand farmers' perception regarding conservation, and therefore help promote a conservation strategy (ies) focusing on long-term soil health improvement and water resource conservation. The analysis will help fill the gap that exists in the literature concerning the drivers of adoption of conservation practices within the region. The remainder of this paper proceeds as follows. Next section provides a brief overview of the theoretical framework. Section 3 describes survey design and data and summarizes sample characteristics. The empirical model results are presented in Section 4 while Section 5 provides conclusions.

2. Methodology

As mentioned in Section 1, several empirical studies have investigated the influence of socio-economic variables on farmers' adoption of soil conservation and water efficiency practices decisions separately (Habron, 2004; Kim et al., 2005). Farmers tend to adopt technologies and conservation practices that are perceived to be most economical (De Graaff et al., 2008); however, the decision to adopt multiple practices is more complex and could imply a long-term strategy to include conservation within the enterprise (Caswell et al., 2001). This study accounts for the interrelationships among adoption decisions and views adoption in terms of practices that address multiple resource concerns using practices that provide the most economic benefit to the farmers. This type of analysis, thus, examines the adoption of multiple practices. The advantage of this analysis is that it provides information on the type of producer who would adopt a specific technology under the two conservation strategies. Each strategy is thus treated differently. Our assumption is that decision to adopt soil management and water management practices might not be an independent decision but an interrelated one; the two joint decisions might be correlated. Hence, a model that would account for this joint distribution is preferred. We argue that the adoption of soil management practices is likely to condition positively the decision to adopt water management practices, and vice versa; thus, treating these decisions separately would generate biased estimates.

A bivariate probit, which considers two dichotomous decisions simultaneously and depicts these decisions as interdependent, is an extension of the individual probit (Greene, 1996), is used to analyze the data. In this case, the two decisions are to adopt/not-adopt a soil conservation practice and a water quality protection and conservation practice. The decision to adopt is conditioned by a set of variables related to natural, social, human, physical, and financial factors that explain the probability to accept the BMPs associated with the farm and the farmer (Adusumilli et al., 2014; Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008). Hence, the two dichotomous response variables, soil management practices, and water management practices, are coded 1 if a farmer adopts at least two conservation practices and 0 otherwise. The explanatory variables are based on the relevant literature. Following Greene (1996), the specification of the bivariate probit model can be expressed as

$$y_1^* = X_1'\beta_1 + \varepsilon_1 \tag{1}$$

$$y_2^* = X_2'\beta_2 + \varepsilon_2 \tag{2}$$

where y_1^* and y_2^* are latent unobserved variables which represent farmers' adoption decisions; X_1' and X_2' are vectors of potential explanatory variables that influence the farmer's decisions to adopt the BMPs; β_1 and β_2 are vector of associated parameters to be estimated. In this model, the stochastic errors, ε_1 and ε_2 are assumed to be normally-distributed with $E(\varepsilon_1) = E(\varepsilon_2) = 0, V(\varepsilon_1) = V(\varepsilon_2) = 1$, and $Cov(\varepsilon_1, \varepsilon_2) = \rho$. It also assumed that the two errors are independent of X_1' and X_2'. The observed dichotomous outcomes are specified as

$$y_1 = \begin{cases} 1, & if\ y_1^* > 0 \\ 0, & otherwise \end{cases} \tag{3}$$

$$y_2 = \begin{cases} 1, & if\ y_2^* > 0 \\ 0, & otherwise \end{cases} \tag{4}$$

The estimations in both Eqs. (1) and (2) with response variables indicated in Eqs. (3) and (4) can be derived from the joint distribution of y_1 and y_2 (conditional on X_1' and X_2'). These joint probabilities can be identified as

$$\Pr\left(y_1 = 1, y_2 = 1 X_1', X_2'\right) = \Pr\left(\varepsilon_1 > -X_1'\beta_1, \varepsilon_2 > -X_2'\beta_2\right) = \Phi_2(X_1'\beta_1, X_2'\beta_2, \rho) \tag{5}$$

$$\Pr\left(y_1 = 1, y_2 = 0 X_1', X_2'\right) = \Pr\left(\varepsilon_1 > -X_1'\beta_1, \varepsilon_2 < -X_2'\beta_2\right) = \Phi_2(X_1'\beta_1, -X_2'\beta_2, -\rho) \tag{6}$$

$$\Pr\left(y_1 = 0, y_2 = 1 X_1', X_2'\right) = \Pr\left(\varepsilon_1 < -X_1'\beta_1, \varepsilon_2 > -X_2'\beta_2\right) = \Phi_2(-X_1'\beta_1, X_2'\beta_2, -\rho) \tag{7}$$

$$\Pr\left(y_1 = 0, y_2 = 0 X_1', X_2'\right) = \Pr\left(\varepsilon_1 < -X_1'\beta_1, \varepsilon_2 < -X_2'\beta_2\right) = \Phi_2(-X_1'\beta_1, -X_2'\beta_2, \rho) \tag{8}$$

where Pr denotes probability, and Φ_2 stands for the bivariate standard normal cumulative distribution function, while other parameters were introduced in Eqs. (1) and (2). Using maximum likelihood method, the log-likelihood function of the bivariate probit model is given by

$$lnL(\beta_1, \beta_2, \rho) = \sum (y_1 y_2 ln\Phi_2(X_1'\beta_1, X_2'\beta_2, \rho) + \sum y_1(1 - y_2)ln\Phi_2(X_1'\beta_1, -X_2'\beta_2, -\rho) + \sum (1 - y_1)y_2 ln\Phi_2(-X_1'\beta_1, X_2'\beta_2, -\rho) + \sum (1 - y_1)(1 - y_2)ln\Phi_2(-X_1'\beta_1, -X_2'\beta_2, \rho) \quad (9)$$

3. Data and description of variables

3.1. The Best Management Practices (BMPs)

Significant effort has been devoted by conservation agencies and the Louisiana Master Farmer Program (LMFP) of the Louisiana State University Agricultural Center to encourage adoption of BMPs.[3] Thirteen specific soil management BMPs and 11 specific water management/efficiency BMPs were identified by the members of the technical committee, consisting of scientists from the Louisiana State University and state conservation agency personnel, of Louisiana Master Farmer Program (Table 1), as recommended BMPs that farmers can adopt to mitigate nutrient runoff as well as improve irrigation efficiency. Descriptions of each of the BMPs and effective implementation can be found in the Natural Resources Conservation Service Resource Management System (RMS) planning tool as well as in the Louisiana State University Agricultural Center publication 2807 (LeBlanc, Sceffield, Kruse, & Nix, 2011).

A summary of producers adopting each of the BMPs is included in Table 1. The most frequently adopted soil conservation practices were soil test every 3 years (67.62%), conservation tillage practices (60%), and rotate crops (59.05)%); the most frequently adopted water quality protection & water conservation/efficiency practices were water grassed waterways (vegetative ditches) (57.14%) and water-control structures (57.14%). These five BMPs were adopted by more than half of the respondents. Although some practices can be considered diagnostic practices, for example, soil testing, the practice is strongly recommended and is a precursor to any farm-wide nutrient management plan. In other words, nutrient use is based on the knowledge of residual nutrients in the soil so as to ration the nutrients needed for the next growing season. Hence, practices such as soil testing are considered recommended BMPs to achieve nutrient efficiency on the farm.

The least frequently adopted soil conservation practices were terraces of contour farm on extreme slopes (14.29), sub-soil or chisel in the fall (15.24%), and use zero grade fields in rice production (13.33%); on the other hand, the least frequently adopted water quality protection and water conservation/efficiency practices were side inlet irrigation in rice production (10.48%) and tailwater recovery system (4.76%). These five BMPs were adopted by less than 20% of the respondents. The frequency of adoption rates of BMPs is presented in Table 2. Forty percent of the sample has adopted at least six to eight recommended soil management practices, whereas, 34% have adopted three to five recommended water management practices, indicating that adoption of multiple conservation practices is often a norm in a production enterprise. Adoption of multiple conservation practices is perceived as a significant shift in a farmer's production strategy that is geared not only toward monetary benefits but also toward nonmonetary benefits, environmental protection, albeit over a long-term (Caswell et al., 2001). Hence, information on the number of management practices adopted provides an understanding of farmers' perception toward his/her long-term resource conservation strategy.

Table 1
Summary of producers adopting each of the BMPs.

Soil Conservation Practices	Adopters		Non-adopters	
	Freq.	Percent	Freq.	Percent
1. Farm-specific conservation plan	46	43.81	59	56.19
2. Soil test every 3 years	71	67.62	34	32.38
3. Grassed turn rows or pads around fields	49	46.67	56	53.33
4. Terraces or Contour farm on extreme slopes	15	14.29	90	85.71
5. Conservation tillage practices	63	60.00	42	40.00
6. Burn crop residue	16	15.24	89	84.76
7. Disc crop residue	44	41.90	61	58.10
8. Sub-soil or chisel in the fall	30	28.57	75	71.43
9. Rotate crops	62	59.05	43	40.95
10. Use cover crops	36	34.29	69	65.71
11. Use zero grade fields in rice production	14	13.33	91	86.67
12. Inject or side-dress fertilizers to reduce the amount on the soil surface	46	43.81	59	56.19
13. Use biological pest controls	29	27.62	76	72.38
Water Quality Protection &Water Conservation/Efficiency Practices				
1. Filter strips or buffers separating crop fields from drainage areas on your farm	38	36.19	67	63.81
2. Filter strips around mixing facilities	33	31.43	72	68.57
3. Grassed waterways (vegetative ditches)	60	57.14	45	42.86
4. Water-control structures (ex. pipes with riser)	60	57.14	45	42.86
5. Hold winter water on your fields	31	29.52	74	70.48
6. Use side inlet irrigation in rice production	11	10.48	94	89.52
7. Tailwater recovery system	5	4.76	100	95.24
8. Capture and use surface water for irrigation	20	19.05	85	80.95
9. Use computer programs to improve furrow irrigation efficiency	21	20.00	84	80.00
10. Prevent surface runoff from reaching the area immediately surrounding a water well	39	37.14	66	62.86
11. Utilize a closed or semi-closed mixing system	33	31.43	72	68.57

Table 2
Summary statistics for frequency of adopting the BMPs.

Percentage of Producers Adopting Each of the BMPs						
Number of Practices	Soil Management Practices			Water Management Practices		
	Freq.	Percent	Cum.	Freq.	Percent	Cum.
0	18	17.14	17.14	24	22.86	22.86
1	6	5.71	22.86	7	6.67	29.52
2	10	9.52	32.38	12	11.43	40.95
3	5	4.76	37.14	12	11.43	52.38
4	5	4.76	41.90	17	16.19	68.57
5	5	4.76	46.67	7	6.67	75.24
6	14	13.33	60.00	11	10.48	85.71
7	12	11.43	71.43	8	7.62	93.33
8	15	14.29	85.71	5	4.76	98.10
9	7	6.67	92.38	1	0.95	99.05
10	4	3.81	96.19	1	0.95	100.00
11	4	3.81	100.00			

[3] LMPF is a state-approved voluntary producer certification that a farmer would get once the required three phases of the certification process are complete. Several farmers across the state are known to be at different stages of Master Farmer certification process, i.e., some farmers might have finished Phase I and/or Phase II, which involves training and field-day participation, but not yet completed Phase III. Phase III, the final phase of the certification process, involves developing a farm-specific resource management plan, which will be approved by the state conservationist of the Natural Resources Conservation Service. Phase III plan requires farm-wide implementation of practices over several years to address the resource concerns on the farm. Once all resource concerns are addressed, a farmer would receive his/her Master Farmer certification.

3.2. Survey design and data summary

The focus of this study is to determine farmer's decisions concerning the adoption of soil management and water management practices, thus a detailed analysis requires the use of farmer survey data. The objective of the survey is to gather information on the BMPs currently adopted within crop and/or animal production practice across the state of Louisiana, a state in the humid-south of the United States. This information is then used to identify the potential opportunities within each parish (county) to develop workshops or training for farmers to promote adoption of nutrient management and irrigation management practices.

A data set of 500 sample of row crop and pasture farmer in Louisiana were used in this study. County agents provided contact information for the farmers in the region. Farmers, conservation agency personnel, and extension agents volunteered to test the survey for validity. The survey was designed and implemented using Dillman (2011) tailored design method for internet survey. The online survey was conducted during January 2016 to March 2016. The survey questionnaire was approved by the Louisiana State University Agricultural Center Institutional Review Board (IRB) during the first week of December, a month prior to the initiation of the online survey. In the second week of December, an initial email was sent as a pre-notification to 500 farmers. In the first week of January, an email of the survey was sent to the producers. A reminder email was sent three weeks later reminding the non-respondents to complete the survey. No incentive was provided to survey respondents. The survey asks detailed information about farm characteristics, producer characteristics, attitudes, current adoption of 13 soil management practices and 11 water management/efficiency practices.

The survey instrument consisted of four sections. The first section contained multiple choice questions on perceptions regarding nutrient management and water quality practices and their impact on natural resource conservation. The second section contained questions on nutrient management practices adopted within row crop and pasture production. The third section contained questions on water management practices within row crop and pasture production. The final section gathered socio-demographic information. Removing the undelivered surveys and incomplete surveys, a total of 105 surveys were usable toward the analysis. Dillman et al. (2009) provide guidance for minimum samples sizes needed to get results that reflect the target population and corresponding level of sampling error.[4] The 105 responses usable for analysis are above the 10% margin of sampling error. Of the total, the majority of farmers (77%) adopted at least two soil management practices, while 70% of farmers reported that they used at least two water management practices.

Survey results were compiled into Microsoft Excel for data cleaning and analysis. Data were analyzed using Statistical Analysis Systems software, version 9.4 (SAS Institute Inc, 2013). Table 3 presents a summary of demographic data obtained from the survey. Response on the age of the decision maker was categorized into five groups, from 20 to over 60 years old. About 38% of farmers were more than 60 years old, followed by the farmers who were 51–60 years old (26%), while about 35% of farmers were less than 50 years old. In terms of annual gross farm revenue, less than 25% of respondents reported that they had annual gross farm revenue of $249,000 or less, while 10% of the respondents had annual gross farm revenue in the range of $250,000 to $499,000. In addition, about 13% of respondents had annual gross revenue ranging from $500,000 to $1000,000, while 34% of the respondents reported annual gross revenue over $1000,000. With respect to education, more than half of the survey respondents reported having a bachelor degree while 14% of the total respondents reported a graduate or professional degree. About 3% respondents reported a technical/vocational degree and about 31% of the total respondents reported a college degree or less. In addition, the survey sought to determine the numbers of years in farming. Majority of respondents (73%) reported 15 or more years in farming business.

Table 3
General socioeconomic and demographic characteristics of farmer.

Description	Percent (%)	Cumulative percent (%)
Age of the decision maker for your farm operation		
20–30	3.13	3.13
31–40	15.63	18.75
41–50	16.67	35.42
51–60	26.04	61.46
Greater than 60 years	38.54	100.00
Annual gross farm revenue		
Less than $50,000	4.39	4.39
$50,000–$99,000	7.02	11.40
$100,000–$249,000	13.16	24.56
$250,000–$499,000	9.65	34.21
$500,000–$1000,000	13.16	47.37
Greater than $1000,000	34.21	100.00
Highest level of education		
Graduate or professional degree	13.68	13.68
Bachelor degree	52.63	66.32
Technical/vocational degree	3.16	69.47
Some college	20.00	89.47
High school	10.53	100.00
Numbers of years in farming		
Less than 5 years	5.25	8.25
5–10 years	12.37	20.62
11–15 years	6.19	26.80
16–20 years	6.19	32.99
Greater than 20 years	67.01	100.00

Descriptive statistics for total BMPs adopted in Table 4 showed that the mean number of soil management practices adopted was 4.96 with a range of 0–11, while the average number of water management practices adopted was 3.34 with a range of 0–10.

Table 4
Summary statistics on number of BMPs adopted from each conservation strategy.

	Mean	Std. Dev.	Min	Max
Soil Conservation Practices	4.96	3.42	0	11
Water Quality Protection &Water Conservation/ Efficiency Practices	3.34	2.64	0	10

3.3. Factors influencing decisions to adopt BMPs

This section defines the response and potential explanatory variables employed in the econometric model (bivariate probit model). A list of response and explanatory variables and descriptive statistics of these variables are given in Table 5.

As mentioned, the response variables are whether or not the farmer adopts at least two soil management practices and whether or not the farmer adopts at least two water management practices. The response variables are represented by binary variables y_1 (*SOIL_MGMT*) and y_2 (*WATER_MGMT*) equal to 1 if the farmer adopted at least two soil management practices and water

[4] The equation to calculate the sampling size: $N_s = N_p p(1-p)/(N_p-1)(B/C)^2 + p(1-p)$, where N_s is the sample size needed for the corresponding level of error, N_p is the size of the population (~500), B is the acceptable amount of sampling error (we assume 10%), C is the statistical certainty usually set at the 95% confidence level (1.96),and p is the estimated level to be investigated, usually a p=0.5 is chosen. These parameters yielded a sample size of 81.

Table 5
Variable definitions and descriptive statistics.

Variable	Description	Mean	Std. Dev
Response Variables			
SOIL_MGMT	Farmer who adopts at least two soil management practices = 1; Else = 0	0.77	0.42
WATER_MGMT	Farmer who adopts at least two water management practices = 1; Else = 0	0.70	0.46
Explanatory Variables			
ATTITUDE	Farming practice affect water quality = 1; Else = 0	0.91	0.28
CROPSONLY	Farmers own commodity/vegetable crops only = 1; Else = 0	0.49	0.50
LANDOWNED	Owned majority of land = 1; Else = 0	0.50	0.50
CROPACRES	Crops acre < = 500 acres = 1; Else = 0	0.49	0.50
ENROLLED	Enrolled in at least one federal program = 1; Else = 0	0.52	0.50
LSUNRCS	LSU Agcenter and/or NRCS-source of information = 1; Else = 0	0.57	0.49
FARMINGYEAR	Number of years in farming less than 15 years = 1; Else = 0	0.25	0.43
INCOME ($)	Farmers' annual gross revenue less than $500,000 = 1; Else = 0	0.53	0.50
EDUCATION	Technical/college degree or less = 1; Else = 0	0.30	0.46
AGE	40 years or younger = 1; Else = 0	0.17	0.38

management practices and 0 otherwise, respectively. Farmer characteristics included both socioeconomic and demographic variables as well as variables representing opinions held by the farmers. Explanatory variables include farmers' belief about the relationship between farming practices and water quality (*ATTITUDE*), type of farm operation (*CROPSONLY*), percent of land owned (*LANDOWNED*), number of acres farmed during the most recent cropping year (*CROPACRES*), participation in federal programs (*ENROLLED*), source of technical assistance, i.e., support from LSU AgCenter Research or Extension and/or Natural Resource Conservation Services (*LSUNRCS*), number of years in farming (*FARMINGYEAR*), annual gross farm revenue (*INCOME*), education level (*EDUCATION*), and age of the farmer (*AGE*). The discussion for these variables is provided below.

3.3.1. Attitude

For purpose of this analysis, *attitude* was coded 1 if a farmer believed that farming practices affect water quality. Producers were asked about their perception of the relationship between conservation practices and water quality. Dummy variable *attitude* was included to capture producers' awareness.

3.3.2. Cropsonly

Farmers adopt conservation practices to mitigate resource concerns that are more prevalent on their farm. Certain practices are can address multiple resource concerns, whereas, some are unique to address a resource concern. Similarly, certain conservation practices can fit any production enterprise, crop and/or pasture. For example, cover crops can be used as a practice to minimize soil loss as well as water retention in the crop as well as in a pasture setting. Farmers with a portfolio that includes both crops and pasture or livestock could be more likely to adopt a practice that can achieve multiple benefits rather than a practice that achieves a single benefit. Hence, the *cropsonly* variable is used in this study to account for the farmers that have either only crops or crops, pasture, and livestock. The variable takes a value of 1 for crops and 0 otherwise.

3.3.3. Landowned

Natural Resources Conservation Service (NRCS) cost-share program, Environmental Quality Incentives Program (EQIP), provides incentives at varying levels for farmers to adopt conservation on the ground. The program has certain predetermined eligibility criteria to qualify for the cost-share program. One such criterion is the ownership of the land, i.e., a farmer who intends to adopt these conservation practices and wishes to utilize the cost-share program must own the land. In the case of leased land, farmers would need the approval of the landowner to adopt a conservation practice on that land. Moreover, in some instances, it may take several years to generate positive net returns by a conservation practice, which is likely to influence adoption if the land is rented (Henning & Cardona, 2000; Soule, Tegene, & Wiebe, 2000). Thus, ownership of land or lease arrangements could strongly influence participation in a cost-share program and conservation adoption. The variable *landowned* is used to account for ownership of land in this study. The variable would take a value of 1 if the land is owned and 0 otherwise.

3.3.4. Cropacres

For purpose of this analysis, *cropacres* was coded 1 if the number of acres used less than or equal to 500 acres during the most recent cropping year and 0 otherwise. Farms that are between 200 and 500 acres constitute majority of the farms in the southern United States, more specifically farms located in the Arkansas-Red River basin and the Lower Mississippi River basin (USDA-FRIS, 2014), which provides justification that these farms of 500 acres or less can play a major role in mitigating agricultures' negative environmental impacts in the region. Moreover, previous studies suggested that large-sized farms, greater than 250 acres, are generally more likely to adopt technology than smaller ones (Westra & Olson, 1997). In this study, the variable *cropacres* is used to account for farm size effects.

3.3.5. Enrolled

For purpose of this analysis, *enrolled* was coded 1 if the farmer previously participated in any federal program and 0 otherwise. This variable was included to examine whether those that have participated in the federal cost-share program in the past were more likely to adopt BMPs. Farmers that participated in the cost-share program are not only more likely to be familiar with the process but also understand that practices that address multiple resource concerns are more preferred and would provide more economic benefit.

3.3.6. Lsunrcs

For purpose of this analysis, *lsunrcs* was coded 1 if the farmer obtained technical assistance and production research support from LSU AgCenter Research or Extension and/or Natural Resource Conservation Services and 0 otherwise. Land-grant universities and conservation agencies have strong programs in place to promote adoption of conservation practices to address natural resource concerns. Information provided by these agencies can influence adoption (Traore, Landry, & Amara, 1998); hence, variable *lsunrcs* was considered a determinant of BMP adoption in this study.

3.3.7. Farmingyear

For purpose of this analysis, *farmingyear* was coded 1 if the farmer operated his/her farm for less than or equal to 15 years and 0 otherwise. The effect of experience has been examined in a number of adoption studies (Caswell et al., 2001; Gould, Saupe, & Klemme, 1989). Relatively young farmers are expected to more likely adopt conservation practices and agricultural technology with an expectation that returns can be captured on the investment over the long-time horizon that he/she intends to be in farming business. Variable *farmingyear* is used to account for the length of time in farming business.

3.3.8. Income

For purpose of this analysis, *income* was coded 1 if the farmers' annual gross revenue from farming is less than $500,000 and 0 otherwise. Farmers might be reluctant to adopt practices if their farm income might decline as a result. Research has found that farmers are slow in adopting practices if a sizeable amount of their income is from farming (Traore et al., 1998). On the other hand, higher levels of income could imply fewer financial constraints and a greater ability to purchase technology, equipment, and materials.

3.3.9. Education

For purpose of this analysis, *education* was coded 1 if a farmer had a technical/college degree or less and 0 otherwise. A higher education level is expected to increase the awareness of conservation, its impact on natural resources, and improve decision making regarding adoption of conservation practices (Caswell et al., 2001).

3.3.10. Age

For purpose of this analysis, *age* was coded 1 if a farmer was 40 years or younger and 0 otherwise. The influences of *age* on adoption of BMPs is not consistent with previous studies. Mango et al. (2017), for example, found that adoption of land, soil, and water conservation practices by farmers increase with *age*. Moges and Taye (2017), on the other hand, found that *age* had a significantly negative influence on farmer's decision to invest and participate in conservation programs. Daberkow and McBride (2003) pointed out that the *age* of the farmer does not significantly influence the farmer's decision to adopt the precision agriculture technologies. Given the inconsistency among studies examining the influence of age on adoptions, the expected relationship between age and adoption of the BMPs in this study is unknown.

4. Results and discussion

The maximum-likelihood estimates of the bivariate probit model are given in Table 6 with associated standard errors. Estimates for soil management practice equation and water management practice equation are presented in Table 6. The results reveal that, overall, the parameter estimates are significant, with a log-likelihood value of −56. In addition, the rho (ρ) coefficient is positive and significant at the 1% level, indicating that the disturbance terms of the two equations are correlated, which indicated that the bivariate probit model is more appropriate than a univariate probit model. Significant variables in the bivariate model influence the decision of whether or not to adopt the BMPs and can be interpreted as increasing or decreasing the likelihood of adopting conservation practices.

In the Soil management practices equation, five coefficients out of ten are significant at the 10% level or better. Two coefficients are marginally significant. *ATTITUDE, CROPSONLY,* and *ENROLLED* all have a positive and significant effect on the likelihood of adopting conservation. *LANDOWNED* and *FARMINGYEAR* have a negative and significant influence on adoption. Variables *CROPACRES* and *LSUNRCS* have a positive and marginally significant effect on adoption. In the water management practices equation, three coefficients out of 10 are significant at least at the 10% level or better. *CROPSONLY, ENROLLED,* and *EDUCATION* have a positive and significant effect on adoption.

The variable *ATTITUDE* represents a binary variable that captures the perception of an individual regarding the role farming practices can play in protecting the water quality in surrounding waters. As expected, the coefficient is positive and significant suggesting that those who believe that conservation on land and modifications to current farming practices can result in water quality protection in streams and rivers are more likely to adopt conservation.

Table 6
Estimation results of bivariate probit model.

Explanatory Variables	Response Variables			
	SOIL_MGMT		WATER_MGMT	
	Coefficient	Standard Errors	Coefficient	Standard Errors
ATTITUDE	0.929*	0.555	0.123	0.537
CROPSONLY	0.985**	0.425	1.251***	0.421
LANDOWNED	−1.000**	0.444	−0.416	0.411
CROPACRES	0.565	0.360	0.204	0.359
ENROLLED	0.888**	0.370	1.426***	0.397
LSUNRCS	0.537	0.340	0.176	0.342
FARMINGYEAR	−0.950**	0.470	−0.418	0.434
INCOME	0.604	0.425	−0.023	0.404
EDUCATION	0.529	0.466	0.766*	0.459
AGE	−0.154	0.472	−0.420	0.467
Constant	−0.817	0.607	−0.456	0.607
Log-Likelihood = −56.460				
Rho (ρ) = 1.0***				
Number of observations = 105				

Note: *, **, and *** donate significance at 10%, 5%, and 1% levels, respectively. Standard errors reported.

The variable *ENROLLED* that measures whether an individual in the past has participated in a conservation cost-share program. The assumption is that those that participated have a better understanding of the expectations of the conservation program and would likely adopt additional conservation. As expected, the coefficient is positive and significant.

The variable *LANDOWNED* is negative and significant. It is interesting to see that those who farm own-land rather than leased-land are less likely to adopt conservation practices. Previous research has found mixed results where ownership status has a negative impact on the number of conservation practices adopted (Lynne, Shonkwiler, & Rola, 1988), a positive impact on the number of practices adopted (Rahelizatovo & Gillespie, 2004) or no impact at all (Daberkow & McBride, 2003). We think that farmers who farm majority of leased-land have more incentive to adopt given that some of the conservation practices can produce benefits quickly, which could compensate for land rent payments and justify investments, whereas those returns from conservation might not fully justify investments by land-owners. Moreover, some land-owners might not meet the eligibility criteria for participation in the conservation cost-share programs; however, the effect is not easy to narrow down to a single factor.

Similarly, those that have been in farming for less than 15 years, captured through the variable *FARMINGYEAR*, are less likely to adopt. It was our expectation that for those who are relatively young to farming would be more inclined to adopt conservation practices; however, it could be that the majority of their returns are allocated toward equipment and land payments; thus, would have less to invest in conservation practices and technologies (Soule et al., 2000). Moreover, conservation practices could involve extra labor and time, which in some cases can be a deterring factor. The result is consistent with mixed findings reported in the literature. Amsalu and De Graaff (2007) argued that experience in farming is expected to have a positive effect on adoption. On the other hand, researchers argued that young farmers are more aware of the benefits of BMPs and are more likely to adopt conservation practices and new technologies (Gould et al., 1989).

The variable *EDUCATION* is consistent with our expectation that higher the education, it would provide a greater understanding of the link between conservation and crop profitability. The result is consistent with results reported by previous research.

5. Conclusions

We investigated the joint decision of adoption of BMPs, factors that influence adoption, and types of producers most likely to adopt the BMPs. The results reveal that the overall predictive ability of the model is statistically high; hence, is a suitable approach. Adoption of BMPs presents an interesting situation. Adoption of a BMP may not be independent of adoption of another BMP because many of them may be complimentary practices. Conventional wisdom suggests that fewer BMPs with the capacity to address multiple resource concerns would be preferred to a BMP that would address only one resource concern; however, the cost of implementation of such practices might take a bigger role in the decision-making. Information about these factors and a number of variables that affect adoption decisions can help shape policy and tailor outreach to farmers by conservation agencies as well as land-grant universities.

Farmers' perceptions regarding practices and the suitability of the practice to current farming methods strongly influenced adoption. Ownership, participation in conservation programs in the past, years in farming, education are important variables that have an influence on adoption. The significant role of ownership on adoption of practices suggests the need for strengthening institutions to accelerate adoption among farmers renting land for farming. Adoption can be greatly limited and gains in benefits from conservation could be minimal if efforts are not targeted to increase adoption of practices on rental lands through programs decisions.

The importance of tenure (number of years in farming) calls for improving opportunities for young farmers and ranchers to enter farming business by providing access to capital, bridge knowledge gap through education, and improve safety-net programs and risk-management programs. Similarly, the effect of participation in conservation programs in the past provides an opportunity for special focus on facilitating participation in government programs through a change in farm policies. More effort is needed to target those farmers that have not participated in the government farm programs because they tend to be slow in recognizing that their operations might pose environmental problems and the conservation practices might provide long-term gains that exceed their short-term costs. In addition, information on consequences of management practices and long-term productivity gain should be disseminated through various extension channels such as producer meetings, workshops, and field days, which could influence their perception regarding these practices. Indeed, our results indicate that perception regarding consequences and conservation practices helps stimulate awareness and improve adoption.

Moreover, there are no physical limits to the number of BMPs that can be used on the farm. Information should be disseminated on practices that can address various resource concerns on the farm and practices that are compatible with current farming methods. The programs should emphasize and allow adoption of a package of practices that would address multiple resource issues. Finally, it is important for policymakers to recognize, as suggested by our results, that farmers differ in their attributes and their characteristics and such information is critical for farm policymakers to define their strategies for an effective conservation policy.

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