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# Adopting Cover Crops and Buffer Strips to Reduce Nonpoint Source Pollution: Understanding Farmers’ Perspectives in the U.S. Northern Great Plains

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# Adopting cover crops and buffer strips to reduce nonpoint source pollution: Understanding farmers' perspectives in the U.S. Northern Great Plains

**Abstract:** Agricultural nonpoint source pollution has been identified as a major cause of water quality impairments. Utilizing survey data from the Northern Great Plains, this paper provides a better understanding of farmers' perceptions on water quality issues in their local areas. Excessive algal bloom and aquatic plants were among producers' top water quality concerns in North Dakota, South Dakota, and Nebraska. Fertilizers/pesticides were perceived as either not a problem (28.7%) or a slight problem (43.7%) when it comes to the water pollution sources. While only 17.2% of the respondents indicated agreement upon paying taxes to help protect the local water quality; 43.5% agreed to implement conservation practices (CPs) at some cost; and 70.1% agreed to implement CPs at no direct cost to farmers to improve water quality. This paper examined the factors associated with the adoption of cover crops and buffer strips. We found that producers' adoption decisions of cover crops largely hinged on farm characteristics and management variables, such as land ownership, farm size, livestock ownership, and adoption status of other farm management practices, while water quality information and producer perceptions affected the adoption decisions of both cover crops and buffer strips. To further promote CP adoption and reduce water pollution, our results highlighted the importance of both monetary incentives and outreach efforts that disseminate information on water pollution status, pollution sources, as well as technical support on CPs suitable for the farm.

**Key words:** adoption—best management practice—buffer strip—cover crop—nonpoint source pollution

**Agricultural nonpoint source pollution has been identified as a major cause of water quality impairments in the United States (USEPA, 2017).** Increased fertilizer use, while contributing to increased productivity, leads to pollution of aquatic ecosystems when not absorbed by the plants (Savci, 2012). Nitrogen is often regarded as one of the best inputs in terms of cost-effectiveness, therefore its over-application is common (Pikul *et al.*, 2005; Scharf *et al.*, 2005). With plant nutrient uptake as low as 30%, the unabsorbed nitrogen is susceptible to leaching and surface runoff (Legg and Meisinger, 1982).

Soil, when left without plant coverage for an extended time period, can be eroded at an accelerated rate (Montgomery, 2007). Rainwater carries soil sediments, as well as the nutrients and agricultural chemicals that attach to the soil particles to nearby waterbodies. A high nitrate level in water in return causes various aesthetic, health and economic issues, including rapid growth of aquatic plants and algal bloom, decreased fish population, polluted swimming and boating areas, potential health risks, and eroded tourism revenues (Bhargava, 1994; Suplee *et al.*, 2009; Ward, 2009; Khan *et al.*, 2018; Nieman *et al.*, 2018).

By making decisions on selecting conservation practices (CPs), farmers play a critical role in reducing the nonpoint source pollutants and their negative, unintended consequences. Cover crops have been identified as an effective practice that can improve water quality by providing a protection cover to the soil. In addition to reducing the energy of rainfall on soils, cover crops also help improve soil infiltration and water storage capacity. As a return, cover crops can decrease runoff by up to 80% and reduce sediment loss of between 40% and 96% (Blanco-Canqui *et al.*, 2015). Cover crops reduce runoff of phosphorus that is contained in both soluble runoff and eroded soil particles (Zeimen *et al.*, 2006). Cover crops can also absorb excessive soil nitrogen during spring when the crop utilization rate is low (Strock *et al.*, 2004; Tonitto *et al.*, 2006; Castellano *et al.*, 2012). For example, rye cover crops can scavenge between

25% and 100% of residual nitrogen from cornfields, thereby preventing the nutrients from washing into nearby water bodies (Clark, 2012). In addition to the aforementioned off-site social benefits, cover crops also possess on-site farm benefits such as enhancing cash crop yield through soil health improvement (Carlson and Anderson, 2012; CTIC, 2014; Dagel *et al.*, 2014; CTIC, 2015), suppressing weed, reducing pest pressures (Montgomery, 2007; CTIC, 2017), and generating additional revenue from haying and grazing (Lichtenberg, 2004).

Even with the well-documented benefits, challenges remain due to the difficulties in cover crop establishment, upfront economic costs, unpredictable yield benefits, and variations in weather and soil conditions (Bergtold *et al.*, 2012; CTIC, 2015). One of farmers' concerns when considering cover crop adoption is successful establishment of cover crops to get the associated benefits. According to a U.S. nationwide cover crop survey (CTIC, 2017), 73% of the respondents planted cover crops after harvesting cash crops. Regions with a short growing season have a short window to plant cover crops because cover crops that are not winter hardy such as legumes, need at least 4 to 6 weeks to obtain full benefits (MCCC, 2015). In addition, the benefits of cover crops are also contingent on other implemented CPs such as no-till, as long-term no-till use can strengthen the soil benefits of cover crops while tillage weakens such benefits (Hoorman, 2009; Clark, 2012). Despite the cost-share programs, short-term cover crop use generally reduces farm profitability (Plastina *et al.*, 2020). Risks and extra costs render cover crop adoption potentially more challenging than the other recommended nutrient management practices (Fan *et al.*, 2020)

Buffer strips, also referred to as buffer zones, riparian buffers, filter strips, grassed waterways, are well-established agricultural practices that effectively trap sediment in the field and reduce the nonpoint source pollutants from agricultural production (Dosskey, 2001; Hebblethwaite and Somody, 2008; Stutter *et al.*, 2012; NRCS, n.d.). The use of perennial grasses or trees as buffer strips between agricultural fields and water bodies can effectively intercept water flow and reduce soil sediments, nutrients and chemicals from runoff (Castelle *et al.*, 1994; Blanco-Canqui *et al.*, 2004; Dabney *et al.*, 2006). Previous studies have shown that buffer strips' sediment trapping efficiencies vary between 41% and 100% (Helmers *et al.*, 2008; Liu *et al.*, 2008) and nitrate reduction efficiencies between 25% and 100% (Daniels and Gilliam, 1996; Simpkins *et al.*, 2002).

Relative to cover crops, the benefits offered by buffer strips are primarily off-site. In addition to the establishment and maintenance costs of buffer vegetation, buffer strips on cropland also incur the opportunity cost of foregone crop production and those on pastureland also incur forgone livestock production and livestock exclusion (fencing) cost (Liu *et al.*, 2011). Based on six counties in the Lower Kentucky River Basin, Liu *et al.* (2011) estimated the total annualized costs of riparian buffers for cropland varied between $110 and $621 per acre, while those for pastureland ranged between $105 and $128 per acre. Despite the offered financial incentives by programs such as Conservation Reserve Program (CRP) and Environmental Quality Incentives Program (EQIP), additional costs and lost production remain the major concerns regarding buffer strip adoption. Other constraints to buffer strip adoption include increased labor and management costs, and uncertain economic circumstances (Liu *et al.*, 2008; Klapproth and Johnson, 2009; Rhodes *et al.*, 2018).

Both cover crops and buffer strips are highly recommended conservation practices to reduce soil erosion, nutrient leaching, and thereby reducing the pollution of groundwater and surface water. Yet the adoption rates of these practices remain low. For example, a study utilizing farmer survey data in Maumee watershed of Ohio found that even though 42.3% farmers used cover crops *sometimes*, only 7.9% planted cover crops *all the time,* while 29.2% and 34.7% reported *always* using grass waterways and filter strips, respectively (Wilson *et al.*, 2013). The relatively low adoption rates further motivate studies that examine influencing factors of farmers' adoption decisions, which are likely to vary across different conservation practices (Knowler and Bradshaw, 2007; Prokopy *et al.*, 2008; Prokopy *et al.*, 2019). This study aims to understand the motivating and constraining factors that affect farmers' adoption behavior of two conservation practices—cover crops and buffer strips. Cover crops generate a combination of on- (private) and off-site (public) benefits, while buffer zones primarily target the off-site (public) benefits. As the recommended policy mechanisms that encourage the two practices differ (Pannell, 2008), we examine the potential disparities in the influencing factors that affect adoption decisions of the two practices.

We carried out a mail survey among farmers in the Northern Great Plains of U.S., comprising North Dakota (ND), South Dakota (SD), and Nebraska (NE). Agricultural production is the major contributor of the region's economy, yet a lack of adequate conservation practices has greatly compromised the beneficial uses of local water bodies. In North Dakota, 68% of the 4,864 assessed river and stream miles were either threatened for or not fully supporting aquatic life use as of 2018 (NDDH, 2019). Similarly, 78% of the 5,875 stream miles in South Dakota were found not supporting one or more beneficial uses of the water during the 2014-2019 period (SDDENR, 2020). Among 13 major river basins in Nebraska, while the basin at the best condition had 59% of the streams in good condition, the basin that presented most concerns only had 14% of the streams in good condition (NDEQ, 2016). A site-specific conservation system approach is needed to reduce nonpoint source pollution and improve water quality in this region. Therefore, the main objectives of this study are to (1) understand farmers' perceptions on water pollution sources and measures they desire to adopt to improve water quality; (2) understand the current adoption status of two best management practices, namely cover crops and buffer strips; (3) explore a combination of sociodemographic factors that are likely to influence cover crop and buffer strip adoption; and (4) identify ways to improve outreach and engagement in order to increase future conservation practice adoption.

## Materials and Methods

### *Empirical Model.*

The outcome variables, cover crop adoption and buffer strip adoption, are binary in nature. They are denoted as 1 when a farmer adopts the practice, and 0 otherwise. Due to the potential correlation between the two CP adoption decisions, we first estimated a bivariate logit model for the joint adoption decisions of cover crops and buffer strips. We found the correlation coefficient between the errors when jointly modeling the two latent variables for adoption decisions was not significantly different from 0, which means cover crop and buffer strip adoption decisions are not interrelated. Therefore, logistic regression models were employed in the analysis to explain the adoption behaviors of two CPs separately using multiple explanatory variables (Hastie *et al.*, 2009; Greene, 2018).

Logistic regression is specified as a latent variable model. Let $Y_i$ and $Y_i^*$ denote the actual adoption behavior and the continuous latent adoption tendency for individual $i$, respectively. The actual adoption occurs if the adoption tendency is positive, and no adoption will occur otherwise, as indicated in Equation (1):

$$(1) \qquad Y_i = \begin{cases} 1, & \text{if } Y_i^* > 0 \\ 0, & \text{otherwise} \end{cases}$$

Denote $\boldsymbol{X_i} = \left[X_{i1}, X_{i2}, \cdots, X_{ip}\right]^T$ as the vector of explanatory variables for individual $i$. The latent adoption tendency variable $Y_i^*$ is modeled as in Equation (2):

$$(2) \qquad Y_i^* = \beta_0 + \boldsymbol{X_i^T \beta} + \epsilon_i$$

where $\epsilon_i \sim \text{Logistic}(0,1)$, $\beta_0$ is the intercept term, and $\boldsymbol{\beta} = (\beta_1, \beta_2, \cdots, \beta_p)^T$ is the vector of regression coefficients. That is, the latent variable $Y_i^*$ is written as the sum of a linear predictor function $\beta_0 + \boldsymbol{X_i^T\beta}$ and an error term that follows a standard logistic distribution (Greene, 2018).

Then we can derive the formulae for the adoption probability, $P(Y_i = 1)$, the odd, $P(Y_i = 1)/P(Y_i = 0)$, and the logit expression, $\ln\left(\frac{P(Y_i=1)}{1-P(Y_i=1)}\right)$, as the following:

$$P(Y_i = 1) = \frac{e^{\beta_0 + \boldsymbol{X_i^T\beta}}}{1+e^{\beta_0 + \boldsymbol{X_i^T\beta}}} \tag{3}$$

$$Odd_i = P(Y_i = 1)/P(Y_i = 0) = e^{\beta_0 + \boldsymbol{X_i^T\beta}} \tag{4}$$

$$Logit_i = \ln\left(\frac{P(Y_i=1)}{1-P(Y_i=1)}\right) = \beta_0 + \boldsymbol{X_i^T\beta} \tag{5}$$

In the logit model, the logit is modeled as a linear function as in Eq. (5). For clarity, we can suppress the subscript *i* in Eq. (5) and obtain:

$$Logit = \ln(Odd) = \beta_0 + \boldsymbol{X^T\beta} \tag{6}$$

One small unit change in the *j*-th explanatory variable, holding other variables unchanged, will have the marginal effect of $\beta_j$ on the logit, i.e., log transformation of the odd. Denote the odds ratio (OR) as $OR = Odd_{after}/Odd_{before}$, we have:

$$\ln(OR) = \ln(Odd_{after}) - \ln(Odd_{before}) = Logit_{after} - Logit_{before} = \beta_j \tag{7}$$

Therefore, $OR = e^{\beta_j}$. The coefficient vector is estimated using Maximum Likelihood Estimation (MLE) and the statistical inference is conducted based on the statistical properties of MLEs (Scott Long, 1997; Hosmer and Lemeshow, 2000). Denote the MLE estimator of $\boldsymbol{\beta}$ as $\widehat{\boldsymbol{\beta}}$. According to the invariant property of MLE, the MLE estimator of odds ratio can be estimated as $\widehat{OR} = e^{\widehat{\beta}_j}$ (Greene, 2018; Hastie et al 2001). Testing the significance of $\beta_j$ from 0, i.e., $\beta_j$ = 0 is equivalent to testing the significance of odds ratio from 1, i.e., $OR = 1$. The two tests share the same p value and significance level (Hosmer and Lemeshow, 2000; Greene, 2018). We conducted logistic regression using logit function STATA software (version 15.0). Estimation and statistical inference were implemented using STATA software (StataCorp, 2017).

***Survey Description.***

The mail survey was conducted in three states of the Northern Great Plains, i.e., North Dakota, South Dakota, and Nebraska, to understand agricultural producers' perceptions of water quality problems in their local areas and the conservation practices they adopted to improve soil health and water quality. We conducted the survey from January to March in 2018 utilizing the "Dillman Method" (Dillman *et al.*, 2014), which involved an advance letter, two mailings of survey questionnaires, followed by a reminder or thank you letter after each mailing of survey questionnaire. In addition to the hardcopy survey questionnaire, recipients were also provided with the option to complete the survey online. We obtained the producer addresses from publicly available online sources, including federal farm subsidy databases, White Pages, and Manta. Together, we had 3,218 farmer addresses, with 877, 1,314 and 1,027 addresses from North Dakota, South Dakota, and Nebraska, respectively. The survey sample contained 3,177 eligible addresses from the sample of a 2016 farm survey (Wang *et al.*, 2019), plus 41 additional addresses supplied by university students, Extension specialists, and researchers from U.S. Department of Agriculture.

Among the selected survey samples, 79 were categorized as ineligible due to reasons such as no longer farming, undeliverable or deceased. Of the 3,139 eligible samples included in the surveys, 620 (19.8%) responded, and 574 completed the survey questionnaire in a manner that is useful for our analysis, resulting in an effective survey response rate of 18.5%. Overall, our survey response rate is comparable with other published studies that surveyed agricultural producers using generic databases (Fielding *et al.*, 2005; Werner *et al.*, 2017; Wang *et al.*, 2020a). Of those completed surveys, 482 were returned by mail, and 92 were completed online. Among the 574 effective survey responses, 109 (19.0%), 309 (53.8%), and 143 (24.9%) were from ND, SD, and NE, respectively, while 13 (2.3%) did not provide the unique IDs that link with the states.

While publicly available sources offer free and readily available farm addresses, a limitation is that no pre-selection criteria could be imposed. To evaluate the representativeness of our survey sample in each of the study states, we compared respondent information with state average information in 2017 Agricultural Census (NASS, 2017). Respondent average ages in ND, SD, and NE were 62.2, 61.7 and 65.9 years respectively, compared with the state average principal operator ages of 57.6, 57.8 and 57.8, respectively. On average, respondents reported farm acres of 3,297, 1,649 and 1,286 respectively for ND, SD, and NE. This is greater than the average farm acres of 1492, 1443 and 971 in ND, SD, and NE respectively, as calculated using total operated acres divided by total number of operations in each state according to NASS (2017). These findings indicate our survey respondents were on average older and operating more acres when compared to the state average data.

***Data Description.***

The survey inquired producers on how compromised water quality in their local areas had affected their lives in various aspects. We summarized the potential issues listed in the questionnaire into two major categories in Table 1, comprising 1) environment and recreation issues, and 2) health and economic issues. Six issues were listed under the first category, which are 1) excessive aquatic plants; 2) excessive algal bloom; 3) decline in water birds and wild animals; 4) polluted swimming areas; 5) fishing; and 6) canoeing, kayaking or boating. Similarly, six health and economic issues caused by poor water quality were included in the second category, namely 1) health problems; 2) water in the local area no longer suitable for drinking; 3) fish in the local area no longer suitable for eating; 4) death of livestock; 5) decrease of property values; and 6) negative impact on tourism. For each issue, producers can choose one of the four categories: 0 = ‘not a problem’; 1 = ‘slight problem’; 2 = ‘moderate problem’; and 3 = ‘severe problem’.

To examine farmers’ adoption decisions on cover crops and buffer strips as well as effects of influential factors, we recoded the 5-scale choices on cover crops and buffer strips to two dummy variables, with 1 = ‘currently using’ and 0 = ‘never heard of’, ‘somewhat familiar’ or ‘know how to use but do not use’. We excluded the observations where farmers who regarded cover crops or buffer strips as ‘not applicable’ on their farms in the corresponding regression models. Table 2 provides descriptions of the explanatory variables used in the regression models. Based on factor types, we divided them into four broad categories. Several survey questions were asked to gather information associated with farmer characteristics including farmer age, education level, and gender. Among these, farmer age is a continuous variable, whereas the education level is a binary variable which takes the value 1 for those who have some college, college degree or above and the value 0 for those who have some high school or high school degree. Gender is also a binary variable, with 1 and 0 standing for male and female, respectively.

Under the farm characteristics and management category, we considered five variables, namely, land ownership and size, livestock ownership, and adoption status of conservation tillage (CT) and diversified crop rotation (DCR). Survey respondents were asked about the type of land ownership with three options, namely, tenant, both and owner, denoted as 1, 2, and 3, respectively. Livestock ownership and adoption status of CT and DCR are binary variables that take two values with 1 = ‘yes’ and 0 = ‘no’.

Other than the farmer and farm characteristics categories, we also included the information and perception category to capture farmers’ information source, perceptions of water pollution sources and consequences, and motivations/concerns towards adoption of cover crops and buffer strips. Respondents were inquired on their degree of recognition on nine listed information sources on water quality, including 1) friends and neighbors; 2) lead farmers; 3) farm associations; 4) consultants; 5) farm supply dealers; 6) water associations; 7) university Extension service; 8) government agencies; and 9) non-governmental organizations. We considered an information source as important to the respondents (= 1) if ‘moderately’ or ‘very much’ was chosen, or not important to them (= 0) if ‘not at all’ or ‘slightly’ was chosen. We then added up the number of information sources that producers considered as important, referred to as ‘information source’ in Table 2, which provides an indicator on how concerned and/or knowledgeable the respondents were about water quality.

In the information and perception category, we also asked producers about their perceptions of nitrogen as a water pollutant in their areas. Respondents could choose one of the four options, 1 = ‘not a problem’; 2 = ‘slight problem’; 3 = ‘moderate problem’; and 4 = ‘severe problem’. To capture producers’ perceptions of water quality related issues in their region, we converted the two major categories listed in Table 1 into two perception variables in Table 2, namely, 1) environment and recreation, and 2) health and economy. Specifically, the number of issues that respondents perceived as ‘moderate problem’ or ‘severe problem’ under each of the two categories were used as indicators of the severity of water quality issues.

The survey also inquired about producers’ motivators on cover crop adoption, namely, being motivated by others who already practiced them, referred to as ‘follower attitude’, and being motivated by evidence of economic benefits of these practices, referred to as ‘profit priority’ (Table 2). A total of five options were provided on the level of agreement or disagreement about these two motivators, namely, ‘strongly disagree’, ‘disagree’, ‘neither agree nor disagree’, ‘agree’, and ‘strongly agree’, denoted by 1 through 5, respectively. Additionally, we inquired producers about their perceived constraints for buffer strip adoption. Specifically, producers were asked to provide a ‘yes’ or ‘no’ answer (= 1 or 0, respectively) for two issues: whether high expenses limited respondents’ ability to adopt buffer strips, and whether respondents considered buffer strips as suitable on their farms.

Lastly, we included the region category to examine potential regional heterogeneity in producers’ decisions. Among the three states, two dummy variables for South Dakota and North Dakota were included as regional variables. Both variables take the value of 1 if the respondents are located in the specified state or 0 otherwise.

## Results and Discussion

### ***Perception difference on water quality related issues among states.***

Table 1 displays the average value for each water quality related issue, grouped by state, to compare producers’ perception differences at the state level. We also conducted Duncan’s multiple range tests for all listed issues, with different letters denoting statistically different results among the three states. Of the three states, South Dakota producers generally regarded the water quality related issues as more severe than the producers located in the other states. On the contrary, North Dakota producers provided significantly lower ratings on most of the water quality issues than those from South Dakota and Nebraska. On average, South Dakota producers provided ratings of greater than 1 (‘slight problem’) for 7 out of 12 issues listed, while those from North Dakota only provided similar ratings for 1 issue. Nebraska farmers’ perceptions were in the middle, with 4 out of 12 issues rated as more than a slight problem.

The issues under the environment and recreation category are largely related to water appearance and associated water activities, and these issues could be readily discerned even at the early stage of water pollution. Most issues under the health and economy category, however, generally take a longer time to fully manifest, and therefore they are generally unobservable unless the water pollution is already a serious problem. As a result, we can see that the issues rated as more than a slight problem under the former category outnumbered those under the latter category for all the three states. The top three issues for all states include excessive aquatic plants and algal bloom, and both issues are caused by high levels of nitrogen in water (Strock *et al.*, 2004; Suplee *et al.*, 2009).

Nevertheless, even under the first category, no issue received a rating of greater than 1.5. This indicates that while most producers, especially those in South Dakota, started to realize water related issues in different aspects, no issue listed was considered as serious as a moderate problem in the surveyed states. This suggests water quality issues are not of paramount concerns in the Northern Great Plains. By contrast, a study conducted in Mashavera River Basin, Georgia, a hotspot of water quality deterioration, found that 44.6% of farmers perceived the rivers as polluted; 42.4% perceived limited swimming activities; and 63.8% perceived their health at risk due to water pollution (Withanachchi *et al.*, 2018).

### ***Water pollution sources and agreeable measures to improve water quality.***

Producers were also asked about their perceptions on water pollution sources in their local areas. Of the five potential sources listed, the two leading pollution sources were fertilizers/pesticides and lawn care chemicals, with 28% producers viewing them either as a moderate problem, or as a severe problem (Figure 1). However, even though fertilizers and pesticides have been found as an important issue that leads to nonpoint source pollution (Dowd *et al.*, 2008), 29% of the survey respondents failed to realize it as a pollution source in their local areas. Chemicals used to enhance crop production or grassland maintenance were considered as more important pollution sources than the septic systems and industry discharge, which is possibly linked to the predominant role of agriculture in our study region.

When being asked about their agreement with different types of measures to help improve water quality, nearly half of the producers showed either disagreement (31.8%) or strong disagreement (14.2%) towards paying taxes to protect local water quality (Figure 2). In comparison, less than 20% of farmers disagreed (12.7%) and strongly disagreed (3.5%) to implement CPs if it involves additional costs from their pocket. When the option changes from CPs at some cost to CPs at no direct cost to farmers, the percentage of farmers who showed disagreement or strongly disagreement further reduced to 8.1% and 0.2%, respectively. Such a contrast suggests that preventative measures that improve soil health and minimize water pollution from the source could garner more farmer support than curative measures that require tax payment to improve water quality. Additionally, when shifting from CPs at some cost to CPs at no direct cost to farmers, the percentage of farmers who showed agreement or strong agreement increased from 43% to 70%. This indicates that financial assistance provided for the conservation practices could potentially play an effective role for 27% out of 70% producers.

### ***Knowledge and adoption status of cover crops and buffer strips.***

The rest of this paper, therefore, will be devoted to studying knowledge and adoption status of CP among farmers and factors potentially affecting farmers' adoption decisions. Specifically, we studied two CPs—cover crops and buffer strips. As indicated in Figure 3, very few respondents indicated that they had never heard of these two practices, and only 7.7% and 13.5% of the producers indicated these two practices were not applicable for their farms.

Figure 3 shows that 40.2% of the respondents adopted cover crops and 36.4% adopted buffer strips. The finding that more farmers showed interest in cover crops than in buffer strips is potentially due to the soil and cash crop benefits attributable to cover crops as well as their wider applicability (Eanes *et al.*, 2017). Additionally, 33.0% and 25.5% of the respondents identified themselves as knowledgeable non-users of cover crops and buffer strips, respectively. This implies that among the current non-users who believed the two conservation practices applicable for their farms, 63.4% and 50.9% identified themselves as knowledgeable for cover crop and buffer strip practices, respectively, and those people could be considered as the potential target groups to promote these practices.

It is noteworthy that the majority of non-users indicated they ‘know how to use but do not use’ the practice, which implies lack of knowledge is not the major barrier that prevents producers from adopting cover crops and buffer strips. For knowledgeable non-users of cover crops (‘know how to use but do not use’), 16.5%, 40.8% and 76.0% showed agreement (either ‘agree’ or ‘strongly agree’) towards tax payment, CPs at some cost, and CPs at no direct cost to farmers, respectively. Among the current cover crop users, the corresponding percentages for these three choices were 17.4%, 53.4%, and 70.6%, respectively. A comparison between the preferences of these two groups indicated that a higher percentage of current users indicated willingness to implement CPs at some cost (53.4%) when compared to knowledgeable non-users (40.8%), while a higher proportion of knowledgeable non-users expressed agreement for CPs involving no direct cost from farmers (76.0%) when compared to current users (70.6%). Similar differences in agreement levels exist between the knowledgeable non-users and current users of buffer strips. For those who “know how to use but do not use” buffer strips, 15.4%, 45.7%, and 76.1% showed agreement (either ‘agree’ or ‘strongly agree’) towards tax payment, CPs at some cost, and CPs at no direct cost to farmers. Among the current buffer strip users, the corresponding percentage for those three choices were 21.7%, 57.1%, and 73.0%, respectively. Such findings indicate that monetary concerns constitute a primary reason that hinders CP adoption among knowledgeable non-users.

### ***Descriptive Statistics.***

Table 2 demonstrates the descriptive statistics of the explanatory variables used in the cover crop and buffer strip regression models. Under the farmer characteristics category, our result showed that average age of the survey respondents was 62.8 years. On the highest education level achieved, 47.9% of the survey respondents had some college, college degree or above, and the rest had either a high school degree or below. As expected with any farmer survey, we found 92.8% of our survey respondents were male.

Regarding farm characteristics, we found the average ownership score was 2.39, which indicated that majority of the respondents/producers had both owned and rented land in their operation. The acreage of farmland averaged 1,886 acres. Similar to Wang *et al.* (2019), average farm size reported by the respondents for this survey was much higher than the average farm acres based on the NASS census data. We found that the majority of producers (68.9%) had livestock, which could help enhance cover crop profit by utilizing cover crops for grazing purposes. The adoption rates of CT and DCR were 79.7% and 77.3% respectively, indicating that the majority of our survey respondents were current users of one or more conservation practices.

Eight variables were included under the information and perception category. Regarding information source, the mean value of 2.748 indicates that producers on average considered nearly three out of the nine listed information sources as important. The average rating for nitrogen is 2.075, indicating that regarding the role of nitrogen as a potential water pollutant, the survey respondents generally perceived it only as a slight problem in their local regions (Table 2). Of all the respondents, only 27.6% viewed nitrogen pollution as a moderate or severe problem, while the rest perceived it as not a problem or slight problem. For producers who viewed nitrogen pollution as a moderate or severe problem, the adoption rates were 57.9% and 60.7% for cover crops and buffer strips, respectively. Adoption rates declined to 40.4% and 37.0% for cover crops and buffer strips, respectively, among those who viewed nitrogen pollution as not a problem or slight problem. This indicates that those who realize nitrogen pollution as a critical issue are much more likely to adopt conservation practices that prevents nutrient runoff into water bodies. Meanwhile, producers who do not view nitrogen as an important water pollutant could also implement adequate conservation practices, probably due to other reasons such as soil health concerns.

Table 2 shows the average values for the health and economic issues and the environment and recreation issues were 0.463 and 0.976, respectively, which indicates that the former was perceived as less severe than the latter. Of the six issues listed under both categories in Table 1, the producers on average regarded less than one issue as a moderate or severe concern. The average ratings for follower attitude and profit priority were 2.513 and 2.906, respectively. This means that while producers demonstrated slight disagreement with both motivations on conservation practice (i.e., cover crops) adoption, they showed more agreement with the economic profit motivation than the follower motivation. About 34.5% of producers perceived the high cost as a limiting factor for their adoption of buffer strips, yet more producers (44.8%) considered buffer strips as not suitable for their farm. Note that Figure 3 demonstrates that only 13.5% reported that buffer strips not applicable for their farm, yet the percentage of farmers who reported buffer strips as not suitable (44.8% in Table 2) is more than tripled the non-applicability reporting. Table 2 shows that 54.7% of the respondents were from South Dakota and 19.5% from North Dakota, and the rest were from Nebraska.

### ***Logit model regression.***

Table 3 presents logit model estimation results for cover crop and buffer strip adoption decisions. Coefficient and odds ratio for each explanatory variable are reported in Table 3. After eliminating those observations either with missing values or deemed as non-applicable for adopting cover crops or buffer strips, logistic regressions were performed using 276 and 250 observations for cover crop and buffer strip adoption, respectively. Log likelihood test was conducted and the hypothesis that all coefficients are zero was rejected at 1% significance level for both models. The concordant percentages for the cover crop and buffer strip models were 74.6% and 70.3%, respectively, which indicates a reasonably good fit of the models.

As indicated in Table 3, land ownership had a positive effect on cover crop adoption, which indicated that farmers are more likely to adopt cover crops on their owned land. This is consistent with an Alabama row crop study which showed that farmers with more rented land are less likely to adopt cover crops because of a greater perceived risk to farm income on rental land (Bergtold *et al.*, 2012). Short-term versus long-term considerations are important for cover crop adoption decisions (Bergtold *et al.*, 2017). Producers are more likely to schedule sustainable management plans for a longer time on their owned land, and therefore they will be more likely to adopt CPs, such as cover crops, that generally take a longer term to manifest soil and economic benefits (Soule *et al.*, 2000). The results showed that farmland acreage has a positive and significant impact on cover crops adoption, with a larger farming area associated with a greater likelihood of planting cover crops. Farm size is often a good indicator of gross revenue, and larger farms can benefit from economies of scale as they can spread the fixed costs associated with the planting and spraying machinery to more acres (Fan et al., 2020). A national survey on early adopters of cover crops shows that growing cover crops is feasible on larger farms and that the cover crop practice is becoming increasingly common in multiple cropping systems (Dunn *et al.*, 2016).

Compared with those who did not own livestock, producers who owned were 3.119 times more likely to use cover crops. This is consistent with literature findings that livestock producers can incorporate cover crops with livestock production and receive short-term economic returns (MCCC, 2015; Lazarus and Keller, 2018; Wang *et al.*, 2020b). Similarly, for adopters of CT and

DCR practices, the likelihoods of using cover crops were 2.421 and 3.100 greater, respectively, than the non-adopters. The plausible reasons underlying this finding could be that farm conservation practices are complementary in nature and joint adoption increases crop yield and farm profit (Teklewold et al., 2013; Prokopy et al., 2019), and that producers who are conservation-minded are likely to try a combination of CPs to achieve maximum soil benefits (Schimmelpfennig and Ebel, 2016; Bergtold et al., 2017). Similarly, Lee and McCann (2019) also found that producers using CT and DCR were more likely to utilize cover crops in soybean production. Incorporating cover crops may be easier for producers that have already practiced CT because of available equipment. For instance, no-till producers already have the no-till drills and planters to handle cover crop residues, while additional expenses on relevant equipment may impede conventional tillage growers from planting cover crops (Grisso *et al.*, 2009; Mirsky *et al.*, 2013). In addition, producers planting a variety of crops may be more open to try cover crops because they have more relevant equipment and experience with different crops compared to the monoculture farmers (Singer *et al.*, 2007; Arbuckle and Roesch-McNally, 2015). Research findings show cover crops have been considered as critical and consistent components of DCR in U.S. corn belt (Singer *et al.*, 2007).

Farmers who deemed more information sources as important in obtaining water quality information are more likely to adopt cover crops. More information about water quality enables producers to be more aware of water pollution (Eanes *et al.*, 2017), which encourages them to take actions including adopting farm conservation practices in agricultural production (Prokopy *et al.*, 2008; Arbuckle and Roesch-McNally, 2015). Among the nine listed information sources, neighbors and friends may provide their opinions based on personal experience. Dealers, consultants, extension personnel and associations may provide technical support and scientific evidence regarding how water quality problems can be dealt with in the area (Bergtold *et al.*, 2012; Eanes *et al.*, 2017; Prokopy *et al.*, 2019). Government may provide cost shares to cover crop adopters, which is an important factor to account for when farmers make CP adoption decisions (Myers *et al.*, 2019).

The number of issues farmer perceived as a moderate or severe problem under the health and economy category shows a positive effect on cover crop adoption. Specifically, when the perceived number of moderate and severe issues increase by 1, farmers are 1.552 times more likely to adopt cover crops. This suggests that producers who are more aware of the negative consequences of water pollution on health and economy related issues are more likely to plant cover crops. On the contrary, for those who show more agreement with CP adoption because others are practicing them, the likelihood of using cover crops is 0.637 times less likely. Currently, cover crop is still a relatively new practice with low statewide adoption rates, e.g., the number of cover crop users only account for 10.3% of the total crop operations in South Dakota as of 2017 (NASS, 2017). This also echoes the low adoption rate in the semi-arid Northern Great Plains (Wade *et al.*, 2015). Therefore, most of the respondents probably know more non-adopters than adopters of cover crops. Consequently, producers with the follower attitude at this stage probably would more likely follow the conventional practice of no cover crops. In this case, one farmer’s adoption decision generates a positive externality, since it would likely motivate some neighbors with the follower mentality to adopt. Our finding in this regard supports the suggestions of previous research that government initiatives on improving adoption of conservation practices should target the early adopters (Reimer *et al.*, 2012; Perry-Hill and Prokopy, 2014).

Table 3 also presents the regression results of buffer strip adoption. Acreage shows a positive effect on buffer strip adoption as when farm size increases by 1000 acres, the odds of adopting buffer strips increase by 1.128. This indicates a large area encourages producers to use some land for buffers that improve local water quality. A synthesis of the literature shows that an average of 33 feet buffer strip can provide an optimal trapping capability and reduce sediment transport (Liu *et al.*, 2008). With a larger farming area, a producer is more willing to allocate a portion of the land to maintain an effective buffer width (Castelle *et al.*, 1994; Rhodes *et al.*, 2018).

Additionally, our results show that more information sources encourage farmers to practice buffer strips. Consistent with the adoption of cover crops and other conservation practices, adoption of buffer strips needs evidence from neighbors and friends, and some information can better facilitate producers to have access to technical and financial support (Ryan *et al.*, 2003; Helmers *et al.*, 2008; Rhodes *et al.*, 2018). As a major fertilizer used for crop production, excessive nitrogen not utilized by crops has caused the nutrient to accumulate in waterbodies (Dabney *et al.*, 2006). We find that for producers who regard nitrogen as a more severe water pollution source, the likelihood of adopting buffer strips is 1.645 times greater. This indicates that as producers' perceived environmental costs of agricultural pollutants increase, they would more likely use buffer strips. Evidence has shown that benefit perceptions and knowledge of environmental impacts can contribute to the adoption of riparian buffers by landowners and producers (Buckley *et al.*, 2012; Rhodes *et al.*, 2018). For example, a field survey in the Spring Creek watershed of central Pennsylvania also confirmed the belief that buffers lead to positive outcomes would motivate landowners to adopt the riparian buffers (Armstrong and Stedman, 2012).

Moreover, producers who placed more concerns on high expenses and suitability of buffer strips are 0.535 and 0.558 times less likely to adopt buffers. Extra costs or profit loss have been found to be significant barriers for CPs. Therefore, government subsidies are necessary to eliminate producers' concern in this regard and to further promote buffer strip adoption. Producers' concern with the suitability of buffer strips on their farm reveals the importance of technical support on buffer strip implementation in a site-specific manner. For example, Dosskey (2001) concluded that it remains unclear on the degree of pollution reduction to be expected from utilizing buffer strips in agricultural fields. Kreig *et al.* (2019) also mentioned that the effectiveness of filter strips in trapping water contaminants could be contingent on landscapes, site locations, and presence of tile drains.

Among the explanatory variables, the factors under farm characteristics and management category and those under information and perception category play a major role in cover crop adoption, while variables under information and perception category play a predominant role in buffer strip adoption. The primary reason that farm characteristics barely show any effect on buffer strip adoption could be that the benefits of buffer strips are entirely off-farm, and therefore the adoption decision is more contingent on the cost and perceived suitability. Similar to Wang *et al.* (2019), we find that information source and producer perceptions are the primary influencing factors on the adoption decisions of both CPs. However, both respondent characteristics and regional heterogeneity play no significant role in producers' adoption decisions of cover crops and buffer strips.

## Summary and Conclusions

Utilizing farmer survey data from the North Great Plains, this paper investigated farmers' perceptions on water quality related issues, water pollution sources, and their agreeable measures to improve water quality. On average, South Dakota producers rated 7 out of 12 issues listed as more than a slight problem, followed by Nebraska producers (4 issues) and North Dakota producers (1 issue). Excessive aquatic plants and algal bloom, attributable to high levels of nutrients in water, were ranked as the top severe issues by producers, yet no issue received a rating of greater than 1.5 on a 0 to 3 scale (0 = 'not a problem'; 1 = 'slight problem'; 2 = 'moderate problem'; 3 = 'severe problem'). In our studied region, where agriculture plays a dominant role, producers viewed fertilizers/pesticides and lawn care chemicals as the two leading water pollution sources. This indicates that producers are mindful of both farm and non-farm related chemical inputs that may pose detrimental effects on water quality (Dosskey, 2001; Withanachchi *et al.*, 2018).

Producers generally showed disagreement (31.8%) or strong disagreement (14.2%) towards paying taxes to protect water quality, while implementing CPs as alternative measures to improve water quality encountered much less opposition. We then analyzed producers' knowledge and adoption status of cover crops and buffer strips, as well as the factors that affect farmers' adoption decisions. Among the survey respondents, 40.2% and 36.4% of the respondents were users of cover crops and buffer strips, respectively, while 33.0% and 25.5% of the respondents perceived themselves as knowledgeable of the two practices but had not adopted them yet.

We found that the adoption decision of cover crops, as a conservation practice that generates both on- and off-site benefits, hinges largely on farm characteristics and existing farm management practices. For example, landowners with more farm acres are more likely to plant cover crops, possibly due to the longer-term planning horizon and improved economies of scale. Our research further demonstrates the compatibility of livestock ownership with cover crop adoption, which helps increase farm income. By further reducing fertilizer and herbicide expenses, cover crops has also been found as jointly used with conservation tillage and diversified crop rotations. As cover crop is still largely an emerging farm practice, producers with a follower attitude are more likely to wait rather than adopt at this stage.

Producers who obtain water quality information from a greater number of sources are more likely to be adopters of both practices. Meanwhile, our findings suggest that when producers perceive the water pollution problems in their local areas and realize their farming practices could aggravate the problems, they are more likely to adopt the conservation practices to improve water quality. Compared to cover crops, the adoption decisions on buffer strips are more influenced by the perception factors. For example, producers more concerned about extra costs and suitability of buffer strips are less likely to adopt. Our results highlight the importance of outreach efforts to disseminate accessible information on current pollution status of local water bodies, as well as information on the sources of water pollution. Furthermore, our findings show that buffer strip adoption decisions are inhibited by site suitability concerns yet encouraged by information availability, which suggests that besides monetary incentives, technical support is of paramount importance on adoption decisions of conservation practices that only target the off-site benefits.

While our study provides an enhanced understanding of agricultural producers' perceptions of water quality problems in U.S. Northern Great Plains and the factors that affect their CP adoption decisions, it has certain limitations that could be further improved by future research. For example, we obtained survey sample from publicly available databases with no prerequisite criteria on farm size and locations. To better understand farmer concerns and reduce nonpoint source pollution in a more cost-effective way, future studies could first identify water pollution hotspots in the study area, and then target the producers in selected watersheds with paramount water quality concerns. Furthermore, CP adoption decisions are typically a sequential process, where producers first obtain information and become knowledgeable, and then implement the practice on their farms. More research could be conducted to better understand CP adoption processes and identify key steps and information sources that could help farmers make accelerated and better-informed decisions to curtail water quality problems.

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**Table 1.** Description of water quality related issues and mean value comparison among states.

| | | | **Mean Value** | | |
|---|---|---|---|---|---|
| **Category** | **Issue** | **Description** | **North Dakota** | **South Dakota** | **Nebraska** |
| **Environment & Recreation Issues** | 1 | Excessive aquatic plants | 0.718 b | 1.325 a | 1.230 a |
| | 2 | Excessive algal bloom | 1.010 b | 1.426 a | 1.106 b |
| | 3 | Decline in water birds and wild animals | 0.418 b | 0.848 a | 0.719 a |
| | 4 | Polluted swimming areas | 0.752 b | 1.287 a | 1.000 ab |
| | 5 | Fishing | 0.714 b | 1.153 a | 0.970 ab |
| | 6 | Canoeing/Kayaking/Boating | 0.558 b | 1.047 a | 0.940 a |
| **Health & Economic Issues** | 7 | Health problems (e.g., allergic reactions, skin rashes, eye irritations, stomach illness) | 0.889 a | 1.147 a | 1.148 a |
| | 8 | Stopped drinking water from my area | 0.248 b | 0.690 a | 0.615 a |
| | 9 | Stopped eating fish or shellfish from my area | 0.376 b | 0.727 a | 0.687 a |
| | 10 | Livestock death | 0.686 ab | 0.881 a | 0.564 b |
| | 11 | Decrease in property values | 0.337 b | 0.824 a | 0.526 b |
| | 12 | Negative impact on tourism | 0.515 b | 1.036 a | 0.807 ab |

Notes: 0 = ‘Not a problem’; 1 = ‘Slight problem’; 2 = ‘Moderate problem’; 3 = ‘Severe problem’. Letters are used to denote Duncan’s multiple range test results, where the same letter implies no statistically significant difference among the average values of the three states at $p < 0.05$. The top three most severe water quality issues for each state are highlighted in grey.

**Table 2.** Description of explanatory variables used in the logistic models.

| **Category** | **Variable** | **Description** | **N** | **Mean** | **Std. Dev.** |
|---|---|---|---|---|---|
| Farmer Characteristics | Age | Respondent age | 504 | 62.867 | 12.049 |
| | Education | Highest education level of the respondent (1 = Some college, college degree or above; 0 = High school degree or below) | 511 | 0.479 | 0.500 |
| | Gender | Gender of the respondent (1 = Male; 0 = Female) | 517 | 0.928 | 0.258 |
| Farm Characteristics and Management | Ownership | Type of farmland ownership (1 = Tenant; 2= Both; 3 = Owner) | 543 | 2.390 | 0.565 |
| | Acre (x $10^3$) | Total acres of farmland | 492 | 1.886 | 2.756 |
| | Livestock | Ownership of livestock (1 = Yes; 0 = No) | 570 | 0.689 | 0.463 |
| | CT | Adoption of conservation tillage (CT) (1 =Yes; 0 =No) | 498 | 0.797 | 0.402 |
| | DCR | Adoption of diversified crop rotation (DCR) (1 =Yes; 0 = No) | 484 | 0.773 | 0.420 |
| Information and Perception | Information source | Number of water quality information sources perceived as important by respondent (0 – 9) | 448 | 2.748 | 2.486 |
| | Nitrogen | Nitrogen as a water pollutant in respondent's area (1 = Not a problem; 2 = Slight problem; 3 = Moderate problem; 4 = Severe problem) | 442 | 2.075 | 0.847 |
| | Environment and recreation | Number of moderate/severe water quality problems related to environment and recreation issues (0 – 6) | 497 | 0.976 | 1.595 |
| | Health and economy | Number of moderate/severe water quality problems related to health and economy issues (0 – 6) | 503 | 0.463 | 1.091 |
| | Follower attitude | Adopt soil conservation practices because others are practicing them (1 = Strongly disagree, 2 = Disagree, 3= Neither agree nor disagree, 4 = Agree, 5 = Strongly agree) | 524 | 2.513 | 0.800 |
| | Profit priority | Need evidence of economic benefits to adopt soil conservation practices (1 = Strongly disagree, 2 = Disagree, 3= Neither agree nor disagree, 4 = Agree, 5 = Strongly agree) | 524 | 2.906 | 1.017 |
| | Cost limit | High cost limiting respondent's ability to adopt buffer strip (1 = Yes, 0 = No) | 484 | 0.345 | 0.476 |
| | Suitability concern | Buffer strip considered suitable for respondent's farm (1 = Yes, 0 = No) | 484 | 0.448 | 0.498 |
| Region | South Dakota | Respondent from South Dakota (1 = Yes, 0 = No) | 570 | 0.547 | 0.498 |
| | North Dakota | Respondent from North Dakota (1 = Yes, 0 = No) | 570 | 0.195 | 0.396 |

**Table 3.** Logistic model estimation results for cover crop and buffer strip adoption.

| | | **Cover Crop Adoption** | | | **Buffer Strip Adoption** | | |
|---|---|---|---|---|---|---|---|
| **Category** | **Variable** | **Estimate** | **Std. Error** | **Odds Ratio** | **Estimate** | **Std. Error** | **Odds Ratio** |
| Farmer Characteristics | Age | -0.020 | 0.013 | 0.980 | -0.005 | 0.014 | 0.995 |
| | Education | 0.202 | 0.298 | 1.224 | 0.403 | 0.296 | 1.495 |
| | Gender | -0.411 | 0.686 | 0.663 | 0.130 | 0.669 | 1.139 |
| Farm Characteristics and Management | Ownership | $0.572^{**}$ | 0.276 | 1.772 | 0.375 | 0.282 | 1.456 |
| | Acre ($10^3$) | $0.128^{**}$ | 0.063 | 1.136 | $0.120^{*}$ | 0.063 | 1.128 |
| | Livestock | $1.138^{***}$ | 0.323 | 3.119 | 0.413 | 0.320 | 1.511 |
| | CT | $0.884^{*}$ | 0.454 | 2.421 | 0.103 | 0.436 | 1.108 |
| | DCR | $1.132^{***}$ | 0.399 | 3.100 | -0.005 | 0.379 | 0.995 |
| Information and Perception | Information source | $0.113^{*}$ | 0.060 | 1.120 | $0.097^{*}$ | 0.059 | 1.102 |
| | Nitrogen | -0.003 | 0.198 | 0.997 | $0.498^{**}$ | 0.201 | 1.645 |
| | Environment and recreation | -0.150 | 0.120 | 0.860 | 0.147 | 0.119 | 1.158 |
| | Health and economy | $0.440^{**}$ | 0.179 | 1.552 | -0.218 | 0.166 | 0.804 |
| | Follower attitude | $-0.451^{**}$ | 0.185 | 0.637 | - | - | - |
| | Profit priority | -0.132 | 0.141 | 0.876 | - | - | - |
| | Cost limit | - | - | - | $-0.626^{**}$ | 0.294 | 0.535 |
| | Suitability concern | - | - | - | $-0.584^{**}$ | 0.288 | 0.558 |
| Regional Factor | South Dakota | -0.457 | 0.359 | 0.633 | -0.135 | 0.357 | 0.874 |
| | North Dakota | -0.301 | 0.457 | 0.740 | -0.468 | 0.457 | 0.626 |
| | Number of observations | 276 | | | 250 | | |
| Model Fit Statistics | Likelihood ratio | 56.873 | | | 33.991 | | |
| | Prob > Chi-Squared | < 0.001 | | | 0.005 | | |
| | Percent concordant | 74.6% | | | 70.3% | | |

Notes: $^{***}$ $p < 0.01$, $^{**}$ $p < 0.05$, $^{*}$ $p < 0.1$.

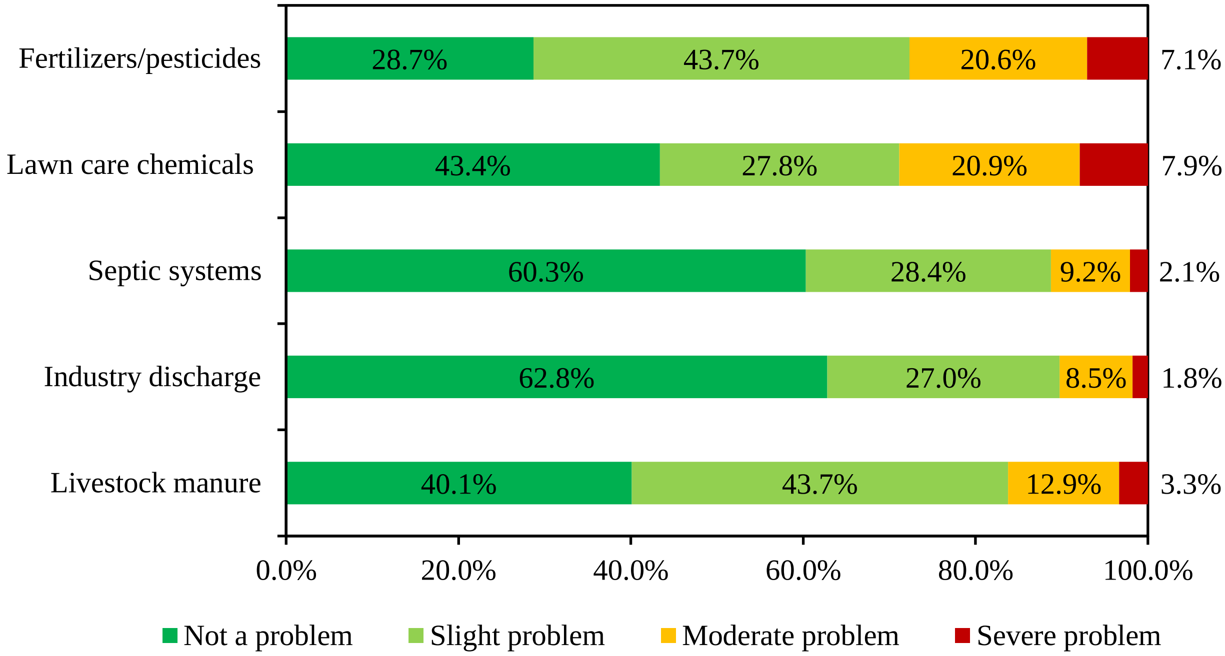

**Figure 1.** Farmers’ perceptions on water pollution sources in their local areas.

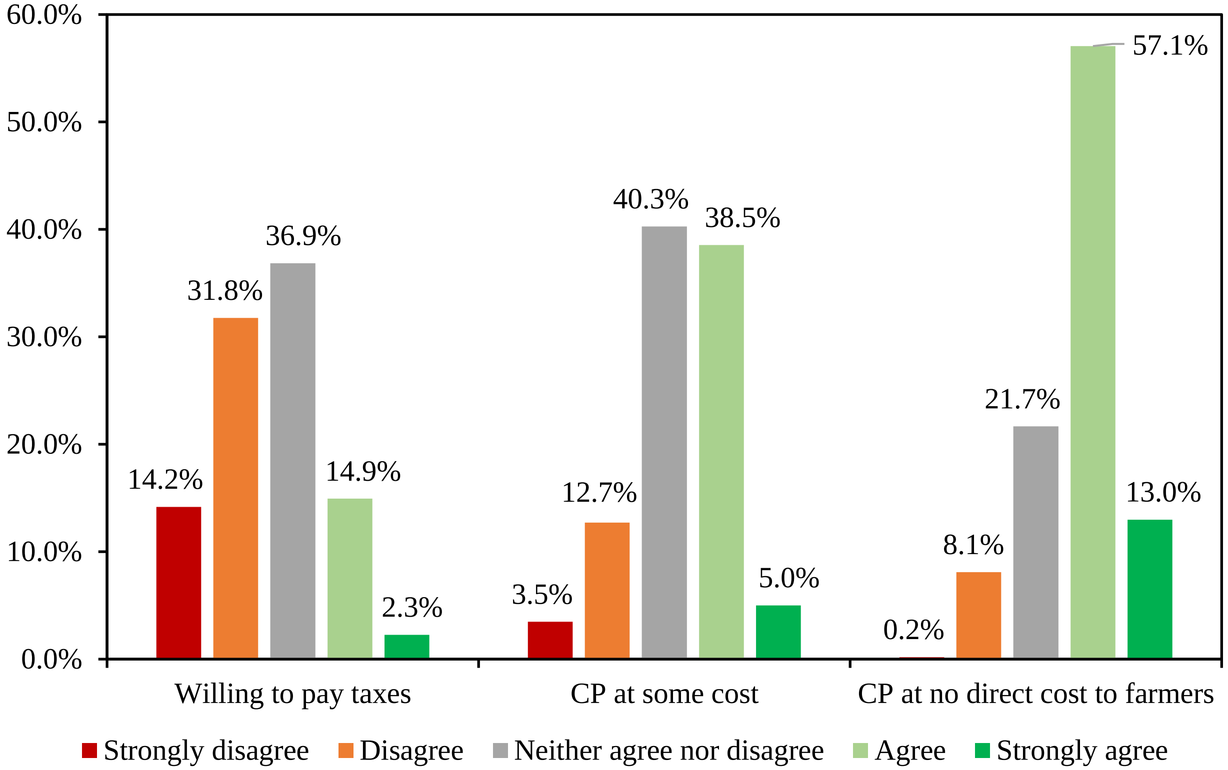

**Figure 2.** Farmers' agreement with various efforts to improve water quality (CP: conservation practice).

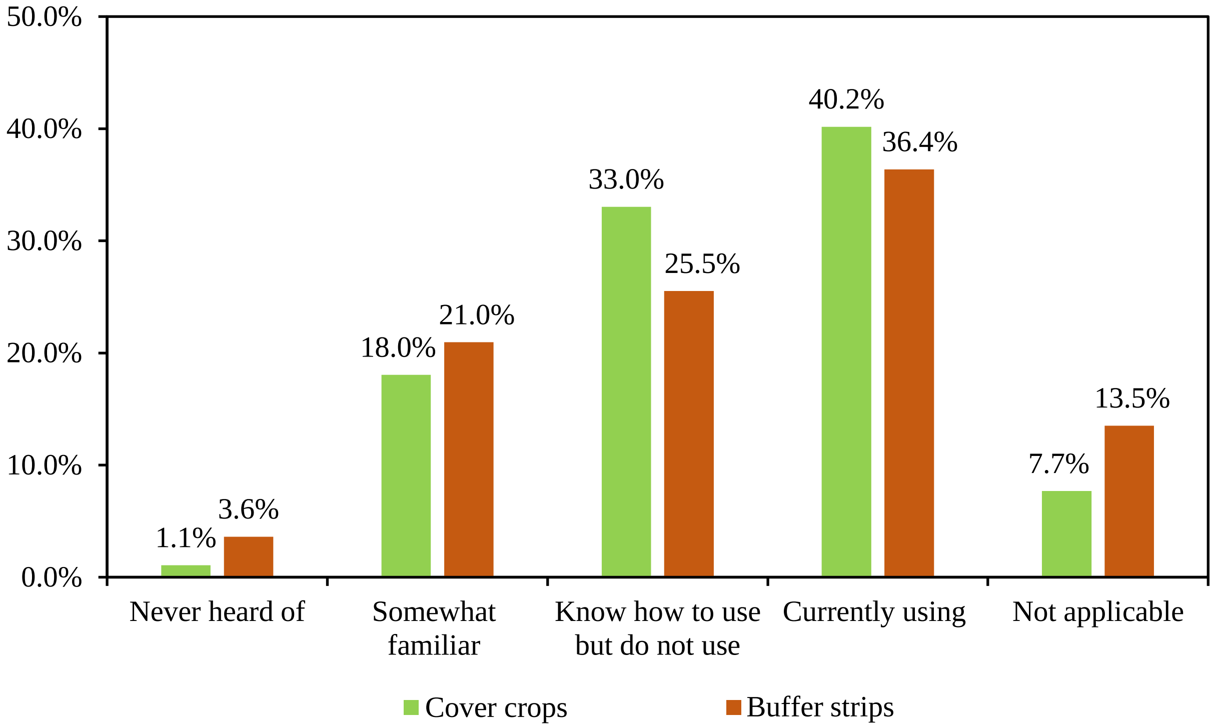

**Figure 3.** Farmers' knowledge and usage status of cover crops and buffer strips.

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