doi:10.2489/jswc.2023.00002

Individual- and county-level factors associated with farmers' use of 4R Plus nutrient management practices

S. Upadhaya, J.G. Arbuckle, and L.A. Schulte

Abstract: The 4R Plus approach to agricultural nutrient management—ensuring that the "right source" of nutrients is used at the "right rate," "right time," in the "right place," and combined with appropriate in-field and edge-of-field practices—is posited to lead to win-win outcomes for farmers and the environment. While industry and conservation organizations are promoting the approach, farmers have not yet adopted 4R Plus practices at rates sufficient to meet the state's nutrient reduction goals. We employed multilevel modeling with survey data from 6,006 Iowa farmers to examine the complex relationships among individual- and county-level social, economic, and ecological factors associated with 4R Plus practice adoption. We found that adoption was associated with clusters of factors at both the individual and county levels. At the individual level, the variable crop area was positively associated with predicting use of all 4R Plus practices except Right Rate. Farmers' perceived lack of agronomic capacity to address nutrient losses was negatively associated with use of all 4R Plus practices but the Right Source. At the county level, farmers in counties with a higher percentage of rented land were less likely to have adopted Right Time, Right Source, and Edge-of-Field practices. Those farming in counties with a greater average slope were more likely to adopt Plus practices, such as cover crops and terraces. County-level crop insurance coverage rate was negatively associated with In-Field and Edge-of-Field Plus practices. Overall, this study provides quantitative support for qualitative studies that call for conservation programs to simultaneously address factors operating at multiple scales to improve outcomes. Programs that combine local, direct assistance to farmers with broader efforts to remove structural barriers may be more likely to be effective at facilitating conservation adoption than those operating at one scale alone. Specific to 4R Plus programming, efforts that simultaneously help farmers address farm-level capacity barriers and improve policies and programs (e.g., crop insurance) to ensure encouragement rather than hindrance of practice adoption would likely lead to better environmental outcomes.

Key words: agriculture—conservation practice adoption—Corn Belt—environmental stewardship—hierarchical modeling—Iowa

Surplus nutrients lost from agriculture to the environment pose high ecological and economic consequences (Alagele et al. 2019; Smith et al. 2019). Nonpoint nutrient pollution is among the most significant water quality concerns globally, the effects of which are well documented (Diaz and Rosenberg 2008; Costello et al. 2009; Rabalais and Turner 2019). According to the National Water Quality Inventory prepared by the US Environmental Protection Agency (USEPA), agricultural runoff is the most widespread stressor of water bodies in the United States (USEPA 2017). Similarly, excess nutrient loading in the US Midwest region is a well-known cause of the hypoxic zone in the Gulf of Mexico (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008; Costello et al. 2009).

Received December 27, 2021; Revised April 11, 2023; Accepted June 1, 2023.

The economic impacts of nutrient loss are large, and investments in efforts to manage nutrient loss from agricultural fields are also costly (USEPA Office of Water 2015). A study by Sobota et al. (2015) showed that the loss of nitrogen (N) from fertilizers to the environment costs Americans US$157 billion a year in damages to human health and the environment. Keiser and Shapiro (2019) estimated that the United States had spent approximately US$5 trillion on efforts to improve water quality since 1970. The establishment and continuous maintenance of on and off-farm conservation structures also add financial burden to farmers (Zhou et al. 2009). Therefore, reducing agricultural nutrient pollution could simultaneously benefit the environment while reducing economic costs and increasing farmers' profitability.

There are numerous efforts to reduce nutrient loss from agricultural fields and curtail local, regional, and global consequences of agricultural nonpoint source pollution (The Royal Society 2009; Power 2010; Hyland et al. 2018). This research focuses on a major US-based effort called the 4R Plus initiative, a science-based framework designed to guide improved nutrient management among farmers and reduce nutrient loss from agricultural fields (Vollmer-Sanders et al. 2016). Led by a coalition of agribusiness interests and conservation nongovernmental organizations (NGOs) in major crop-growing areas in the US Midwest and Mid-Atlantic, the 4R Plus approach to nutrient management involves applying the "right source" of nutrients at the "right rate" at the "right time" and in the "right place," combined with "plus" conservation practices such as cover crops and terraces (Vollmer-Sanders et al. 2016; The Nature Conservancy 2021). Promotion of the 4R Plus framework generally posits that use of relevant practices will lead to win-win outcomes in boosting productivity and minimizing farming's ecological impacts. 4R Plus focuses on optimizing the efficiency of fertilizer use by implementing site-specific best management practices (BMPs) (Bruulsema et

Suraj Upadhaya (corresponding author) is a research scientist at the Bioeconomy Institute, Iowa State University, Ames, Iowa. **J. Gordon Arbuckle** is a professor at the Department of Sociology, Iowa State University, Ames, Iowa. **Lisa A. Schulte** is a professor at the Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa.

al. 2009; Fixen 2020), where properly utilized nutrients on a farm not only enhance productivity, profit, and social goods, but also reduce the environmental impacts. While focal geographies of the 4R Plus effort include the Upper Mississippi River Basin, the Western Lake Erie Basin, and the Chesapeake Bay watershed (Vollmer-Sanders et al. 2016; The Nature Conservancy 2021), similar nutrient management approaches have become common among farmers and their advisers globally (Fixen 2020).

Application of 4R Plus stewardship occurs at the farm level, where different social, economic, cultural, and ecological characteristics affect farmers' behaviors (Prokopy et al. 2008; 2019; Ranjan et al. 2019a; Upadhaya et al. 2021). The development, adoption, and evaluation of 4R Plus stewardship, however, may also be influenced by contextual factors at a higher level than farm and farmers, such as county and region. Recent work has called for a much greater emphasis on understanding how both biophysical and especially the social-structural factors (e.g., policies) might influence the adoption of BMPs (Prokopy et al. 2019). At a landscape level, diverse biophysical, social, economic, and policy factors may shape farmers' decisions. Farmers' management decisions are not only influenced by their beliefs and values but also by interactions with the biophysical and socioeconomic contexts they work within (Arbuckle 2013; Reimer et al. 2014; Roesch-McNally et al. 2018). Biophysical and socioeconomic characteristics can vary by farm, watershed, county to local, regional, and global markets (McGuire et al. 2015). While the factors affecting farmers' conservation behaviors are well-investigated and described in the scientific literature (Prokopy et al. 2008, 2019), there is a gap in knowledge about which and how factors operate at different scales (Reimer et al. 2014).

There is a further paucity of information on the factors affecting farmers' propensity to adopt multiple practices that make up the 4R Plus framework. The use of a single 4R Plus practice, such as cover crops (Roesch-McNally et al. 2017), or several of the practices that comprise the 4R Plus suite of practices, such as complementary nutrient management practices (Bates and Arbuckle 2017), has previously been studied. This research generally shows that farmers' individual characteristics influence their adoption behaviors; however, individual-level factors are not the only potential factors affecting conservation practice adoption. Farmers' conservation behaviors are also scale-dependent and influenced by issues of broader space and institutions (Reimer et al. 2014). Additional consideration of scale, study area characteristics, and social-ecological interactions at higher-order levels can provide a more holistic understanding of farmers' conservation practice adoption (Reimer et al. 2014; Prokopy et al. 2019). Very few studies on agricultural BMP adoption have employed a multilevel modeling approach, such as integrating individual farm operations and broader environmental or structural variables in the same analysis (Roesch-McNally et al. 2018).

Our study aimed to improve our understanding of 4R Plus adoption by evaluating the contributions of factors that might be operating at different scales (i.e., individual, farm, and county) to address research gaps. As there are logical hierarchical groupings within the data, i.e., farms and farmers within counties, we employed a multilevel modeling approach to achieve our aim (Hox 2010). Multilevel models can incorporate factors operating at multiple levels and better represent variation in responses (Lu and Yang 2012). The multilevel model of farmers' conservation adoption behavior has the advantage of quantifying the contribution of individual- and county-level variables, and both operating together (Fan and McCann 2020). We thus systematically quantified the contributions to 4R Plus adoption of social, economic, and ecological factors that might be operating at different levels. Fuller understanding of relationships among multiple variables and 4R Plus adoption can improve the design and cost-effectiveness of 4R Plus programming and outreach to farmers by conservation agronomists, watershed coordinators, extension professionals, and other farm advisors within the Midwest and beyond.

Materials and Methods

Study Area. This study was carried out in Iowa, a rain-fed agricultural state located between the Mississippi and Missouri rivers in the Upper Midwest region of the United States (figure 1). The state's average annual precipitation and temperatures are 815.1 mm y^{-1} and 8.6°C, respectively (NOAA 2020). The major crops of Iowa are corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) (figure 1). In 2018 more than 9,830,218 ha of land, or 67.5% of the state, were planted with grain crops such as corn, soybeans, sorghum (*Sorghum bicolor* L.), oats (*Avena sativa* L.), etc. (USDA NASS 2019). The USDA National Agricultural Statistics Service (NASS) reports that Iowa alone accounted for more than 17% of corn and 12% of total soybean production in the United States in 2018. The state is also the top producer of pork, eggs, and ethanol and produces large quantities of beef and poultry (USDA NASS 2019; US EIA 2020).

Data. The individual farmer-level data were collected through a five-year survey of Iowa farmers conducted to support the implementation of the Iowa Nutrient Reduction Strategy (INRS) (http://www.nutrientstrategy.iastate.edu/). The INRS, a science and technology-based framework, sets a goal of reducing nonpoint and point source generated N and phosphorus (P) loads by 45% in the waterways across Iowa that drain to the Gulf of Mexico (INRS 2020). The survey aimed to support the implementation of the INRS by assessing farmers' self-reported attitudes, behaviors, and knowledge related to nutrient loss reduction using conservation practices (Nowatzke and Arbuckle 2018). Iowa farmers who operated at least 60 ha of row crops (corn and soybeans) in the year before the survey comprised the sample population because, although farm operations of this size (>60 ha) represent only about half of the state's farms, they operate more than 90% of the state's farmland (USDA NASS 2017; Nowatzke and Arbuckle 2018). The five-year annual survey was sent to farmers in a different Hydrologic Unit Code 6 (HUC6) watershed each year, rotating through Iowa's largest HUC6 watersheds. It was sent to 14,139 farmers between 2015 and 2019. We received 6,006 valid responses for a response rate of 42%. The county-level data were collected from publicly available sources.

Dependent Variables. We employed five dependent variables measuring farmers' use of BMPs representing five components of 4R Plus nutrient management: Right Rate, Right Time, Right Source, Plus In-Field, and Plus Edge-of-Field. Right Place was not considered due to a lack of data on those practices. 4R Plus nutrient management requires the implementation of different agronomic and conservation BMPs (The Nature Conservancy 2021). As each farm is different, the practices each farmer chooses to implement in their farm operation for nutrient management and soil and water conservation may be different than others. Therefore we selected several of the most common and effective practices based on the INRS science assessment (Thompson et al. 2014) (table 1).

The survey provided a list of 4R Plus (https://4rplus.org) practices from the five 4Rs Plus categories that can reduce nutrient loss into waterways and asked farmers to indicate whether or not they were using them in their operations and assigned a "1" to respondents who reported use of the practice and a "0" to nonusers. Each dependent variable is a simple count of the number of practices in each of the five 4Rs Plus practice categories. The dependent variable Right Rate measures the use of two practices—variable-rate N application and N rate based on corn N rate calculator (MRTN)—that fall under the 4R Plus approach of matching the amount of fertilizer to the crop's needs (table 1). The dependent variable Right Time measures the use of two practices that fall under the 4R Plus approach of making nutrients available

Figure 1
The distribution of the major crops of Iowa—corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.)—in 2019. Source: USDA NASS Cropland Data Layer (2021).

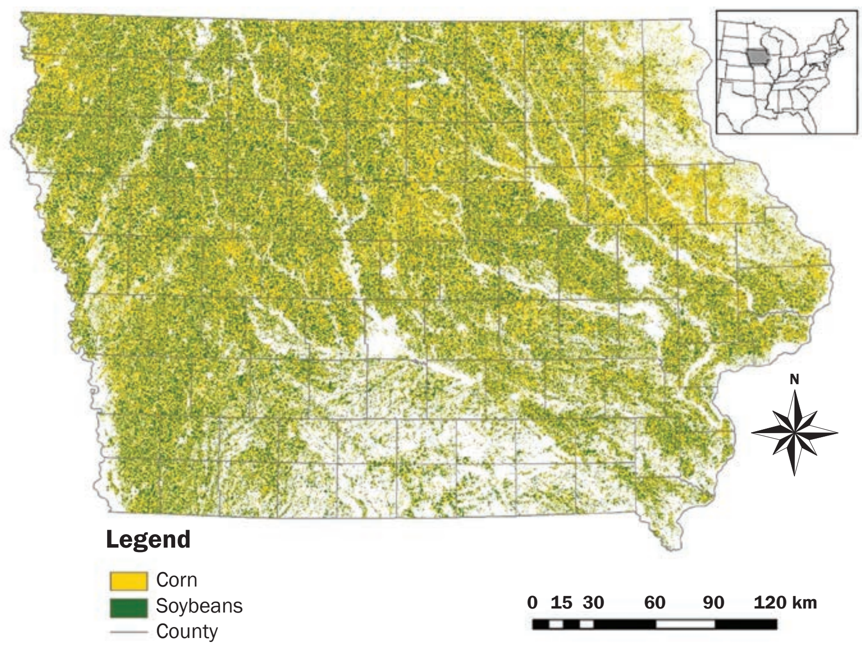


Table 1
Dependent variables: Farmers' self-reported use of 4R Plus practices.

4R Plus practices	Min/max	Used (%)	Not used (%)	Total practices used (%) 0	1	2	3	4	5	6
Right Rate (*RR*)	0/2			63	28	8	—	—	—	—
Variable-rate nitrogen (N) application		23	78							
Nitrogen rate based on corn N rate calculator (MRTN)		26	74							
Right Time (*RT*)	0/2			15	55	30	—	—	—	—
Growing season N application (i.e., side-dress)		38	62							
Spring N application		78	22							
Right Source (*RS*)	0/1			53	47	—	—	—	—	—
Nitrogen stabilizer (e.g., N-Serve)		48	52							
Plus In-Field (*Plus.IF*)	0/3			32	40	22	6	—	—	—
Cover crops		27	73							
No-till (all years of rotation)		52	48							
Extended rotations (three or more crops over a three to five year rotation)		21	79							
Plus Edge-of-Field (*Plus.EoF*)	0/6			17	21	23	22	12	5	1
Bioreactors		1	99							
Cropland converted to perennial crops (e.g., hay, pasture, trees)		22	78							
Terraces		53	47							
Pond(s)/sedimentation basin(s)		24	76							
Buffers along streams or field edges to filter nutrients and sediment from runoff		61	39							
In-field buffer strips (e.g., contour) to filter nutrients and sediment		42	58							

when crops need them, growing season N application and spring N application (table 1). The third dependent variable is a measure of Right Source practices, defined as practices that match fertilizer types to crop needs and ensure a balanced supply of essential nutrients. Our survey collected data on just 1 of 10 Right Source practices, use of a N stabilizer (e.g., N-Serve) (table 1) (The Nature Conservancy 2021). The "Plus" in 4R Plus involves in-field and edge-of-field agronomic and conservation practices that increase the resiliency and health of soils and promote soil and water conservation. The dependent variable Plus In-Field (*Plus.IF*) is a summated scale of three different conservation practices: cover crops, no-till (all years of rotation), and extended rotations (table 1). Edge-of-field practices focus on reducing agricultural sources of excess nutrients, which can threaten the health of streams, rivers, and lakes. The dependent variable Plus Edge-of-Field (*Plus.EoF*) is a summated scale of six edge-of-field practices (table 1). Together, these five dependent variables represent a diverse range of practices recommended by the 4R Plus program to reduce nutrient loss into waterways (The Nature Conservancy 2021).

Level 1 Explanatory Variables: Individual Level. Based on a prior understanding of social, economic, and ecological factors that can influence farmers' conservation practice adoption behavior (Prokopy et al. 2019, 2008; Ranjan et al. 2019a; Upadhaya et al. 2021), we included 25 predictor and control variables (see table 2 for a detailed description of variables and summary statistics). These 25 variables were created using

Table 2

Description and summary statistics for individual- and county-level variables.

Variable names	Description	Min/max	Mean	sd
Information sources				
Info.Priv	Private sector sources of information about the INRS	0/3	0.58	0.91
Info.Pub	Public sector sources of information about the INRS	0/3	1.67	1.13
Info.Press	Press sector sources of information about the INRS	0/2	1.30	0.74
Influential actors				
Infl.Pub	Influence on nutrient management practices: Public sector	1/5	2.45	0.92
Infl.Priv	Influence on nutrient management practices: Private sector	1/5	2.08	0.82
Infl.On-Farm	Influence on nutrient management practices: On-farm research groups	1/5	1.70	0.83
Engagement in networks				
CSTA	Received cost-share or technical assistance for conservation	0/1	0.58	0.49
Inv.W.Group	Are you involved in organized watershed management activities?	0/1	0.28	0.45
Awareness and attitudes				
Awareness	How knowledgeable about the INRS	1/5	2.95	0.97
Attitude	Attitude toward the INRS	1/5	3.59	0.53
Perceived capacity				
Capacity.Econ	Perceived (lack of) economic capacity to attain water quality improvement	1/5	3.35	0.76
Capacity.Agron	Perceived (lack of) economic capacity to attain water quality improvement	1/5	2.80	0.68
Farmer and farm characteristics				
*Education**	Highest level of education	1/4	2.03	0.98
Age	Age	22/94	57.57	11.73
Crops.Acres	Total area of crop land (ha)	9/5,697.97	330.95	363.48
Pasture.Acres	Total area of pasture (ha)	0/809.37	20.57	52.530
Livestock	Raise livestock for sale or for milk production	0/1	0.40	0.49
GFS†	Gross farm sales	1/8	5.03	1.83
Per.Rent.Crop	Percentage of rented cropland	0/100	47.46	36.99
WaterBorder	Does any of the land you farm border any water bodies?	0/1	0.81	0.39
County level				
Farm.Income	Farm-related income per acre	41.57/105.62	75.24	13.07
Per.Rent.Land	Percentage of rented farmland	26.11/67.66	51.10	8.10
SlopeMean	Mean slope	0.89/7.46	2.83	1.31
Avg.Cov.Lvl	Average insurance coverage level	75.24/82.63	79.74	1.29

Notes: INRS = Iowa Nutrient Reduction Strategy. CSTA = cost-share or technical assistance.

*High school or less = 1; some college = 2; bachelors = 3; graduate school/profesional degree = 4.

†None = 1; <US$50K = 2; US$50K to US$150K = 3; US$150K to US$250K = 4; US$250K to US$350K = 5; US$350K to US$500K = 6; US$500K to US$100K = 7; >US$1000K = 8.

single or multiple items from the survey. We employed factor analysis to guide the creation of summated scales that combined multiple items. Summated scales can improve both the reliability and precision of measurement of scale constructs (DeVellis 2003). To evaluate the summated scales' internal consistency, we used Cronbach's alpha reliability coefficient, a standard measure of scale reliability (Field 2009).

Information Sources. According to diffusion of innovations theory (Rogers 2003), the source from which individuals obtain information plays an important role in shaping knowledge of a problem or innovation that may lead to adopting or rejecting the technology. Barbercheck et al. (2014) stated that farmers' conservation practices might be affected by the sources or communication networks from which they obtain information. Studies show that farmers rely on different sources for information about nutrient management (Arbuckle and Rosman 2014; Stuart et al. 2015; Houser et al. 2019). We thus used explanatory variables to measure the sources of information from which farmers had learned about the INRS, selected from a list of eight private, public, and press sources (table S1 in supplementary material). From these, we created three summated scales based on information source: *Info.Priv*, *Info.Pub*, and *Info.Press* (table S1).

Influential Actors. Diffusion of innovations theory posits that actors who are seen as "change agents" can actively influence decisions to adopt or reject specific technologies (Rogers 2003). In the field of conservation, research shows that farmers' involvement with different stakeholders, such as private sector agricultural consultants (Eanes et al. 2017) or with different conservation organizations (Gillespie et al. 2007) can be positively linked to practice adoption. Therefore, we used a second set of explanatory variables that measure various stakeholders' influence on farmers' nutrient management practices and strategy decisions. Farmers were asked to rate 11 different agricultural stakeholders on a scale ranging from no influence (1) to very strong influence (5) on the extent to which those sources of information influence their decisions about nutrient management practices and strategies (table S1). Three summated scales measuring influence of public sector stakeholders (*Infl.Pub*), private sector entities (*Infl.Priv*), and on-farm research groups (*Infl.On-farm*) were created (table S1).

Engagement in Conservation Networks. Farmer engagement in soil and water conservation-related networks were measured based on whether farmers had received cost-share or technical assistance (*CSTA*) from different agencies and organizations over the previous five years. Research on soil and water conservation has shown that contact with natural resource professionals and cost-share and technical assistance can encourage the adoption of conservation practices (Church et al. 2019; Morris and Arbuckle 2021; Sawadgo and Plastina 2021). Previous research has also suggested that farmer involvement in watershed management activities positively affects water quality outcomes (McGuire et al. 2013; Floress et al. 2018); a survey question thus asked farmers if they were involved in organized watershed management activities in the watershed where their farm operation was located and assigned a 1 for yes and 0 for no (*Inv.W.Group*).

Awareness and Attitudes. Awareness and attitudes are important variables that affect pro-environmental behaviors (Prokopy et al. 2019). Prokopy et al. (2019) found that awareness and attitudes can be positively linked to the adoption of conservation practices. In terms of awareness, if farmers do not know about problems or possible remedies, they are not likely to take action. Similarly, once farmers are aware of issues and potential actions to address them, the positive or negative attitudes they form toward those actions will influence their proclivity to act. Our awareness variable (*Awareness*) is a measure of farmers' knowledge of the INRS and its goals (table S2). Similarly, the *Attitude* scale was constructed from farmers' ranking of four statements representing their attitude toward the INRS on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5) (table S2).

Perceived Capacity. Another explanatory variable is perceived behavioral control, which refers to an individual's beliefs about their ability to choose particular behaviors within a set of contextual factors (Fishbein and Ajzen 2010). In conservation research, this concept is often referred to when considering farmers' views about their capacity to adopt and implement, and greater perceived capacity is generally hypothesized to be positively associated with conservation behavior (Reimer et al. 2012; Arbuckle and Roesch-McNally 2015; Lee et al. 2018). Farmers were asked to indicate their levels of agreement or disagreement on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5) for the seven statements (table S2). Guided by factor analysis, the two summated scales measuring perceived economic capacity to adopt sufficient conservation practices (*Capacity.Econ*) and perceived agronomic capacity to effectively address nutrient losses were constructed (*Capacity.Agron*) (table S2). For both scales, higher scores indicate lower perceived confidence in economic or agronomic capacity to address nutrient loss.

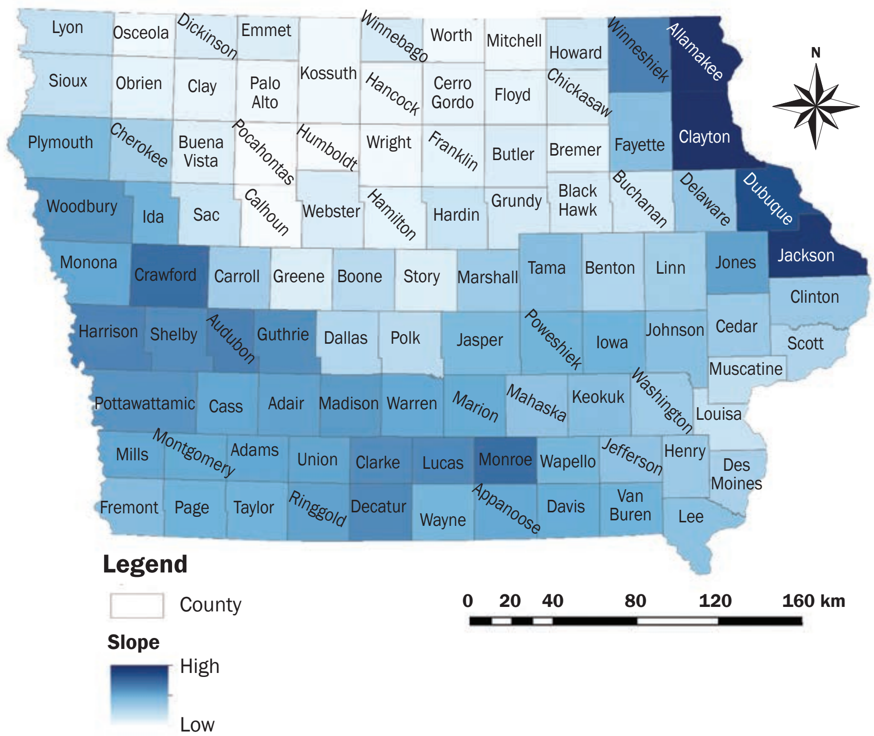
Farmer and Farm Characteristics. We included the demographic variables education (*Educ*) and age (*Age*). These two variables are often included in adoption studies to control for the generally negative influence of age and positive influence of education on conservation practice adoption (Prokopy et al. 2008, 2019).

We include farm size and type measures as these provide information on important farm-level context that may influence practice adoption, as farm size is a relatively consistent predictor of adoption of some conservation practices (Prokopy et al. 2019). To also control for farm type, we summed all corn, soybeans, and other grain crop acres into a measure of all crop acres (*Crop.Acres*). This variable is important to include in the model because 4R Plus nutrient management practices are primarily relevant to farmers growing row crops. That said, farmers may also apply fertilizer to pasture, so we also include the variable pasture acres (*Pasture.Acres*). We include a binary measure of whether the farmer raised livestock (*Livestock*) because (1) livestock manure has nutrient management implications (Andersen and Pepple 2017), and (2) having livestock has been shown to be associated with use of a number of types of conservation practices (Lu et al. 2022).

Two variables measured economic dimensions of farming. First, gross farm sales (*GFS*) measured the overall gross income from farming. A second is a measure of the proportion of cropland that farmers rent into their operations (*Per.Rent.Crop*). Higher levels of ownership, a proxy for control over the land on which conservation practices are established, is generally hypothesized to be a positive predictor of adoption (Prokopy et al. 2019). Conversely, the economic pressures associated with the expense of land rent

Figure 2

Map of mean slope across all 99 counties in Iowa.



are seen to be negatively related. However, Prokopy et al. (2019) found just 9% of analyses examining tenure at the individual level to be significant and consistent with hypotheses, while 7% were significant and inconsistent with hypotheses. Inconsistencies in previous research notwithstanding, we include this variable to control for farm-level land tenure.

The final farm characteristic included in the model is a measure of whether the farmers' cropland bordered any water bodies such as creeks, streams, rivers, or lakes (*WaterBorder*). Consistent with Prokopy et al.'s (2019) findings regarding vulnerability to soil or nutrient loss, we anticipate farmers whose farms border water bodies will be more likely to adopt conservation practices.

Use of Other 4Rs Practices. Use of other, potentially complementary, practices can be associated with adoption of new practices (Prokopy et al. 2019). To examine the dynamics and interrelationships between use of the different types of 4Rs Plus practices, we included the four other 4Rs Plus practices as explanatory variables in each model.

Level 2 Explanatory Variables: County Level. Our first county-level variable is a proxy for farmland vulnerability to erosion. Because the vulnerability of land, especially to erosion (e.g., the presence of highly erodible land), has been found to be a strong, positive farm-level predictor of conservation behavior (Morton et al. 2015; Prokopy et al. 2019), we constructed a county-level measure of vulnerability by calculating the average slope (*MeanSlope*) using the 30 m elevation data prepared by the USDA NRCS National Geospatial Center of Excellence (figure 2). This elevation model was downloaded from the USDA Geospatial Data Gateway. This National Elevation Dataset is a seamless mosaic of best-available elevation data for calculating slope derivatives (USDA NRCS 2021). Spatial variability in topographic factors like slope affects the infiltration versus runoff of precipitation, soil moisture content, and thus N availability, resulting in variable crop responses to fertilizer application across agricultural landscapes (Adler et al. 2020; Kaur et al. 2020).

Three other variables measure key county-level agricultural statistics. Two county-level variables mirror farm-level income and land tenure variables: mean agricultural gross income from farm-related activities per acre (*Farm.Income*) and percentage rented land (*Per.Rent.Land*). These two data were drawn from the USDA NASS Census of Agriculture (USDA NASS 2017). As noted above, at the individual level, land tenure is viewed as an economic measure—both as ownership control over a scarce resource and conversely, for tenants, as a lack of control and an expense. Given the unsettled understanding of the relationships between land tenure and the adoption of BMPs, Prokopy et al. (2019) called for innovation in the measurement of tenure, moving beyond simple farm-level binary or rented/owned ratio measures. Our county-level percentage rented land variable does this by measuring the landscape-level proportion of rented land, considering tenure as more of a social-structural contextual factor that, in the aggregate, may exert influence in addition to the individual economic effects. Thus, our county-level variable measures the proportion of rented farmland.

A third variable relates to risk management in farming: average insurance coverage level (*Avg.Cov.Lvl*). The average insurance coverage level data are from the USDA Risk Management Agency (USDA RMA 2021). Crop insurance, which is highly subsidized by the US government (USDA ERS 2020), is a crop and revenue risk management strategy that is nearly universally employed among row crop farmers in the region. We include this as a second level variable because Prokopy et al. (2019) called for further research into the relationship between participation in the federally subsidized crop insurance program and conservation practice adoption. They noted the few studies that have examined crop insurance as a predictor of conservation practice adoption generally hypothesize a negative relationship between the use of subsidized crop insurance and adoption, yet most analyses have found no significant associations (Prokopy et al. 2019). More recent research in the US Midwest also found no relationship between crop insurance and two key BMPs—cover crops and no-till—but concluded that the near-ubiquitous use of crop insurance among their sample of farmers reduced the statistical power of comparisons of BMP use between insurance users and nonusers, making detection of differences difficult (Fleckenstein et al. 2020). Yet, recent qualitative research in Iowa, Illinois, and Indiana found concern among some farmers that potential initial yield declines associated with cover crops could impact their "actual production history," a measure used by the Risk Management Agency to calculate the amount of yield able to be insured, and thus negatively affect their future revenue potential from crop insurance (Ranjan et al. 2020). Given the largely inconclusive results of individual-level research, we propose that variability in county-level indicators of crop insurance use may have more explanatory power. Similar to Connor et al. (2021), who found a negative but small relationship between cover crops use and crop insurance, we employ a county-level measure of average coverage level to estimate magnitude of insurance program participation.

Analytical Approach. This study conceives farmers (individual level) as nested within the counties where their farms were located (county level). We used a two-level hierarchical model or multilevel model to analyze our data. At the first level of the hierarchy (individual level) are farmers and farm-related variables, and at the second level (county level) are county-related variables. In multilevel modeling, the dependent variable of interest is always situated at the lowest level (Hox 2010). Therefore, in this study, the dependent variables, i.e., the use of different 4R Plus components, are measured at the individual level. Equation 1 is used to predict the dependent variable Y using the individual-level explanatory variables X:

$$Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + e_{ij} , \qquad (1)$$

where Y_{ij} represents the probability of using 4Rs practice by farmers i in county j; β_{0j} is the intercept or average odds of adopting the practice by farmers i in county j; X_{ij} includes individual-level variables for farmers i in county j; β_{1j} are the slopes associated with X_{ij}, representing the relationship between the individual-level predictors and the odds of adopting 4Rs plus practices. The e_{ij} have independent logistic distributions with variance. By introducing a county-level intercept (β_{0j}) into the equation, the two-level model extends the standard equation for the hierarchical model, allowing the exploration of county-level covariates and the decomposition of county-level variance across models (Bryk and Raudenbush 1992; Hox 2010). Therefore, the variation in intercept across counties is modeled by the county-level variable C_j as follows in equations 2 and 3:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}C_j + \mu_{0j} , \text{ and} \qquad (2)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}C_j + \mu_{1j} , \qquad (3)$$

where γ_{00} stands for overall mean, γ_{01} is a slope coefficient representing the effects of the county-level variables (C_j) on the β_{0j}, and γ_{10} represents the constant parameter, β_{1j}, and μ_{0j} random error terms. We added farmer and farm-level explanatory variables in the model after assessing the range of variance at the county level for all five dependent variables (individual models were developed for each dependent variable). A combined model, i.e., the two-level model (equation 4), was created by integrating equations 2 and 3 into equation 1:

$$Y_{ij} = \gamma_{00} + \gamma_{10}X_{ij} + \gamma_{01}C_j + \gamma_{11}X_{ij}C_j + \mu_{1j}X_{ij} + \mu_{0j} + e_{ij} . \qquad (4)$$

This combined model incorporates the individual- and county-level explanatory variables as well as composite error. This equation is often termed a mixed model because it includes both fixed and random effects (Bryk and Raudenbush 1992; Hox 2010). Before fitting the model, we considered the potential multicollinearity of predictor variables by using Pearson's coefficient factors for all pairs of variables. We found no strong correlations among variables. All explanatory variables were normally distributed except for *Crop Acres and Pasture Acres*. These two skewed variables were log (logarithmic) transformed prior to inclusion in the model. We used the Lme4 package in R to estimate multilevel model results (R Core Team 2022).

Results and Discussion

Descriptive Statistics. For the dependent variables, 37% of respondents reported that they had either used one or both Right Rate practices. About 86% of respondents reported that they had used Right Time, growing season N application and spring N application, practices that fall under the 4R Plus approach of making nutrients available when crops need them. About 47% of respondents used a Right Source practice, a N stabilizer, e.g., N-Serve. Out of three practices for Plus In-Field conservation practices, about 68% of respondents had used at least one Plus In-Field practice (cover crops, no-till, and extended rotations). Nearly 40% of respondents used only one practice, 22% used two, and only 6% of respondents used all three practices. Nearly all (83%) respondents had used at least one of the Plus Edge-of-Field practices. About 21% of respondents had used only one Edge-of-Field practice, 23% had used two, 22% had used three, 12% had used four, 5% had used five, and less than 1% had used all six practices (table 1).

Survey respondents ranged in age from 22 to 94 years old, with a mean of 58 years old (sd = 11.73) (table 2). Over one-third (38%) of respondents' highest level of education was high school or less. Over one-fourth of respondents' highest level of education was some college coursework (29%), 26% reported a bachelor's degree, and 8% had a graduate or professional degree. Surveyed respondents reported a mean of 331 ha of crop area and mean of 21 ha of pasture land. The mean gross farm sales for respondents was between US\$350,000 and US\$500,000. About two-thirds (62%) of respondents reported that their gross farm sales were below US\$350,000. About one-third (26%) of respondents reported gross farm sales between US\$350,000 and US\$1,000,000, and 12% had gross farm sales of more than US\$1,000,000. About 40% of the respondents raised livestock for sale or for milk production. Eighty-one percent of respondents farmed land that bordered a water body, 28% reported that they were actively involved in watershed management, and 58% had received cost-share or technical assistance for conservation over the previous five years. Regarding the respondents' perceived economic and agronomic capacity to effectively address nutrient losses from their farms, the mean score for the agronomic capacity scale was 2.80 (out of 5), and 3.35 for the economic capacity scale. The mean scale score for the attitude scale was 3.59, and 2.95 for awareness (table 2). Respondents had heard about the INRS from an average of 0.58 out of three private sector sources, by 1.67 out of three public sector sources, and by 1.30 out of two press sources. Among the sources of influence on nutrient management decisions, public sector entities had the highest mean influence (2.45 out of 5), followed by private sector entities (2.08) and on-farm research groups (1.70) (table 2).

Regression Results. We considered five different components of 4Rs Plus—Right Rate, Right Time, Right Source, Plus In-Field, and Plus Edge-of-Field—as dependent variables for this study. The individual models were developed to examine the relationships between the 4R Plus practices adopted and

Table 3
Multilevel regression results for farmers' use of 4R Plus practices, Right Rate, Right Time, and Right Source of nutrient management.

	Right Rate		Right Time		Right Source	
Variables	B	SE	B	SE	B	SE
(Intercept)	1.429	16.800	–16.970	17.720	–25.230	13.120
Year	–0.001	0.008	0.008	0.009	0.012*	0.006
Information sources						
Info.Priv	0.134**	0.042	–0.037	0.041	–0.063	0.033
Info.Pub	–0.018	0.035	0.053*	0.034	0.059*	0.027
Info.Press	0.034	0.038	0.058	0.036	0.096***	0.029
Influential actors						
Infl.Pub	0.043*	0.018	–0.043*	0.018	0.022	0.014
Infl.Priv	–0.004	0.016	0.032*	0.016	0.035**	0.013
Infl.On-Farm	–0.008	0.019	–0.001	0.018	–0.029*	0.015
Engagement in networks						
CSTA	0.023	0.023	–0.010	0.023	0.017	0.018
Inv.W.Group	0.065***	0.026	0.016	0.026	0.013	0.021
Awareness and attitudes						
Attitude	–0.026	0.023	0.045*	0.023	0.014	0.018
Awareness	–0.023*	0.012	–0.001	0.011	0.013	0.009
Perceived capacity						
Capacity.Econ	–0.002	0.016	0.002	0.015	0.025*	0.012
Capacity.Agron	–0.046*	0.018	–0.052**	0.017	–0.015	0.014
Farmer and farm characteristics						
Education	0.035**	0.012	0.013	0.012	0.005	0.009
Age	0.005***	0.001	–0.003**	0.001	–0.002*	0.001
Crops.Acres (log)	0.012	0.014	0.106***	0.013	0.059***	0.011
Pasture.Acres (log)	–0.014*	0.006	0.014*	0.006	–0.009	0.005
Livestock	0.044*	0.023	0.039*	0.022	0.022	0.018
GFS	–0.002	0.006	–0.002	0.006	0.004	0.005
Per.Rent.Crop	0.000	0.000	0.000	0.000	0.000	0.000
WaterBorder	0.019	0.030	0.001	0.029	–0.001	0.024
Other 4Rs practices						
Right Rate			0.146***	0.017	0.082***	0.014
Right Time	0.153***	0.018			–0.022	0.015
Right Source	0.133***	0.023	–0.039	0.023		
Plus In-Field	0.022	0.015	0.043**	0.015	0.027*	0.012
Plus Edge-of-Field	0.048***	0.009	0.022*	0.009	0.017*	0.007
County level						
Farm.Income	–0.002	0.001	0.004*	0.002	–0.002	0.001
Per.Rent.Land	–0.002	0.003	–0.011**	0.004	–0.005**	0.002
SlopeMean	–0.013	0.017	–0.109***	0.022	–0.026*	0.013
Avg.Cov.Lvl	0.002	0.012	0.025	0.016	0.021*	0.010
AIC	5,696		5,530.9		4,222.3	
BIC	5,888.4		5,723.4		4,414.8	
Log	–2,816		–2,733.5		–2,079.2	
Pseudo R^2	0.11		0.18		0.08	

Note: AIC and BIC are Akaike and Bayesian information criterion, respectively.
****P* < 0.001; ***P* < 0.01; **P* < 0.05.

factors at the individual and county levels. The intraclass correlation coefficient (ICC) values ranged from 0.20 to 0.70 for different models, indicating heterogeneity between the two levels and suggesting a multilevel regression model is appropriate. The maximum likelihood estimates of 4R and Plus practices models are displayed in tables 3 and 4, respectively.

Right Rate. We found 12 individual-level variables (9 positively and 3 negatively) to be significant in explaining farmers' adoption of at least one of the Right Rate practices variable rate N and N rate calculator; no county-level variables were significant (table 3). Private information sources (*Info.Priv*) was positively significant among the three information source variables, with a one-unit increase in private-sector sources associated with a 14% increase in odds of use of at least one Right Rate practice (figure 3). Among the three variables measuring the influence of different actors on farmers' nutrient management practices and strategies decisions, public sector actors (*Infl.Pub*) were positively associated with using at least one Right Rate practice (table 3). Farmers' involvement in watershed management groups (*Inv.W.Group*) was also significantly and positively associated with the use of Right Rate practices, with involvement increasing farmers' odds of adopting at least one of the Right Rate practices by 7% (figure 3).

The variables measuring farmers' awareness about the INRS (*Awareness*) and their perceived lack of agronomic capacity to reduce nutrient loss (*Capacity.Agron*) were significant and negatively related to farmers' using Right Rate practices (table 3). The odds ratio statistics showed that a one-unit increase in the five-point awareness scales corresponded to a decrease in odds of use of the Right Rate practice by 2%, while a one-unit increase in the (lack of) agronomic capacity scale was associated with a 4% decrease in the odds of using at least one Right Rate practice (figure 3).

Model results also indicated evidence that farmers' characteristics such as education (*Education*) and age (*Age*) were significantly and positively associated with the use of Right Rate practices (table 3, figure 3), with farmers with more education and of older age being more likely to use the Right Rate practices than others. Concerning farm characteristics, the results indicated that farmers' size of pasture (*Pasture.Acres* [log]) had a significantly negative relationship with the use of Right Rate practices, with a one-unit increase in pasture acres (log) decreasing the odds of farmers' use of Right Rate practices by 2% (figure 3). Also, our findings provide evidence that farmers' livestock holding was significant in explaining the farmers' use of Right Rate practices (table 3, figure 3). The corresponding odds statistic showed that farmers who raised livestock had odds

Table 4

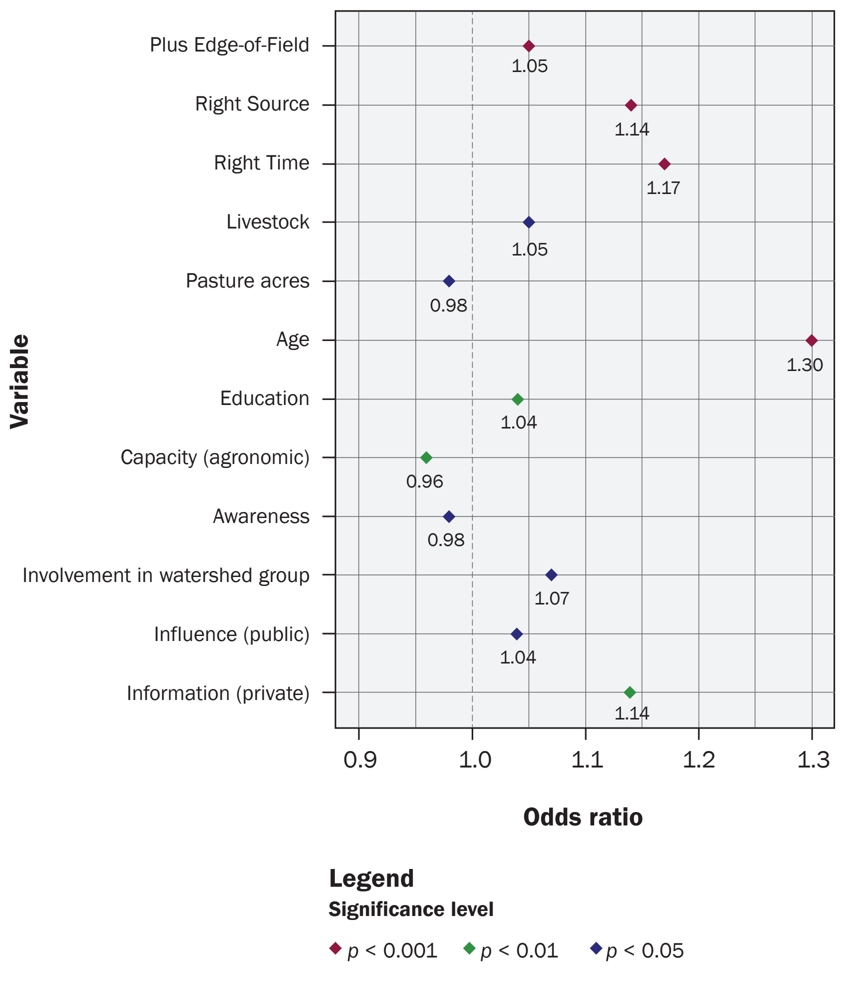
Multilevel regression results of farmers' use of 4R Plus practices, Plus In-Field and Plus Edge-of-Field.

	Plus In-Field		Plus Edge-of-Field	
Variables	**B**	**SE**	**B**	**SE**
(Intercept)	−65.290	21.670	90.310	34.840
Year	0.033**	0.011	−0.041*	0.017
Information sources				
Info.Priv	0.061	0.051	0.057	0.082
Info.Pub	0.042*	0.042	0.055	0.067
Info.Press	−0.033	0.046	0.020	0.073
Influential actors				
Infl.Pub	−0.019	0.022	0.142***	0.035
Infl.Priv	−0.037	0.019	−0.039	0.031
Infl.On-Farm	0.086***	0.023	−0.084*	0.036
Engagement in networks				
CSTA	0.006	0.028	−0.037	0.045
Inv.W.Group	0.038*	0.032	0.295***	0.051
Awareness and attitudes				
Attitude	0.131***	0.028	0.084**	0.045
Awareness	0.023	0.014	−0.024	0.023
Perceived capacity				
Capacity.Econ	−0.032	0.019	−0.026	0.030
Capacity.Agron	−0.102***	0.022	−0.044**	0.034
Farmer and farm characteristics				
Education	0.000	0.015	0.105***	0.023
Age	0.001	0.001	0.000	0.002
Crops.Acres (log)	0.063***	0.017	0.174***	0.027
Pasture.Acres (log)	0.100***	0.007	0.102***	0.011
Livestock	0.017	0.028	−0.015	0.045
GFS	−0.003	0.008	−0.001	0.012
Per.Rent.Crop	0.000	0.000	−0.003***	0.001
WaterBorder	0.012**	0.037	0.584***	0.058
Other 4Rs practices				
Right Rate	0.036	0.022	0.188***	0.035
Right Time	0.066**	0.023	0.084*	0.036
Right Source	0.068*	0.028	0.103*	0.045
Plus In-Field			0.249***	0.029
Plus Edge-of-Field	0.098***	0.011		
County level				
Farm.Income	0.003	0.002	0.000	0.003
Per.Rent.Land	0.001	0.004	−0.024***	0.007
SlopeMean	0.113***	0.025	0.092*	0.041
Avg.Cov.Lvl	−0.031*	0.019	−0.079**	34.840
AIC	6,875.8		9,700.9	
BIC	7,068.3		9,893.400	
Log	−3,405.9		−4,818.500	
Pseudo R^2	0.27		0.33	

Note: AIC and BIC are Akaike and Bayesian information criterion, respectively.

***P < 0.001; **P < 0.01; *P < 0.05.

Figure 3
Odds ratio statistics (ORs) (points) for significant explanatory variables in the Right Rate practices model. No county-level variables were significant predictors of Right Rate practice adoption. The ORs > 1 indicate positive relationships, and ORs < 1 indicate negative relationships.



of using at least one Right Rate practice increased by 5% (figure 3).

Regarding the use of other 4Rs practices, the results indicate that farmers' adoption of Right Time, Right Source, and Plus Edge-of-Field practices significantly and positively affected the use of Right Rate practices (table 3, figure 3).

Right Time. We found 12 individual-level variables and 3 county-level variables significant in explaining farmer adoption of at least one of the two Right Time practices, growing season N application and spring N application. Of the three information channels through which farmers had learned about the INRS, only public information sources was positive and significant in explaining Right Time practice adoption. The results indicated that a one-unit increase in the number of public sector information sources was associated with a 5% increase in odds of using at least one Right Time practice (table 3, figure 4). Among the three influential actors variables, the influence of private sector entities (*Infl.Priv*) was positively associated with the use of Right Rate practices (table 3). On the other hand, model results also indicated that farmers influenced by public sector entities (*Infl.Pub*) were less likely to use at least one Right Time practice; a one-unit increase in the public sector influence scale was associated with a 4% decrease in odds of practice use (table 3, figure 4). In addition, we found strong evidence that farmers' attitude toward the INRS (*Attitude*) had a significant and association with the use of Right Time practices, with a one-unit increase in the five-point attitude scale associated with a 5% greater odds of Right Time practice use (figure 4). Lower perceived agronomic capacity (*Capacity.Agron*) significantly and negatively explained farmers' use of Right Time practices; a one-unit increase in the agronomic capacity scale, indicating lower confidence in the capacity to address nutrient loss, was associated with a 5% decrease in odds of using the Right Time practices (figure 4).

Farmer's age (*Age*) was significantly associated with Right Time practices (table 3), with a one-unit increase in farmer's age decreasing the odds of using at least one Right Time practice by 2% (figure 4). Regarding farm characteristics, cropland (*Crops.Acres* [log]) and pasture acres (*Pasture.Acres* [log]) were positively and strongly significant in explaining the farmers' use of Right Time practices. This implies that farmers managing more crop and pasture land were more likely to use Right Time practices than those with smaller operations. Similarly, farmers who raised livestock were more likely to use at least one Right Time practice than those who did not. Of the other 4Rs Plus practices, farmers' use of Right Rate, Plus In-Field, and Plus Edge-of-Field practices was significantly and positively related to the use of Right Time practices (table 4, figure 4).

Farmers in counties with a higher percentage of rented land and steeper slopes were less likely to use at least one Right Time practice than farmers in other counties. The county-level variables percentage rented land (*Per.Rent.Land*) and mean slope (*MeanSlope*) had negative effects on Right Time practices use (table 3, figure 4). In contrast, the average income from farm activities (*Farm.Income*) was a significant and positive predictor of farmers' use of Right Time practices (table 3, figure 4).

Right Source. The Right Source model showed 11 individual-level and 3 county-level variables that significantly explained farmer adoption of N stabilizers (table 3). Of the three information channels through which farmers had learned about the INRS, farmers who learned about the INRS from the public information (*Info.Public*) and mainstream press (*Info.Press*) sources were significantly more likely to use this Right Source practice; a one-unit increase in the public sector information sources and press sources were associated with a 6% and 10% increase, respectively, in the odds of using an N stabilizer (figure 5). The influence of private actors (*Infl.Priv*) also had a significant positive influence on the use of the Right Source practice (table 3), while the influence of on-farm research groups (*Infl.On-Farm*) was significantly and negatively associated. A one-unit increase in the influence of on-farm research groups resulted in a 3% decrease in odds (figure 5). Concerning economic self-efficacy (*Capacity.Econ*), we found that farmers who believed they lacked the economic capacity to adopt sufficient conservation practices were more likely to use N stabilizers. The corresponding odds ratio statistics showed a one-unit increase in the scale measuring farmers' economic capacity corresponded to a 3% increase in odds of use (table 3, figure 5). Among farmer characteristics, age (*Age*) was significantly and negatively associated with Right Source practices (table 3), with a one-unit increase in farmer's age decreasing the odds of using at least one Right Time practice by 2% (figure 5).

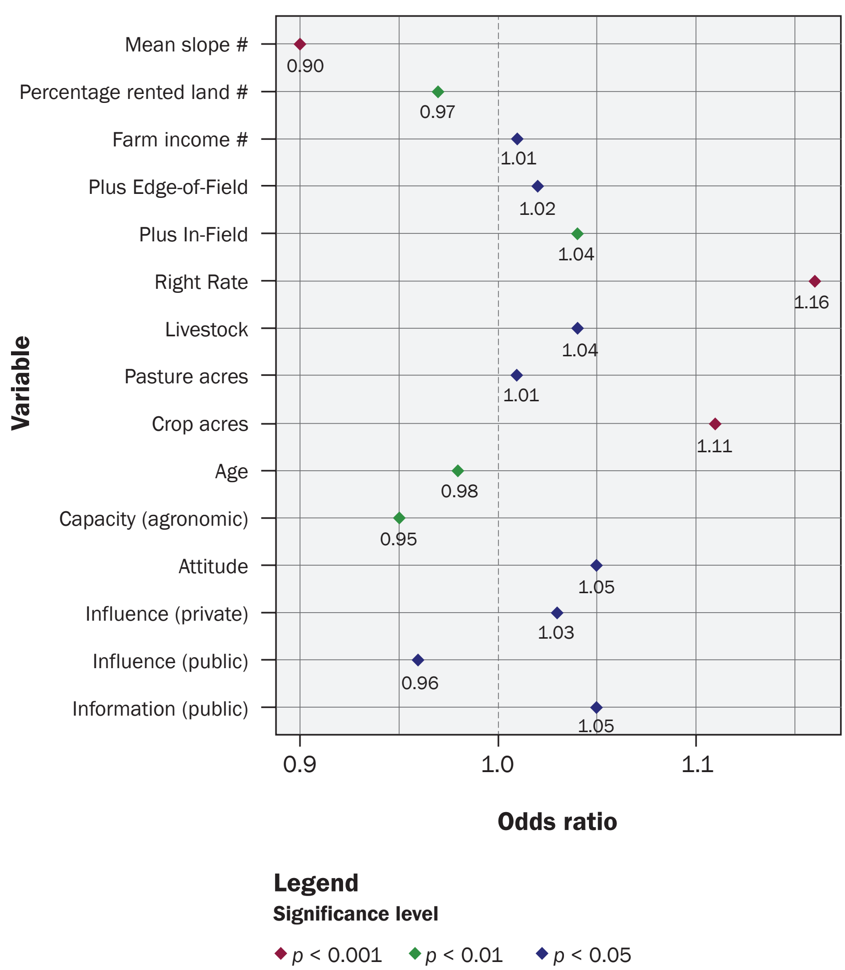
Among farm characteristics, amount of cropland (*Crops.Acres* [log]) was positive and significant in explaining farmers' use of the Right Source practice. The corresponding odds ratio statistics showed a one-unit increase in the cropland acres resulted in a 6% increase in odds (figure 5). The control variable, *Year*, was significant for farmers' adoption of N stabilizers, indicating that farmers who responded later in the survey period were more likely to adopt a N stabilizer.

Among other 4Rs Plus practices, farmers' use of Right Rate, Plus In-Field, and Plus Edge-of-Field practices had a significantly positive effect on the use of Right Source practices (table 3, figure 5).

We found a significant negative effect of county-level percentage rented land (*Per. Rent.Land*) and county's mean slope on the use of the Right Source practices. A one-unit increase in percentage rented land was associated with 2% lower odds of use, and a one-unit increase in mean slope decreased the odds by 3% (figure 5). A third county-level variable, average insurance coverage level (*Avg.Cov.Lvl*), was significant and positive in explaining the farmer's use of Right Source practices. A one-unit increase in average insurance coverage level increased odds of practice use by 2% (figure 5).

Figure 4

Odds ratio statistics (ORs) (points) for significant explanatory variables in the Right Time model. Variables with the # sign are county-level variables. The ORs > 1 indicate positive relationships, and ORs < 1 indicate negative relationships.



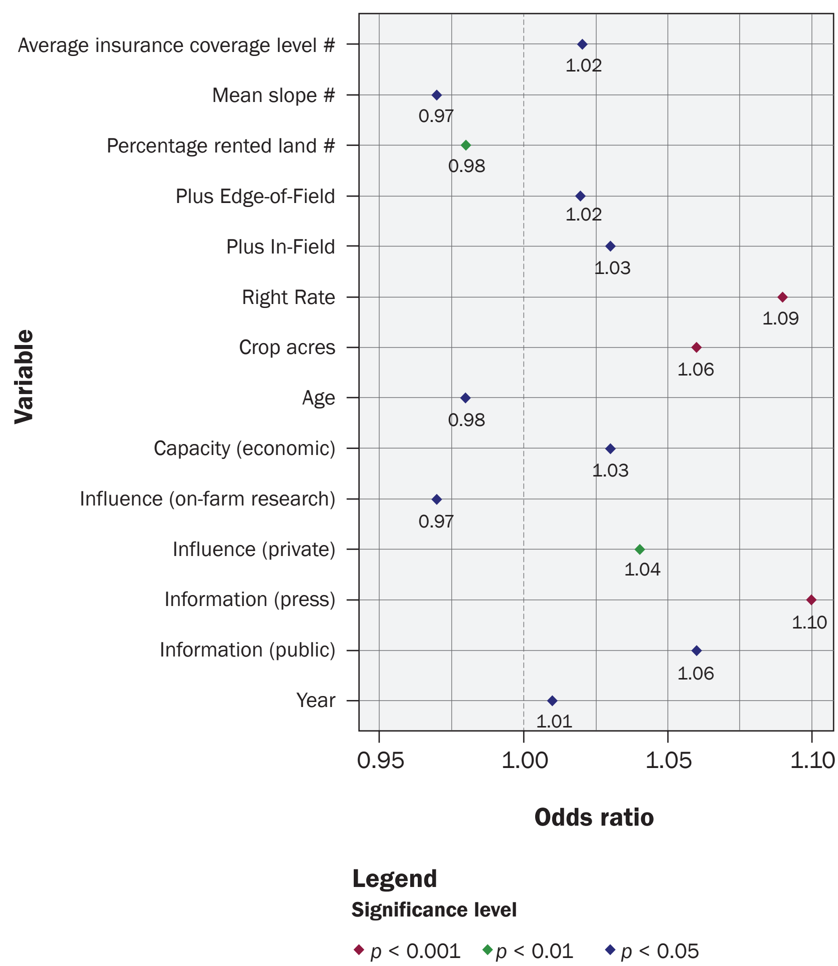
Plus In-Field. We found 11 individual-level and 2 county-level variables to be significant predictors of farmers' use of at least one of the three Plus In-Field conservation practices (cover crops, no-till, and extended rotations) (table 4, figure 6). Among information sources, we found that farmers who learned about the INRS from public sources of information (*Info.Pub*) were more likely to use at least one in-field conservation practice; a one-unit increase in *Info.Pub* was associated with a 4% increase in the odds of use of at least one in-field practice (table 4, figure 6). Farmers who rated on-farm research groups as influential (*Infl.On-Farm*) were more likely to use in-field conservation practices (table 4, figure 6). A one-unit increase in the scale measuring the influence of on-farm research groups was associated with a 9% increase in the odds of use of in-field practices (figure 6). Similarly, the variable measuring farmers' engagement in watershed management (*Inv.W.Group*) was positively associated with the use of Plus In-Field practices (table 4).

In addition, we found that farmers' attitudes toward the INRS (*Attitude*) had a significant and positive relationship with the use of Plus In-Field practices, with a one-unit increase in the five-point attitude scale associated with a 14% greater odds of Plus In-Field practice use (figure 6). The variable measuring perceived lack of agronomic capacity (*Capacity.Agron*) was significantly and negatively associated with farmers' use of Plus In-Field practices (table 4). A one-unit increase in the agronomic capacity scale, indicating lower confidence in the capacity to address nutrient loss, was associated with a 10% decrease in the odds of using Plus In-Field practices (figure 6).

Farmers with more crop and pasture land were more likely to use at least one of the Plus In-Field practices than smaller-scale farmers.

Figure 5

Odds ratio statistics (ORs) (points) for significant explanatory variables in the Right Source model. Variables with the # sign are county-level variables. The ORs > 1 indicate positive relationships, and ORs < 1 indicates negative relationships.



One-unit increases in the log of cropland size and pasture land resulted in 6% and 10% increases in odds, respectively (figure 6). Similarly, the measure of farmland bordering a water body was positively associated with the use of at least one Plus In-Field practice (table 4, figure 6). The control variable, *Year*, was also significant. Farmers who responded later in the survey period were more likely to use at least one of the three Plus In-Field conservation practices. Regarding the influence of other 4Rs Plus practices, farmers' use of Right Time, Right Source, and Plus Edge-of-Field practices had a significantly positive effect on the use of Plus In-Field practices (table 4, figure 6).

The county-level variable *MeanSlope* was significant and positive in explaining the farmers' use of Plus In-Field practices. The corresponding odds ratio statistic showed that a one-unit increase in the county's mean slope increased the odds of in-field practice use by 12% (figure 6). A second county-level variable, average insurance coverage level (*Avg.Cov.Lvl*), was significant but negative in explaining the farmer's use of Plus In-Field practices. A one-unit increase in average insurance coverage level decreased odds of practice use by 3% (figure 6).

Plus Edge-Of-Field. We found 14 individual-level and 3 county-level variables to be significant in explaining farmers' use of at least one of the six edge-of-field practices included (table 4). Farmers who rated the influence of public sector actors on their nutrient management decisions (*Infl.Pub*) highly were more likely to use at least one of the edge-of-field practices. A one-unit increase in the public sector entity influence scale was related to 15% greater odds of practice use (table 4, figure 7). Farmers who rated on-farm research groups as influential (*Infl. On-Farm*) were less likely to use edge-of-field conservation practices (table 4, figure 7). A one-unit increase in the scale measuring the influence of on-farm research groups was associated with an 8% decrease in the odds of use of Plus Edge-of-Field practices (figure 7). Similarly, farmers engaged in watershed groups (*Inv.W.Group*) had 34% greater odds of adopting at least one Plus Edge-of-Field practice compared to nonparticipating farmers (figure 7).

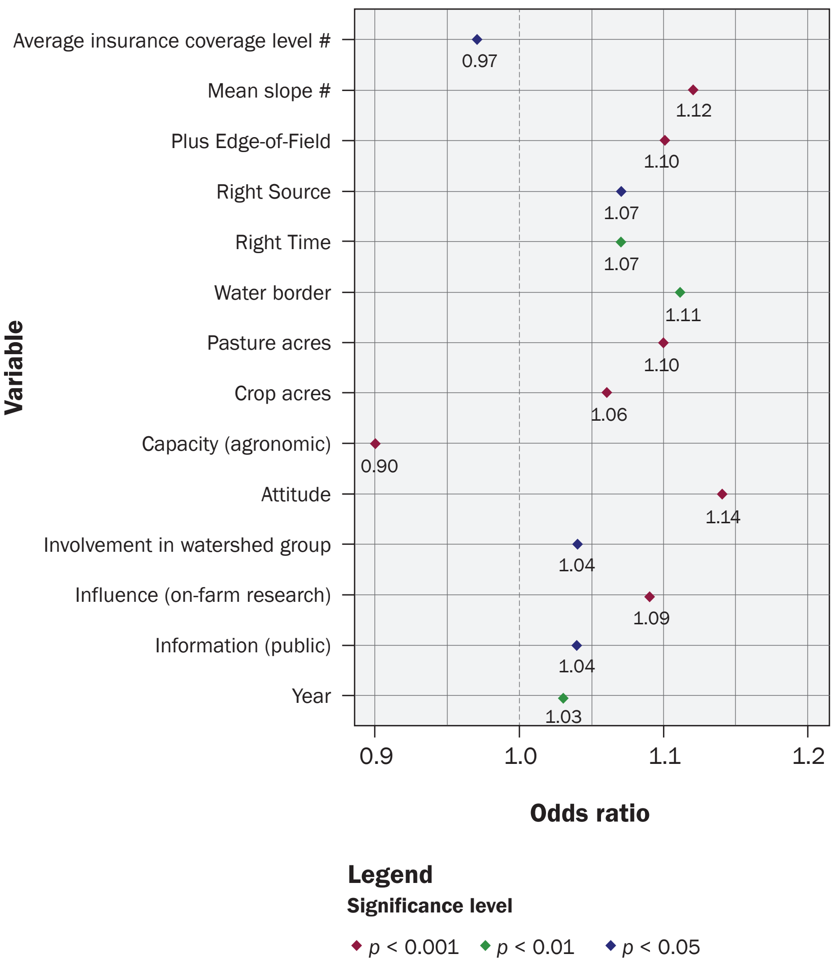
As was the case for in-field practices, farmers' attitudes toward the INRS were also positively related to the use of at least one Plus Edge-of-Field practice. The corresponding odds ratio statistics showed that a one-unit increase in the five-point attitude scale increased the odds of using Plus Edge-of-Field practices by 9% (figure 7). Similarly, the variable measuring perceived lack of agronomic capacity to manage nutrient loss (*Capacity.Agron*) was significantly and negatively associated with farmers' use of Plus Edge-of-Field practices (table 4). A one-unit increase in perceived lack of agronomic capacity (*Capacity.Agron*) decreased the odds of adoption of at least one Plus Edge-of-Field practice by 4% (figure 7).

With respect to farmers' socio-demographic characteristics, we found a positive relationship between farmers' academic qualification (*Education*) and the use of Plus Edge-of-Field practices: a one-unit increase in education level increased the odds of practice adoption by 11% (figure 7).

Regarding farm characteristics, farm size also had a significant positive effect on practice adoption, with a one-unit increase in log-transformed cropland size and pasture size increasing the odds of adoption by 19% and 11%, respectively (figure 7). Similarly, farmers whose cropland bordered any water bodies had odds of adopting Plus Edge-of-Field practices 1.8 times greater than those whose land did not (figure 7). We found that farmers who rented a greater proportion of the cropland they farmed (*Per.Rent. Crop*) were significantly less likely to use Plus Edge-of-Field practices. The control variable, *Year*, was negatively associated with farmers' use of Plus Edge-of-Field practices. Farmers who responded later in the survey period

Figure 6

Odds ratio statistics (ORs) (points) for significant explanatory variables in the Plus In-Field model. Variables with the # sign are county-level variables. The ORs > 1 indicate positive relationships, and ORs < 1 indicates negative relationships.



were less likely to use at least one of six Plus Edge-of-Field conservation practices. Regarding the influence of other 4Rs Plus practices, farmers' use of Right Rate, Right Time, Right Source, and Plus In-Field practices had a significantly positive effect on the use of Plus Edge-of-Field practices (table 4, figure 7).

The county-level variable *MeanSlope* was significant and positive in explaining farmers' use of Plus Edge-of-Field practices (table 4). A one-unit increase in a county's mean slope increased the odds of using at least one Plus Edge-of-Field practice by 10% (figure 7). We also found that higher levels of rented land (*Per.Rent.Land*) and higher insurance coverage levels (*Avg.Cov.Lvl*) had strong negative effects; a one-unit increase in percentage rented land was associated with decreased odds of edge-of-field practices adoption of 3%, while a one-unit increase in average insurance coverage level was related to an 8% decrease in odds (figure 7).

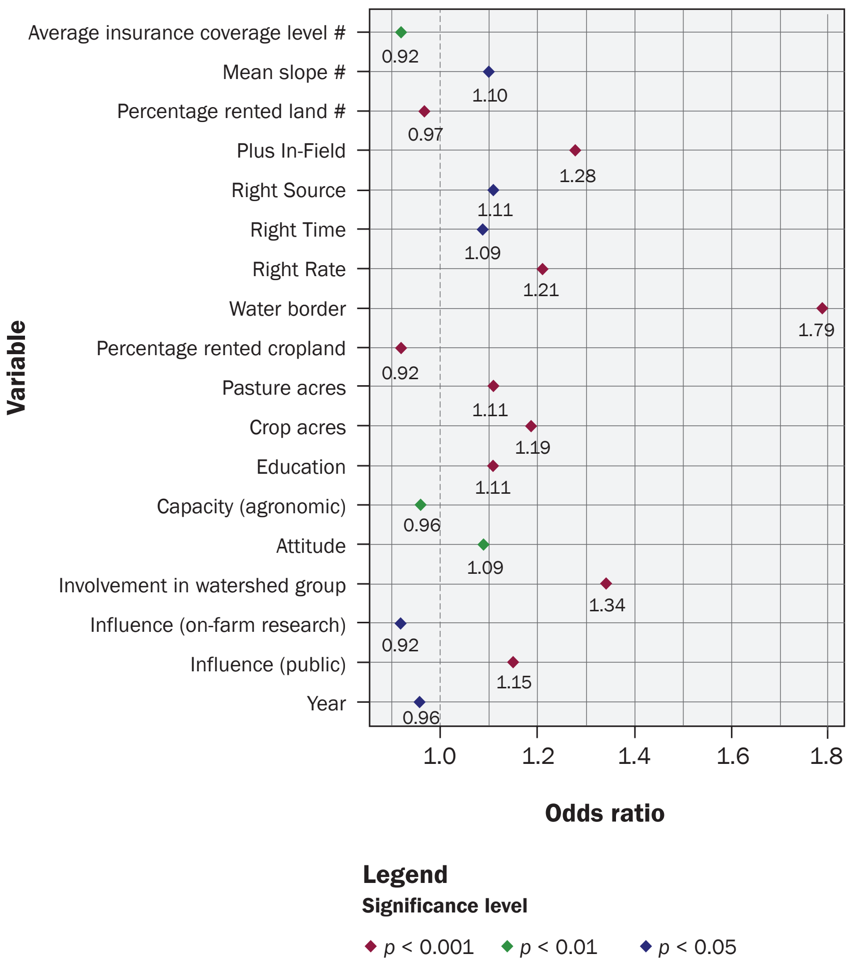
Discussion. To our knowledge, this study is one of the few to employ multilevel modeling to evaluate how higher-level biophysical and social-structural contextual factors may be related to adoption of agricultural BMPs. We followed a multilevel analytical approach in response to calls to evaluate ways that landscape-level context might impact individual-level behavior (Reimer et al. 2014). Our approach provides the opportunity to assess how relationships between practice adoption and major categories of predictor variables at individual and county levels may vary by type of practices (e.g., in-field nutrient management versus edge-of-field structural practices).

Among individual-level predictors, we found inconsistency in predictive power across the 4R Plus practice categories (figure 8). This inconsistency was especially notable among variables related to social networks: two of the three information sources variables were only significant for one model, and the third, public sources, was a predictor in three of the five models. Among the eight network-related variables, public sector actor and on-farm research groups influence, and watershed group involvement were significant predictors in more than two models. These results align with Prokopy et al.'s (2019) review and more recent research (Bressler et al. 2021; Morris and Arbuckle 2021) highlighting the importance of integration in conservation-related networks to practice adoption. Conversely, the lack of influence among other types of actors and information sources suggests opportunities to bolster their role, especially private sector agricultural retailers and crop advisers, whom farmers tend to trust as sources of information and influence (Eanes et al. 2017).

Agronomic self-efficacy was the most consistent predictor variable at the individual level; we found that farmers who indicated that nutrient loss reduction is difficult in corn and soybean and tiled-drained cropping systems were significantly less likely to have adopted practices in two of three 4Rs and both of the Plus categories (figure 8). This finding is important because self-efficacy, or perceived capacity to accomplish a given action or goal, is receiving increased attention as a focal point for outreach activities (Burnett et al. 2018; Perry and Davenport 2020). This finding suggests that many Iowa farmers lack confidence in their capacity to reduce nutrient loss despite major efforts to promote nutrient management across the state by multiple stakeholders, and this lack of confidence probably reduces the likelihood of using the practices on their farms. It also points to a need for increased capacity-building and offers evidence that 4R Plus backers such as The Nature Conservancy and CF Industries (https://www.cfindustries.com/) and other stakeholders should continue efforts to help farmers become more confident in their ability to follow the 4R Plus stewardship guidelines. Among the other individual-level predictors, farmers' education was a positive predictor of Right

Figure 7

Odds ratio statistics (ORs) (points) for significant explanatory variables in the Plus Edge-of-Field model. Variables with the # sign are county level. The ORs > 1 indicate positive relationships, and ORs < 1 indicate negative relationships.



Rate and Plus Edge-of-Field practices, while age was a negative predictor of use of Right Time and Right Source.

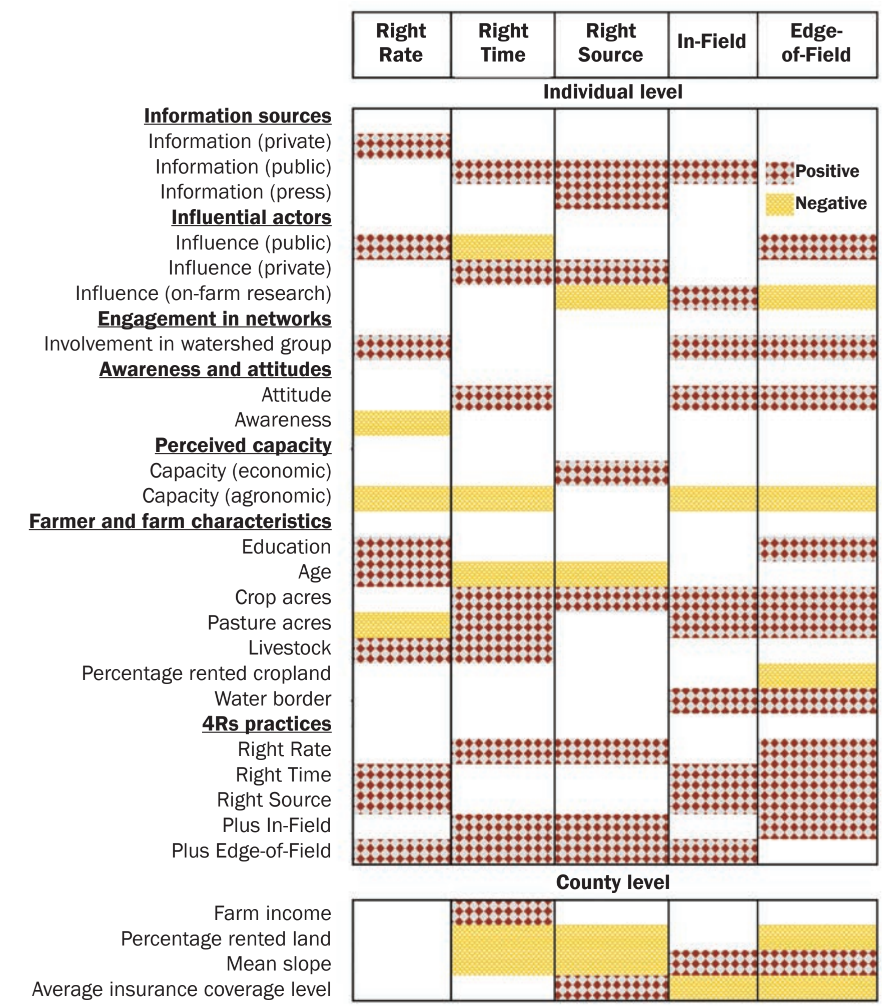
Among farm characteristics, crop acres was the most consistent predictor variable at the individual level—we found that farmers with more cropland were more likely to report all but Right Rate of 4Rs Plus practices, while farmers with higher pasture areas were more likely to have adopted Right Time and both Plus In-Field and Edge-of-Field practices (figure 8). These findings align with expectations and previous research (Prokopy et al. 2019). These findings are important because farm size is considered as a measure of capital and resources, which implies that larger farms have greater economies of scale and greater ability to absorb financial risks (Belknap and Saupe 1988; Roberts et al. 2004). As additional human and financial resources are needed for adopting conservation practices beyond the resources normally available on farms, this greater ability to absorb financial risks plays a role in adopting many conservation practices (Osmond et al. 2015). Finally, it is important to highlight that the variable measuring whether farms bordered a water body was strongly related to the use of Plus practices, especially edge-of-field practices. Given the increasing emphasis on targeting conservation outreach to farmland and farm operators who will "generate greater returns in terms of water quality" (Kast et al. 2021), our results suggest it would be most effective to start with land adjacent to water bodies.

A final important set of findings at the individual level are the consistent positive relationships between use of practices. In four of the five models, at least three of the other practices were significant, positive predictors of use of the practice of interest, and all four practice types were significant in the edge-of-field model. These results are consistent with Prokopy et al. (2019), who found use of similar, potentially complementary practices was a consistent predictor of practice adoption. The adoption literature suggests that adoption of one or more practices can lead to increased knowledge, skills, and capacity, cost reductions, attenuation of risk perceptions, and similar benefits, which in turn facilitate the adoption of other practices (Lichtenberg 2004; Teklewold et al. 2013; Canales et al. 2020; Gong et al. 2021). Importantly, the simultaneous implementation of multiple practices can create synergies that enhance water and soil conservation benefits (Blanco-Canqui et al. 2011).

Compared to individual-level variables, we found county-level variables to be more consistent predictors of 4Rs Plus practice adoption, with use of four of the five 4R Plus practices being significantly associated with at least one county-level variable (figure 8). The most consistent predictor was the mean slope. Slope is considered to be an indicator of vulnerability, as sloped land is more susceptible to erosion and sediment and P loss, major resource issues in Iowa and throughout the Corn Belt. Mean slope was a negative predictor for the 4R practices and positive for the Plus practices (figure 8). The latter finding is consistent with previous research indicating slope tends to be a positive predictor of Plus-type practices (Prokopy et al. 2019). The negative relationship between slope and adoption of the Right Time and Right Source practices is problematic for achieving conservation objectives since 4R-type nutrient management practices are generally highly applicable to crop production on sloped land.

We further found farmers in counties with greater proportions of rented land reported lower rate of adoption of Right Time, Right Source, and Edge-of-Field practices (figure 8). This finding has substantial importance, since Iowa has some of the highest rates of rented farmland in the United States—more than 50% overall, and nearly 70% in the more intensively farmed counties (Arbuckle 2010). The negative relationship between rented land and edge-of-field practice adoption is concerning since these practices are some of the most effective practices for reducing

Figure 8
Individual-level and county-level variables tested, and the number of models in which they were significant predictors at the $p \leq 0.05$ level.



nutrient and sediment loadings into waterways (INRS 2020). Iowa counties with the highest rates of rented land also tend to be the most significant sources of nutrient pollution (Jones et al. 2018a, 2018b). Landowner involvement is often important for edge-of-field practice adoption because such practices generally require substantial monetary investment and some alteration to the land (Ranjan et al. 2019b).

Our results indicate that county-level insurance coverage was negatively related to the use of both In-Field and Edge-of-Field Plus practices. Consistent with previous research (Schoengold et al. 2015; Upadhaya and Arbuckle 2021), our findings suggest crop insurance may act as a deterrent to the adoption of highly efficacious conservation practices such as cover crops and buffers. Considered together with results from other recent research examining crop insurance and conservation (Beckie et al. 2019; Medina et al. 2021, 2020), this result points to an urgent need to examine and ensure alignment between risk management and soil and water conservation goals. Crop insurance and conservation policies that work together could achieve sustainable risk management in both economic and environmental realms (Jones et al. 2021). Many Corn Belt farmers rely on crop insurance as a primary short-term risk management strategy (Mase et al. 2017), and potential crop insurance payment levels depend on annual crop yields over time (i.e., Actual Production History [APH]) (Plastina and Edwards 2017). At the same time, some farmers believe conservation practices such as no-till and cover crops can lead to yield declines, at least in the short term (Arbuckle and Roesch-McNally 2015; Roesch-Mcnally et al. 2017). Concern about yield declines and concomitant reductions in APH and potential crop insurance payout may reduce farmer willingness to adopt in-field and edge-of-field conservation practices, posing a tradeoff between management of short-term yield and revenue risks and long-term sustainability (Ranjan et al. 2020).

Overall, our models were better at predicting the use of Plus practices than 4Rs practices. Sixteen variables were positively or negatively associated with the use of at least one Plus practice, compared to just one (*crop acres* [log]) that was predictive in the same direction for all but Right Rate 4Rs practices. The models' Pseudo R^2 values were also much higher for the two Plus practice models, indicating better model fit and explanatory power. We selected many explanatory variables based on previous research on mostly Plus practices, rather than 4Rs nutrient management practices, so the models may be better specified for Plus practices (Prokopy et al. 2008, 2019). The Plus practices are highly effective but also management intensive (e.g., cover crops, no-till, and extended rotations) or require structural alteration to the farmland (e.g., terraces); thus, understanding factors influencing their use is crucially important to conservation programming. The weaker fit of the 4R nutrient management models suggests future research might consider other variables at the county (e.g., government payments and extreme weather) and individual (e.g., conservation and/or input expenditures, actual farm characteristics such as highly-erodible land status, soil quality, actual level of participation in USDA crop insurance and other risk management programs) levels that might improve understanding of the adoption of 4Rs practices.

Summary and Conclusions

Most conservation adoption research has focused on understanding how individual-level factors influence BMP adoption. We employed multilevel modeling, which allowed us to more effectively understand how context, particularly higher-order level social-structural context such as policy (crop insurance) and land tenure (rented land), as well as ecological factors (highly sloped farmland), may facilitate or constrain farmer behavior. Our findings indicate that factors at higher-order levels (e.g., county) may indeed impact adoption. These results provide evidence supporting calls for conservation programs to simultaneously address factors operating at multiple scales to improve outcomes (Atwell et al. 2010; Reimer et al. 2014), suggesting programs that combine local, direct assistance to farmers with broader efforts to remove structural barriers might be more effective at facilitating conservation adoption than those operating at one scale alone. Specific to 4R Plus programming, efforts that simultaneously help farmers address farm-level capacity barriers and work to ensure that policies and programs (e.g., crop insurance) enhance rather than hinder practice adoption would likely lead to better environmental outcomes.

We explored the relationships between socioeconomic and biophysical factors operating at different scales to guide the 4R Plus outreach campaign for farmers in the United States and globally. Our findings, especially those associated with county-level variables, have both program and policy implications. Overall, our findings reinforce Prokopy et al.'s (2019) call for a more nuanced examination of the associations between land tenure and BMP adoption, indicating that attention should be focused on the landscape-level context in addition to the individual farmer and farm levels. Given the major and growing magnitude of rented land in intensively farmed landscapes in the United States (Petrzelka et al. 2020) and elsewhere (Fenske 2011; Wästfelt and Zhang 2018), our results provide further evidence of the role that high levels of rented land may play in shaping environmental outcomes.

From a policy standpoint, opportunities to align the publicly subsidized annual economic risk management tool crop insurance with long-term environmental and agricultural sustainability goals needs examination. Subsidized crop insurance is purchased by nearly all row crop farmers in intensively farmed areas in the United States. New programs such as the Post-Application Coverage Endorsement (PACE), which reduce the financial risks associated with in-season N application, may be a step in the right direction (USDA RMA 2023). It is crucially important that risk management and conservation policies work together rather than at cross-purposes (Jones et al. 2021).

Supplemental Material

The supplementary material for this article is available in the online journal at https://doi.org/10.2489/jswc.2023.00002.

Acknowledgements

This project was supported by the Iowa State University (ISU) Presidential Interdisciplinary Research Initiative Consortium for Cultivating Human And Naturally reGenerative Enterprises (C-CHANGE) project and a grant from The Nature Conservancy (TNC) and the Iowa Nutrient Research Center (INRC). The NRS survey research was supported by the Iowa Department of Agriculture and Land Stewardship and ISU Extension. Additional support came from the USDA McIntire-Stennis program (IOW05534) and the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, which is supported by USDA National Institute of Food and Agriculture (NIFA) and State of Iowa Funds. The contents are solely the authors' responsibility and do not necessarily represent the official views of any funding agencies stated above.

References

Adler, R.L., G. Singh, K.A. Nelson, J. Weirich, P.P. Motavalli, and R.J. Miles. 2020. Cover crop impact on crop production and nutrient loss in a no-till terrace topography. Journal of Soil and Water Conservation 75(2):153–165. https://doi.org/10.2489/jswc.75.2.153.

Alagele, S.M., S.H. Anderson, R.P. Udawatta, K.S. Veum, and L.M. Rankoth. 2019. Effects of conservation practices on soil quality compared with a corn–soybean rotation on a Claypan soil. Journal of Environmental Quality 48(6):1694–1702.

Andersen, D.S., and L.M. Pepple. 2017. A county-level assessment of manure nutrient availability relative to crop nutrient capacity in Iowa: Spatial and temporal trends. Transactions of the ASABE 60(5):1669–1680.

Arbuckle, J.G. 2010. Rented land in Iowa: Social and environmental dimensions. Iowa State University Extension No.PMR1006 (2010). Ames, IA: Iowa State University.

Arbuckle, J.G. 2013. Farmer attitudes toward proactive targeting of agricultural conservation programs. Society and Natural Resources 26(6):625–641.

Arbuckle, J.G., and G. Roesch-McNally. 2015. Cover crop adoption in Iowa: The role of perceived practice characteristics. Journal of Soil and Water Conservation 70(6):418–429. https://doi.org/10.2489/jswc.70.6.418.

Arbuckle, J.G., and H. Rosman. 2014. Iowa farmers' nitrogen management practices and perspectives. Extension Community and Economic Development Publications 24 (2014). Ames, IA: Iowa State University.

Atwell, R.C., L.A. Schulte, and L.M. Westphal. 2010. How to build multifunctional agricultural landscapes in the U.S. Corn Belt: Add perennials and partnerships. Land Use Policy 27(4):1082–1090.

Barbercheck, M., K. Brasier, N.E. Kiernan, C. Sachs, and A. Trauger. 2014. Use of conservation practices by women farmers in the northeastern United States. Renewable Agriculture and Food Systems 29(1):65–82.

Bates, H., and J.G. Arbuckle. 2017. Understanding predictors of nutrient management practice diversity in midwestern agriculture. Journal of Extension 55(6). doi:10.34068/joe.55.06.48.

Beckie, H.J., S.J. Smyth, M.D.K. Owen, and S. Gleim. 2019. Rewarding best pest management practices via reduced crop insurance premiums. International Journal of Agronomy 2019. https://doi.org/10.1155/2019/9390501.

Belknap, J., and E.W. Saupe. 1988. Farm family resources and the adoption of no-plow tillage in southwestern Wisconsin. North Central Journal of Agricultural Economics 10(1):13–23.

Blanco-Canqui, H., M.M. Mikha, D.R. Presley, and M.M. Claassen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Science Society of America Journal 75(4):1471–1482.

Bressler, A., M. Plumhoff, L. Hoey, and J. Blesh. 2021. Cover crop champions: Linking strategic communication approaches with farmer networks to support cover crop adoption. Society and Natural Resources 34(12):1602-1619.

Bruulsema, T., J. Lemunyon, and B. Herz. 2009. Know your fertilizer rights. Crops & Soils 42(2):13–18.

Bryk, A.S., and S.W. Raudenbush. 1992. Hierarchical Linear Models: Applications and Data Analysis. Thousand Oaks, CA: Sage Publications.

Burnett, E., R.S. Wilson, A. Heeren, and J. Martin. 2018. Farmer adoption of cover crops in the western Lake Erie basin. Journal of Soil and Water Conservation 73(2):143–155. https://doi.org/10.2489/jswc.73.2.143.

Canales, E., J.S. Bergtold, and J.R. Williams. 2020. Conservation practice complementarity and timing of on-farm adoption. Agricultural Economics (United Kingdom) 51(5):777–792.

Church, S.P., N. Babin, B. Bentlage, M. Dunn, J.D. Ulrich-Schad, P. Ranjan, J. Magner, E. McLellan, S. Stephan, M.D. Tomer, and L.S. Prokopy. 2019. The Beargrass story: Utilizing social science to evaluate and learn from the "Watershed Approach." Journal of Contemporary Water Research & Education 167(1):78–96.

Connor, L., R.M. Rejesus, and M. Yasar. 2021. Crop insurance participation and cover crop use: Evidence from Indiana county-level data. Applied Economic Perspectives and Policy 44(4):2181-2208.

Costello, C., W.M. Griffin, A.E. Landis, and H.S. Matthews. 2009. Impact of biofuel crop production on the formation of hypoxia in the Gulf of Mexico. Environmental Science and Technology 43(20):7985–7991.

DeVellis, R.F. 2003. Scale Development: Theory and Applications, fourth edition. Thousand Oaks, CA: Sage Publications.

Diaz, R.J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321(5891):926–929.

Eanes, F.R., A.S. Singh, B.R. Bulla, P. Ranjan, L.S. Prokopy, M. Fales, B. Wickerham, and P.J. Doran. 2017. Midwestern US farmers perceive crop advisers as conduits of information on agricultural conservation practices. Environmental Management 60(5):974–988.

Fan, Y., and L. McCann. 2020. Adoption of pressure irrigation systems and scientific irrigation scheduling practices by U.S. farmers: An application of multilevel models. Journal of Agricultural and Resource Economics 45(2):352–375.

Fenske, J. 2011. Land tenure and investment incentives: Evidence from West Africa. Journal of Development Economics 95(2):137–156.

Field, A. 2009. Discovering Statistics Using IBM SPSS Statistics. Thousand Oaks, CA: Sage Publications.

Fishbein, M., and I. Ajzen. 2010. Predicting and Changing Behavior: The Reasoned Action Approach, 1st edition. New York: Psychology Press.

Fixen, P.E. 2020. A brief account of the genesis of 4R nutrient stewardship. Agronomy Journal 112(5):4511–4518.

Fleckenstein, M., A. Lythgoe, J. Lu, N. Thompson, O. Doering, S. Harden, J.M. Getson, and L. Prokopy. 2020. Crop insurance: A barrier to conservation adoption? Journal of Environmental Management 276(July):111223.

Floress, K., A. Reimer, A. Thompson, M. Burbach, C. Knutson, L. Prokopy, M. Ribaudo, and J. Ulrich-Schad. 2018. Measuring farmer conservation behaviors: Challenges and best practices. Land Use Policy 70(May 2017):414–418.

Gillespie, J., S.A. Kim, and K. Paudel. 2007. Why don't producers adopt best management practices? An analysis of the beef cattle industry. Agricultural Economics 36(1):89–102.

Gong, S., J.S. Bergtold, and E. Yeager. 2021. Assessing the joint adoption and complementarity between in-field conservation practices of Kansas farmers. Agricultural and Food Economics 9(30). https://doi.org/10.1186/s40100-021-00201-8.

Houser, M., S.T. Marquart-Pyatt, R.C.H. Denny, A. Reimer, and D. Stuart. 2019. Farmers, information, and nutrient management in the US Midwest. Journal of Soil and Water Conservation 74(3):269–280. https://doi.org/10.2489/jswc.74.3.269.

Hox, J.J. 2010. Multilevel analysis: Techniques and Applications, second edition. New York: Routledge.

Hyland, J.J., K. Heanue, J. McKillop, and E. Micha. 2018. Factors underlying farmers' intentions to adopt best practices: The case of paddock based grazing systems. Agricultural Systems 162(January):97–106.

INRS (Iowa Nutrient Reduction Strategy). 2020. Iowa Nutrient Reduction Strategy: 2018-19 Annual Progress Report. Ames, IA: Iowa State University.

Jones, C.S., J.K. Nielsen, K.E. Schilling, and L.J. Weber. 2018a. Iowa stream nitrate and the Gulf of Mexico. PLoS ONE 13(4):1–17.

Jones, C.S., K.E. Schilling, I.M. Simpson, and C.F. Wolter. 2018b. Iowa stream nitrate, discharge and precipitation: 30-year perspective. Environmental Management 62(4):709–720.

Jones, K., D. Tobin, L. Ristino, C. Isbell, and J. Jacobs. 2021. The role of crop insurance in shaping production trends and environmental Outcomes in the U.S. agro-food system. *In* Administering and Managing the U.S. Food System: Revisiting Food Policy and Politics, ed. B. Hoflund, J. Jones, and M. Pautz, 43–59. Idaho Falls, ID: Lexington Books.

Kast, J.B., M. Kalcic, R. Wilson, D. Jackson-Smith, N. Breyfogle, and J. Martin. 2021. Evaluating the efficacy of targeting options for conservation practice adoption on watershed-scale phosphorus reductions. Water Research 201(February):117375.

Kaur, G., G. Singh, P.P. Motavalli, K.A. Nelson, J.M. Orlowski, and B.R. Golden. 2020. Impacts and management strategies for crop production in waterlogged or flooded soils: A review. Agronomy Journal 112(3):1475–1501.

Keiser, D.A., and J.S. Shapiro. 2019. US water pollution regulation over the past half century: Burning waters to crystal springs? Journal of Economic Perspectives 33(4):51–75.

Lee, D., J.G. Arbuckle, Z. Zhu, and L. Nowatzke. 2018. Conditional causal mediation analysis of factors associated with cover crop adoption in Iowa, USA. Water Resources Research 54(11):9566–9584.

Lichtenberg, E. 2004. Cost-responsiveness of conservation practice adoption: A revealed preference approach. Journal of Agricultural and Resource Economics 29(3):420–435.

Lu, J., P. Ranjan, K. Floress, J.G. Arbuckle, S.P. Church, F.R. Eanes, Y. Gao, B.M. Gramig, A.S. Singh, and L.S. Prokopy. 2022. A meta-analysis of agricultural conservation intentions, behaviors, and practices: Insights from 35 years of quantitative literature in the United States. Journal of Environmental Management 323(September):116240.

Lu, M., and W. Yang. 2012. Multivariate logistic regression analysis of complex survey data with application to BRFSS data. Journal of Data Science 10(2):157–173.

Mase, A.S., B.M. Gramig, and L.S. Prokopy. 2017. Climate change beliefs, risk perceptions, and adaptation behavior among midwestern U.S. crop farmers. Climate Risk Management 15(2017):8–17.

McGuire, J.M., L.W. Morton, J.G. Arbuckle, and A.D. Cast. 2015. Farmer identities and responses to the social-biophysical environment. Journal of Rural Studies 39(2015):145–155.

McGuire, J., L.W. Morton, and A.D. Cast. 2013. Reconstructing the good farmer identity: Shifts in farmer identities and farm management practices to improve water quality. Agriculture and Human Values 30(1):57–69.

Medina, G., C. Isley, and J.G. Arbuckle. 2020. Iowa farm environmental leaders' perspectives on the U.S. Farm Bill Conservation Programs. Frontiers in Sustainable Food Systems 4(September):1–10.

Medina, G., C. Isley, and J.G. Arbuckle. 2021. Promoting sustainable agriculture: Iowa stakeholders' perspectives on the US Farm Bill conservation programs. Environment, Development and Sustainability 23(1):173–194.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. 2008. Gulf hypoxia action plan—2008. Framework (2008):62. Washington, DC: USEPA.

Morris, C., and J.G. Arbuckle. 2021. Conservation plans and soil and water conservation practice use: Evidence from Iowa. Journal of Soil and Water Conservation 76(5):457-471. https://doi.org/10.2489/jswc.2021.00166.

Morton, L.W., J. Hobbs, J.G. Arbuckle, and A. Loy. 2015. Upper Midwest climate variations: Farmer responses to excess water risks. Journal of Environmental Quality 44(3):810–822.

NOAA (National Oceanic and Atmospheric Administration). 2020. National Centers for Environmental Information (NCEI). Asheville, NC: NCEI. https://www.ncdc.noaa.gov/cag/.

Nowatzke, L., and J.G. Arbuckle. 2018. Iowa farmers and the Iowa Nutrient Reduction Strategy: Survey results from the Missouri-Little Sioux watershed. Ames, IA: Iowa State University.

Osmond, D.L., D.L.K. Hoag, A.E. Luloff, D.W. Meals, and K. Neas. 2015. Farmers' use of nutrient management: Lessons from watershed case studies. Journal of Environmental Quality 44(2):382–390.

Perry, V., and M.A. Davenport. 2020. An inductive framework of self-efficacy to understand and support farmers in conservation agriculture. Journal of Soil and Water Conservation 75(2):198–208. https://doi.org/10.2489/jswc.75.2.198.

Petrzelka, P., J. Filipiak, G. Roesch-Mcnally, and M.J. Barnett. 2020. Understanding and activating non-operator landowners: Non-operator landowner survey multi-state report. Washington, DC: Farmland Information Center.

Plastina, A., and W. Edwards. 2017. Proven yields and insurance units for crop insurance. Ames, IA: Iowa State University Extension and Outreach.

Power, A.G. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. Philosophical Transactions of the Royal Society B: Biological Sciences 365(1554):2959–2971.

Prokopy, L.S., K. Floress, J.G. Arbuckle, S.P. Church, F.R. Eanes, Y. Gao, B.M. Gramig, P. Ranjan, and A.S. Singh. 2019. Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. Journal of Soil and Water Conservation 74(5):520–534. https://doi.org/10.2489/jswc.74.5.520.

Prokopy, L.S., K. Floress, D. Klotthor-Weinkauf, and A. Baumgart-Getz. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. Journal of Soil and Water Conservation 63(5):300–311. https://doi.org/10.2489/jswc.63.5.300.

R Core Team. 2022. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Rabalais, N.N., and R.E. Turner. 2019. Gulf of Mexico Hypoxia: Past, present, and future. Limnology and Oceanography Bulletin 28(4):117–124.

Ranjan, P., S.P. Church, J.G. Arbuckle, B.M. Gramig, C.J. Reeling, and L.S. Prokopy. 2020. Conversations with non-choir farmers: Implications for conservation adoption. Report for the Walton Family Foundation. Sociology Technical Reports 16. https://lib.dr.iastate.edu/soc_las_reports/16.

Ranjan, P., S.P. Church, K. Floress, and L.S. Prokopy. 2019a. Synthesizing conservation motivations and barriers: What have we learned from qualitative studies of farmers' behaviors in the United States? Society and Natural Resources 32(11):1171–1199.

Ranjan, P., C.B. Wardropper, F.R. Eanes, S.M.W. Reddy, S.C. Harden, Y.J. Masuda, and L.S. Prokopy. 2019b. Understanding barriers and opportunities for adoption of conservation practices on rented farmland in the US. Land Use Policy 80(October 2018):214–223.

Reimer, A., A. Thompson, L.S. Prokopy, J.G. Arbuckle, K. Genskow, D. Jackson-Smith, G. Lynne, L. McCann, L.W. Morton, and P. Nowak. 2014. People, place, behavior, and context: A research agenda for expanding our understanding of what motivates farmers' conservation behaviors. Journal of Soil and Water Conservation 69(2):57A–61A. https://doi.org/10.2489/jswc.69.2.57A.

Reimer, A.P., D.K. Weinkauf, and L.S. Prokopy. 2012. The influence of perceptions of practice characteristics: An examination of agricultural best management practice adoption in two indiana watersheds. Journal of Rural Studies 28(1):118–128.

Roberts, R.K., B.C. English, J.A. Larson, R.L. Cochran, W.R. Goodman, S.L. Larkin, M.C. Marra, S.W. Martin, W.D. Shurley, and J.M. Reeves. 2004. Adoption of site-specific information and variable-rate technologies in cotton precision farming. Journal of Agricultural and Applied Economics 36(1):143–158.

Roesch-McNally, G.E., J.G. Arbuckle, and J.C. Tyndall. 2018. Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt. Global Environmental Change 48(December 2017):206–215.

Roesch-Mcnally, G.E., A.D. Basche, J.G. Arbuckle, J.C. Tyndall, F.E. Miguez, T. Bowman, and R. Clay. 2017. The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. Renewable Agriculture and Food Systems 33(4):322–333.

Rogers, E.M. 2003. Diffusion of Innovations, 5th edition. New York: Simon & Schuster.

Sawadgo, W., and A. Plastina. 2021. Do cost-share programs increase cover crop use? Empirical evidence from Iowa. Renewable Agriculture and Food Systems 1(2016):1–9.

Schoengold, K., Y. Ding, and R. Headlee. 2015. The impact of AD HOC disaster and crop insurance programs on the use of risk-reducing conservation tillage practices. American Journal of Agricultural Economics 97(3):897–919.

Smith, P., K. Calvin, J. Nkem, D. Campbell, F. Cherubini, G. Grassi, V. Korotkov, A. Le Hoang, S. Lwasa, P. McElwee, E. Nkonya, N. Saigusa, J.F. Soussana, M.A. Taboada, F.C. Manning, D. Nampanzira, C. Arias-Navarro, M. Vizzarri, J. House, S. Roe, A. Cowie, M. Rounsevell, and A. Arneth. 2019. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? Global Change Biology 26(3):1532-1575.

Sobota, D.J., J.E. Compton, M.L. McCrackin, and S. Singh. 2015. Cost of reactive nitrogen release from human activities to the environment in the United States. Environmental Research Letters 10(2). Bristol, UK: IOP Publishing LIMITED.

Stuart, D., B. Basso, S. Marquart-Pyatt, A. Reimer, G.P. Robertson, and J. Zhao. 2015. The need for a coupled human and natural systems understanding of agricultural nitrogen loss. BioScience 65(6):571–578.

Teklewold, H., M. Kassie, and B. Shiferaw. 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. Journal of Agricultural Economics 64(3):597–623.

The Nature Conservancy. 2021. 4R Plus: Nutrient management and conservation for healthier soils. Des Moines, IA: The Nature Conservancy. https://4rplus.com/conservation-practices/.

The Royal Society. 2009. Reaping the benefits: Science and the sustainable intensification of global agriculture. London: The Royal Society.

Thompson, C.A.J., M.J. Helmers, T.M. Isenhart, and J.D. Lawrence. 2014. Reducing nutrient loss: Science shows what works. Ames, IA: Iowa State University.

USDA ERS (Economic Research Service). 2020. Government programs and risk, major risk management programs. Washington, DC: USDA ERS. https://www.ers.usda.gov/topics/farm-practices-management/risk-management/government-programs-risk/.

USDA NASS (National Agricultural Statistics Service). 2017. 2017 Census of Agriculture. Washington, DC: USDA NASS.

USDA NASS. 2019. Crop production 2018 summary. Washington, DC: USDA NASS.

USDA NASS Cropland Data Layer. 2021. Published crop-specific data layer [Online]. Washington, DC: USDA NASS. http://nassgeodata.gmu.edu/CropScape/.

USDA NRCS (Natural Resources Conservation Service). 2021. Digital Elevation Data. Washington, DC: USDA NRCS. https://datagateway.nrcs.usda.gov/.

USDA RMA (Risk Management Agency). 2021. Crop insurance experience with coverage level-(1989 forward). Washington, DC: USDA RMA.

USDA RMA. 2023. Post-Application Coverage Endorsement (PACE). Washington, DC: USDA RMA. https://rma.usda.gov/News-Room/Frequently-Asked-Questions/Post-Application-Coverage-Endorsement.

US EIA (Energy Information Administration). 2020. State energy production estimates 1960 through 2018. Washington, DC: US Energy Information Administration.

USEPA (US Environmental Protection Agency). 2017. National water quality inventory: Report to Congress, EPA 841-R-16-011. Washington, DC: USEPA.

USEPA Office of Water. 2015. A compilation of cost data associated with the impacts and control of nutrient pollution. Washington, DC: USEPA.

Upadhaya, S., and J.G. Arbuckle. 2021. Examining factors associated with farmers' climate-adaptive and maladaptive actions in the US Midwest. Frontiers in Climate 3(2021):70.

Upadhaya, S., J.G. Arbuckle, and L.A. Schulte. 2021. Developing farmer typologies to inform conservation outreach in agricultural landscapes. Land Use Policy 101(February):105157.

Vollmer-Sanders, C., A. Allman, D. Busdeker, L.B. Moody, and W.G. Stanley. 2016. Building partnerships to scale up conservation: 4R Nutrient Stewardship Certification Program in the Lake Erie watershed. Journal of Great Lakes Research 42(6):1395–1402.

Wästfelt, A., and Q. Zhang. 2018. Keeping agriculture alive next to the city—The functions of the land tenure regime nearby Gothenburg, Sweden. Land Use Policy 78(October 2017):447–459.

Zhou, X., M. Al-Kaisi, and M.J. Helmers. 2009. Cost effectiveness of conservation practices in controlling water erosion in Iowa. Soil and Tillage Research 106(1):71–78.