frontiers in Climate

ORIGINAL RESEARCH
published: 28 June 2021
doi: 10.3389/fclim.2021.677548

Examining Factors Associated With Farmers' Climate-Adaptive and Maladaptive Actions in the U.S. Midwest

Suraj Upadhaya[1] and J. Gordon Arbuckle[2]*

[1] Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA, United States, [2] Department of Sociology, Iowa State University, Ames, IA, United States

The U.S. Midwest is a major producer of grain, meat, dairy, eggs, and other major agricultural commodities. It has also been increasingly impacted by climate change-related extreme weather over the last decade as droughts, extreme rains, floods, and, most recently, a severe derecho have damaged crops, livestock, and livelihoods. Climate and agricultural scientists and other stakeholders are concerned that without major shifts away from degrading practices toward regenerative systems, long-term sustainability will be compromised. We used cumulative logistic regression to analyze data from a 2020 survey of 1,059 Iowa farmers to examine (1) how farmers are adapting to increasingly variable and extreme weather-related to climate change and (2) whether selected factors were associated with different kinds of adaptive (e.g., increased use of cover crops) or potentially maladaptive (e.g., increased use of pesticides) actions. Our results found that many farmers have been taking adaptive and maladaptive actions. Stewardship ethics, attitudes toward adaptive action, and integration in conservation-related networks were consistent, positive predictors of increases in adaptive practices. On the other hand, faith in crop insurance as a coping strategy, farm scale, and other factors were associated with some maladaptive actions, with several positive predictors of adaptation also being positive predictors of maladaptation, use of pesticides and drainage in particular. This research contributes to the growing literature on climate risk management and adaptation in agricultural landscapes by providing empirical evidence of the factors related to farmers' adaptive and maladaptive actions.

Keywords: vulnerability, adaptation, maladaptation, extreme weather, risk, agriculture

Edited by:
Zhao Ma,
Purdue University, United States

Reviewed by:
Jeetendra Aryal,
International Maize and Wheat Improvement Center, Mexico
Stuart Carlton,
Purdue University, United States

***Correspondence:**
Suraj Upadhaya
upadhaya@iastate.edu
orcid.org/0000-0002-8173-9397

Specialty section:
This article was submitted to Climate Risk Management, a section of the journal Frontiers in Climate

Received: *07 March 2021*
Accepted: *03 June 2021*
Published: *28 June 2021*

Citation:
Upadhaya S and Arbuckle JG (2021) Examining Factors Associated With Farmers' Climate-Adaptive and Maladaptive Actions in the U.S. Midwest. Front. Clim. 3:677548. doi: 10.3389/fclim.2021.677548

INTRODUCTION

A large body of research indicates that since the middle of the nineteenth century, the world has warmed (Rosenzweig and Parry, 1994; Loeb et al., 2002; Schlenker and Roberts, 2009; Wuebbles et al., 2017). The annual average temperature is increasing continuously, and the frequency, intensity, and seasonal patterns of temperature, precipitation, and other extreme climate-related events have been observed (Wuebbles et al., 2017). These climate change-related extreme weather events continuously affect people's livelihoods across the globe (Barnes et al., 2020). The agriculture sector is one of the sectors most affected by climate change and extreme weather events (Zhang et al., 2020). Agriculture in the U.S. and globally has already begun to be affected by these changes, and impacts are believed to continue in the future (Porter et al., 2015), challenging global food system sustainability. The Midwestern U.S. Corn Belt contributes substantially to this system as this region is a major producer of grain, meat, dairy, eggs, and other major agricultural commodities (U. S. Department of Agriculture National Agricultural Statistics Service, 2019a). But the region is vulnerable to climate change-related extreme weather events (IPCC, 2007; Walthall et al., 2013). Over the last several decades, the U.S. Midwest has been affected by climate change in several ways, including lengthening growing seasons, more annual precipitation, increased extreme rainfall events, and increased warmer days (Doll et al., 2017). These trends and patterns are predicted to continue and worsen (Walsh et al., 2011), affecting farm yields (Walthall et al., 2013). Due to the sensitivity of agricultural productivity and costs of changing climate conditions, U.S. agriculture faces unprecedented challenges from climate change and extreme weather conditions (Walthall et al., 2013), necessitating adaptive responses from farmers.

Iowa is one of the main agricultural and grain production states in the U.S. Midwest. With more than 85% of its land base (>12 million hectares) used for agriculture (**Figure 1**), the state regularly leads the U.S. in the production of corn, soybeans, eggs, and pork (U. S. Department of Agriculture National Agricultural Statistics Service, 2019a). While climatic conditions (the average annual temperature ranges from 7.2°C in the north to 12°C in the southeast, and the annual average precipitation is around 863 mm) and soil quality have made Iowa's agriculture highly productive (Takle and Gutowski, 2020), global climate change-related impacts such as early-season rainfall, intense precipitation, increased humidity, and increased flash flooding threaten that productivity (Hatfield et al., 2020; Takle and Gutowski, 2020). Most recently, a severe climate change-related derecho damaged an estimated 3.5 million acres of corn and 2.5 million acres of soy in the state (Halverson, 2021). This windstorm was the costliest in U.S. history and caused an estimated $7.5 billion in damages (Halverson, 2021).

To cope effectively with these impacts of climate change and extreme weather, farmers need to respond with effective adaptation strategies (Mase et al., 2017; Barnes et al., 2020). Adaptation is defined as "actions to prepare for and adjust to new conditions thereby reducing harm or taking advantage of new opportunities" (Melillo et al., 2014). To face challenges posed by climate change, it is imperative that farmers have the capacity to respond effectively to weather variability and its impacts in ways that reduce risk and vulnerability. Throughout history, farmers have adapted to changes in climate and extreme weather (Lengnick, 2015). These adaptive behaviors of farmers offer the potential to address changing climate and weather extremes by adjusting, modifying, or changing farm operations to maximize productivity while minimizing the costs and adverse ecological effects (Gornall et al., 2010; Walthall et al., 2013). Farmers' adaptation strategies can include both short-term and long-term changes to their farm activities (Walthall et al., 2013), such as new or improved land use and management practices that respond to changes in climate and extreme weather to reduce the vulnerability. For example, farmers can plant cover crops to help protect cropland soils from erosion and improve soil and water quality. Similarly, reduced or no-till practices that leave 70% or more of the soil surface is covered with crop residue can also reduce soil erosion and surface runoff (Walthall et al., 2013; Thompson et al., 2014). Structural adaptation practices such as terraces, grassed waterways, and contour buffer strips can help stabilize stream banks, potentially reduce flooding, and settle sediments (Walthall et al., 2013; Thompson et al., 2014). These practices may also increase wildlife habitat and biodiversity, sequester carbon, and reduce greenhouse gas emissions (Thompson et al., 2014).

Not all actions taken in response to climate change are adaptive. However, some practices may lead to increased vulnerability over time instead of reducing it. Such changes are referred to as maladaptation, "…a process that results in increased vulnerability to climate variability and change, directly or indirectly, and/or significantly undermines capacities or opportunities for present and future adaptation" (Magan, 2014, p. 3). Scheraga and Grambsch (1999) stated that "maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided." Therefore, instead of reducing vulnerability, maladaptation can increase vulnerability (IPCC, 2001; Magan, 2014). For example, installation of agricultural drainage systems, a major adaptive response to increased precipitation, might show positive impacts at the farm level, but may have negative off-farm impacts on common-pool resources by increasing nutrient leakage and water quality impairment or decreasing biodiversity (Castellano et al., 2019; Neset et al., 2019). Other practices with potentially maladaptive properties include tillage in response to wet and cool springs, which can result in increased nutrient leakage, soil erosion vulnerability, and GHG emissions (Neset et al., 2019; Takle and Gutowski, 2020) and use of pesticides to combat climate-related increases in pest and weed pressure, which can lead to evolution of pesticide-resistant insects and weeds (Beckie et al., 2019; Neset et al., 2019; Zinyemba et al., 2021). These examples of maladaptation suggest that studies of agricultural adaptation to climate change and extreme weather should examine both potentials for increasing socio-ecologically and economically beneficial adaptations and avoiding maladaptation to climate change (Magan, 2014; Doll et al., 2017).

Farmers' adaptation has the potential to reduce vulnerability through the implementation of soil and water conservation practices, incorporation of perennial crops, and avoidance of maladaptive actions. However, adaptive capacities and behaviors may be influenced by numerous factors such as access to financial, knowledge, and technical capacity, and other facilitating resources, and contextual factors such as institutional and governance systems (Brown and Westaway, 2011). Climate change and agricultural scientists and other stakeholders are concerned that without major shifts away from degrading practices and toward regenerative ones, long-term sustainability will be compromised. Several studies have looked into relationships between farmers' beliefs, perceived risks, and their attitudes toward potential adaptive and mitigative responses

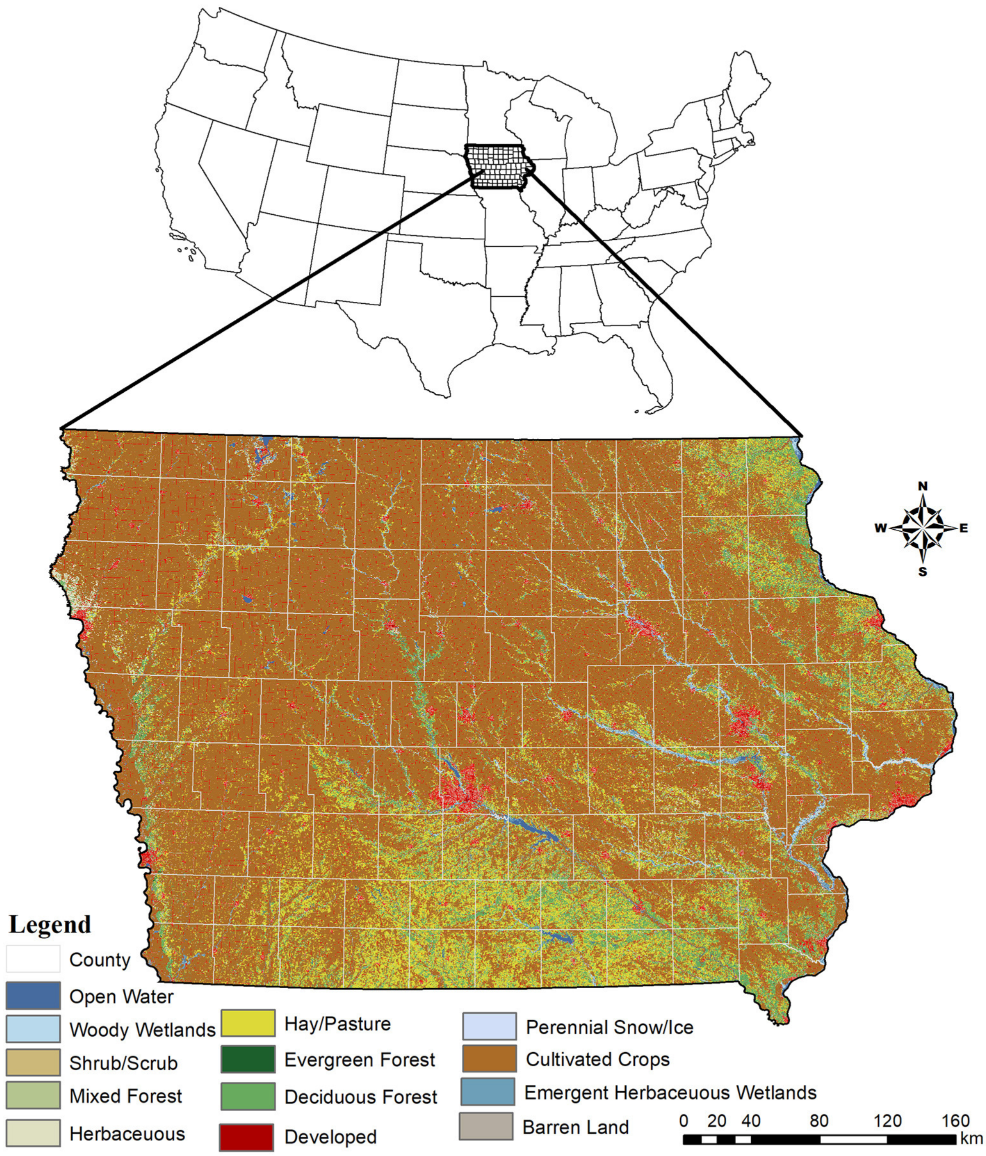

FIGURE 1 | Land use and land cover map of the state of Iowa (Source 2016 National Land Cover Database).

to climate change (Arbuckle et al., 2013a, 2014; Gramig et al., 2013; Burke and Emerick, 2016; Singh et al., 2020). Few studies, however, have examined factors affecting the actual adoption of adaptive management practices (Jones et al., 2013; Niles et al., 2013; Burbi et al., 2016; Jørgensen and Termansen, 2016; Schattman et al., 2016). To help address this gap, this study examines (1) whether farmers in the Midwestern U.S. state of Iowa have been taking steps to adapt their farm operations to increasingly variable and extreme weather, and (2) seeks to identify factors associated with those changes in agricultural management strategies—both adaptive and maladaptive. Given the major contribution of Iowa and its neighboring states in the fertile "Corn Belt" region to global food and feed supply, it is important to understand how the state's farmers have been adapting or maladapting to increasingly negative impacts of climate change on agricultural productivity (USGCRP, 2018).

METHODS

Data

The sample for this study is the 2020 wave of Iowa Farm and Rural Life Poll (IFRLP). The IFRLP is an annual statewide survey of Iowa farmers conducted by Iowa State University Extension and Outreach (Arbuckle, 2020). The 2020 survey was sent to 1,339 farmers. Fourteen cases were found to be ineligible for the survey (i.e., they were retired or deceased), and useable surveys were returned by 1,059 farmers for a response rate of 80%. Comparisons to the 2017 Census of Agriculture for Iowa show that respondents have farms that are somewhat larger scale than the average Iowa farm, with a sample mean of 232 hectares compared to the 144-hectare average for all Iowa farms (U. S. Department of Agriculture National Agricultural Statistics Service, 2019a, p. 396). This suggests that our sample is biased toward farms that are larger than the USDA average for Iowa. We view this bias toward larger-scale farmers as potentially positive for two reasons. First, Census of Agriculture farm size estimates are biased downward because USDA defines a farm as "…any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold, during the census year" (U. S. Department of Agriculture National Agricultural Statistics Service, 2019b). In Iowa, this inclusion criterion resulted in a census population in which 29% of farms reported <$2,500 of gross farm sales (GFS). Thus, our sample is likely more representative of farms that actually contribute to overall net household income. Relatedly, larger-scale operations farm a disproportionate amount of land in Iowa; for example, in 2017, farms with more than 200 hectares represented about 22% of Iowa farms, yet they operated 72% of the farmland area (U. S. Department of Agriculture National Agricultural Statistics Service, 2019a, p. 232). Given our research focus on the adoption of adaptation and maladaptation practices, a better understanding of larger-scale farmers' adaptive capacity and behaviors will allow us to offer perspectives that will be relevant to a greater proportion of the agricultural landscape.

Variables in the Model

Our research is guided by the research questions: (1) are Iowa farmers undertaking key adaptive and maladaptive actions in response to changing climate and weather extremes, and (2) what factors predict that behavioral change? Our analysis focuses primarily on the relationships between key demographic, cultural, social, economic, and institutional characteristics and actual adaptation and maladaptation behaviors.

Dependent Variables

We considered both adaptive and maladaptive practices as dependent variables for our analysis. We provided a list of selected adaptive and maladaptive practices preceded by the following introductory text: "Iowa has experienced increasingly variable weather such as unusually wet springs, more intense rainfall, floods, and drought that has impacted farming. In the last 10 years, have you made any changes to the following types of management operations in response to weather variability and its impacts?" Four adaptive practices *(1) Use of cover crops, (2) Use of no-till, (3) Structural, in-field conservation practices such as terraces, grassed waterways, and contour buffer strips; and (4) Structural, edge-of-field conservation practices such as buffer strips along streams* that are commonly considered to be effective in reducing farmland vulnerability to climate change and weather extremes (Thompson et al., 2014; Moore, 2021) were included in the analysis. Three potentially maladaptive practices were also included: (1) *Use of pesticides* (insecticides, herbicides, or fungicides), (2) *Installation or renovation of agricultural drainage* (tile, ditches, etc.), and (3) *Use of Tillage*. Although the use of pesticides can have yield protection benefits over the short term, over-reliance on pesticides is leading to a global crisis as pest populations are evolving resistance (Beckie et al., 2019), so we categorized increased use of pesticides as maladaptive. Similarly, the use of agricultural drainage is an important adaptation to increasingly extreme precipitation because it protects or enhances yields by hastening the movement of excess water from fields, but it can also significantly increase nutrient losses into waterways and off-farm water quality degradation (Castellano et al., 2019). Tillage may be employed to dry and warm soils more quickly in response to increasingly wet and cool springs, enhancing plant germination and growth (Al-Kaisi, 2019), yet tilled soils are vulnerable to soil erosion and soil carbon degradation, leading to negative impacts both on-farm (soil degradation) and off-farm (GHG emissions, sediment loss into waterways) (Lal, 2019); thus we also categorized tillage as maladaptive behavior. The survey asked farmers to indicate whether they had made changes on a five-point scale ranging from major decrease (−2), moderate decrease, (−1), no change (0), moderate increase (1), to major increase (+2).

It is important to note that the actual magnitude of the reported increases and decreases is unknown. Due to space considerations, the survey did not ask farmers to report the degree to which they had been using the practices at the outset of the recall period. Thus, the relative magnitude of moderate or major increases or decreases was subjective and depended on the farmers' perspectives. In addition, the responses could also be biased upward or downward by social desirability biases.

Independent Variables

Agricultural systems are human-dominated ecosystems; their vulnerability to climate change and weather extremes are strongly dependent not just on the biophysical effects of climate change and weather extremes but also on farmers' willingness and capacity to change behaviors in response to changing climate and weather extremes (Walthall et al., 2013). Therefore, we included different variables measuring attitudes, perceived motivations and barriers, trusted sources of information about climate change, values, beliefs, and other socio-demographic characteristics. The selection of variables was based on a review of the major factors influencing the adoption of conservation practices (Prokopy et al., 2008, 2019), and was guided by Smit and Skinner (2002) typology of agricultural adaptation to climate change, which includes (1) farm production practices, (2) technological development, (3) farm financial management, and (4) government programs and insurance. The descriptive statistics of independent variables used in the model are presented in **Table 1**.

Trusted Sources of Information on Climate Change

The first set of variables in the model measured farmers' trusted sources of information about climate change. Diffusion of innovations theory (Rogers, 2003) poses that information sources shape individuals' initial and evolving knowledge and perceptions of a problem or innovation. Research has shown that access to climate change information is central to adaptation

TABLE 1 | Independent variables included in the analysis and their descriptive statistics.

Variables	Description	Min	Max	Mean	*SD*
TRUSTSCIENCE	Trust in science-oriented entities as a climate information source	1	5	3.21	0.79
TRUSTAGRIBUSINESS	Trust in agribusiness as a climate information source	1	5	3.13	0.73
STEWARDMOTIV	Stewardship motivations for practice adoption	1	5	4.02	0.67
REGMOTIV	Regulation motivations for practice adoption	1	5	3.00	0.86
SOCMOTIV	Social motivations for practice adoption	1	5	2.57	1.01
WILDLIFEVALUES	Wildlife values	1	5	3.30	0.73
AGRONCAPAC	Perceived agronomic capacity	1	5	2.85	0.88
ECONCAPAC	Perceived economic capacity	1	5	3.38	0.73
FINCAPAC	Financial capacity	1	5	2.78	0.67
CROPINSCAPAC	Crop insurance capacity	1	5	2.90	0.79
CONCERN	Concern about climate change's impacts	1	5	3.43	0.83
TECHNOOPTIMISM	Techno optimism	1	5	2.74	0.97
ADAPTATT	Farmers' attitudes toward adaptation	1.2	5	3.42	0.54
ADAPPOLICY	Attitudes toward adaptation policy	1	5	3.30	0.78
COSTSHARE	In the last 10 years have you received cost share to help you fund conservation practices?	0	1	0.49	0.50
INVLVWATERSH	Are you involved in organized watershed management activities?	0	1	0.19	0.39
OPINIONLDR	Opinion leadership	1	5	2.75	0.73
AGE	What is your current age?	20	94	64.33	12.05
GENDER	Are you (0) Female or (1) Male?	0	1	0.92	0.27
EDUC	What is the highest level of education you have completed?	1	6	3.37	1.20
GFS	Which category best represents your gross farm sales for 2019?	1	10	6.01	2.20
SUCCESSORIDENTI	Have you identified a successor who will eventually take over management of your farm operation?	0	1	0.45	0.50

and mitigation (Moser and Ekstrom, 2010), and trust in information sources can shape farmers' attitudes toward adaptive and mitigative actions (Arbuckle et al., 2015). Following the prompt, "thinking about the following agencies, organizations, and groups, how much do you trust or distrust them as sources of information about climate change and its potential impacts?" farmers were provided a list of entities and asked to rate them on a five-point scale ranging from strongly distrust (1) to strongly trust (5). Two summated scales were constructed by adding the items for each scale and dividing the sum by the number of items. The first scale, "TRUSTSCIENCE," represents three science-oriented information sources (1) scientists, (2) university extension, and (3) soil and water conservation organizations. The Cronbach's alpha reliability coefficient, a measure of internal reliability for a scale (Field, 2009) value was 0.79. The second scale, "TRUSTAGRIBUSINESS," represents (1) Agricultural retailers/crop advisers, (2) Crop insurance agents/providers, (3) Agribusiness companies (Cronbach's alpha = 0.77). Following results from previous research on predictors of Iowa farmers' attitudes toward adaptation (Arbuckle et al., 2015), we anticipate that trust in science-oriented groups will be positively related to adaptation actions, and trust in agribusiness-oriented groups will be a negative predictor, and relationships with maladaptive practices the reverse.

Conservation Motivations

A set of three variables measures factors that motivate farmers to incorporate conservation practices into their farm operation. Conservation ethics and other motivational factors have been of increasing interest as potential determinants of soil and water conservation practices (Prokopy et al., 2019); thus, we included measures of multiple motivational dimensions. Soil and water conservation motivations were measured through a set of 23 survey items preceded by the text, "Thinking about the conservation practices that you have used in your farm operation over the years, please rate how important the following reasons have been in your decisions to use them?" The response categories were a five-point importance scale ranging from not important at all (1) to very important (5). The 23 items formed three summated scales measuring three types of motivations: stewardship, regulatory, and social normative.

The stewardship motivations scale (STEWARDMOTIV) comprises 13 items (Cronbach's alpha = 0.93). The wording of the items were as follows: "to maintain or improve soil health; it is the right thing to do; to protect the land for the next generation; due to my stewardship ethics; to increase soil organic matter; to avoid polluting streams, rivers and lakes; to protect my investment in the land; to control soil erosion; to keep chemicals and nutrients on the farm; to reduce my operation's environmental impact; to maintain or enhance productivity; to adapt my operation to increasingly extreme weather; and, feel responsible to earlier generations." The regulation motivations scale (REGMOTIV) was constructed from seven items (Cronbach's alpha = 0.86). The individual items were: "to ensure eligibility for Farm Bill programs and payments; to comply with Farm Bill requirements; to prepare for programs that reward conservation behavior; to prepare for potential future regulations; for discounts on crop insurance; for tax benefits (e.g., farm income deductions); and, cost-share programs helped make it more affordable. The social norms motivations scale (SOCMOTIV) was composed of three items: neighborhood expectations; family member(s) encouraged me to; and, to avoid embarrassment about visible problems" (Cronbach's alpha = 0.76).

Another set of motivation-related items measured farmers' values regarding wildlife-friendly conservation practices. Farmers were provided with four statements related to wildlife values and asked to rate them on a five-point scale ranging from strongly disagree (1) to strongly agree (5). The wildlife value scale (WILDLIFEVALUES) comprises four items: "farmers should improve wildlife habitat on their land; wildlife habitat on my farm adds to its market value; the presence of wildlife on my farm is important to me, and financial incentives would encourage me to do more wildlife on my farm" (Cronbach's alpha = 0.764). Because all of these scales measure positive predictors of conservation behavior, our expectation that their relationships with positive adaptation practices will be positive and their relationships with maladaptive practices negative.

Perceived Capacity

A third set of variables measures various dimensions of farmers' perceived capacity to adopt soil and water conservation practices. Perceived capacity is a critically important mediator of adoption and implementation of practices (Reimer and Prokopy, 2012; Reimer et al., 2012; Burnett et al., 2018; Lee et al., 2018). Farmers were asked to rate multiple survey items on a five-point agreement scale (1 = strongly disagree, 5 = strongly agree). Two summated scales were constructed. A scale measuring agronomic capacity (AGRONCAPAC) comprises the items, "nutrient loss is difficult to avoid in corn-soybean production systems; soil erosion is difficult to avoid in corn-soybean production systems, and nutrient loss is difficult to avoid in tile-drained fields" (Cronbach's alpha = 0.83). Three items comprise a scale measuring perceived generalized economic capacity (ECONCAPAC): "pressure to make profit margins makes it difficult to invest in conservation practices; there is not enough cost-share and other support available from government agencies, and many farmers do not have the economic resources to adopt sufficient conservation practices" (Cronbach's alpha value = 0.69). We view this latter scale as a measure of "treadmill of production" forces that may influence farmers to sacrifice long-term sustainability to ensure short-term economic survival (Houser and Stuart, 2020). As the three items in each scale are negatively phrased, higher scores represent lower perceived capacity to address conservation issues. Our research expectation is that higher scores on both will be negatively related with increased use of adaptation practices and positively related to increased use of maladaptation actions.

Two variables measured perceived capacity specific to adaptation to the potential impacts of climate change. A two-item scale is a self-evaluation of financial and technical capacity to cope: "I have the financial capacity to deal with any weather-related threats to the viability of my farm operation, and I have the knowledge and technical skill to deal with any weather-related threats to the viability of my farm operation," and labeled as FINCAPAC (Cronbach's alpha = 0.67). A final capacity variable measured belief that of crop insurance will provide sufficient protection through two items: "crop insurance and other programs will protect the viability of my farm operation regardless of weather," and "whether climate change is occurring or not, I believe that crop insurance and other programs will protect my farm operation's revenue." We labeled this summated scale of two items as CROPINSCAPAC (Cronbach's alpha = 0.71). We include this measure of crop insurance because the level of crop insurance depends on the maintenance of high year-to-year yield levels over time (Plastina and Edwards, 2017), so farmers who put greater emphasis on crop insurance as an adaptive strategy would be less likely to risk annual yield through practice such as cover crops, or reducing tillage. Our research expectation is that perceived financial and technical adaptive capacity will be positively associated with adaptive and maladaptive practices, while reliance on crop insurance will be negatively related to adaptive practices and positively related to maladaptive ones.

Perceived Risks

The degree to which farmers are concerned about the potential impacts of climate change has long been considered to be a precursor to actions in response (Howden et al., 2007; Arbuckle et al., 2013b). We include four variables measuring concerns about climate change's potential impacts in the model. The first measure of concern contains two items: "I believe that extreme weather events will happen more frequently in the future," and "I am concerned about the potential impacts of climate change on my farm operation." This variable is labeled CONCERN (Cronbach's alpha=0.84). As Arbuckle et al. (2013b) found positive relationships between a similar measure of CONCERN and attitudes toward adaptation, we also anticipate a positive relationship. The second variable measuring concern is a single statement: "climate change is not a big issue because human ingenuity will enable us to adapt to changes." This item was developed by Arbuckle et al. (2013a), drawing on the "human exemptionalist" thread of the new environmental paradigm (NEP) literature that highlights human propensity to consider themselves to be exempt from constraints of nature (Dunlap et al., 2000). Following Gardezi and Arbuckle (2020), who found this variable to be negatively related to support for climate change adaptation, we labeled it as TECHNOOPTIMISM and anticipate negative relationships with conservation-related adaptation practices, but potentially positive relationships with the maladaptive technological fixes that pesticide use, mechanical tillage, and engineered drainage represent.

Attitudes Toward Adaptation

Like perceived risks, farmers' attitudes toward potential adaptive or mitigative behavior changes are also viewed as important antecedents to such changes (Chatrchyan et al., 2017). We constructed this scale from a set of attitudinal statements introduced by the text, "a number of people and organizations are concerned about the potential impacts of climate change on Iowa agriculture. Please provide your opinions on the following statements related to climate change and agriculture." Respondents rated their agreement or disagreement with the statements on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5). Five items, "I should take additional steps to protect the land I farm from increased precipitation; extension should do more to help farmers and landowners to prepare for increased precipitation, I plan to use more conservation practices to increase my farm operation's resilience to extreme weather, and seed companies should be developing crop varieties adapted to coming changes in weather patterns" were combined into a summative scale that measures the farmers' adaptation attitudes. The summated scale for the five items, labeled as ADAPTATT, had a Cronbach's alpha value of 0.72. A second adaptation attitude variable consists of two items related to policies and programs that could facilitate adaptation: "Profitable markets for biomass should be developed to encourage the planting of perennial crops (grasses, trees) on vulnerable land, and programs and/or markets for carbon capture should be developed to help farmers earn money from adopting practices that capture greenhouse gases." We labeled this summated scale for two items as ADAPTPOLICY. The Cronbach's alpha value for this scale was 0.63. Clearly, since these variables consist of positively phrased measures of attitudes toward diverse types of positive adaptation, we anticipate positive associations with the three adaptation practices. Since two of the attitudinal items specifically reference increased precipitation, we also expect positive relationships with the tillage and drainage maladaptation practices.

Conservation Networks

Integration into social networks related to conservation has long been viewed as an important driver of pro-environmental behavior in agriculture (Prokopy et al., 2019), with proxies such as receipt of cost-share for conservation and contacts with natural resource professionals being positively correlated with practice adoption (Morris and Arbuckle, 2021). We include two binary measures (1 = yes) of conservation network orientation: Receipt of cost-share to support conservation practice adoption (COSTSHARE) and whether or not the farmer was involved in watershed management group or not (INVLVWATERSH). A third network-related variable is a measure of the degree to which respondents considered themselves to be leaders in the agricultural community. Opinion leaders play an important role in the diffusion of innovations theory, serving both as information channels and as behavioral exemplars (Rogers, 2003). We constructed a summated scale, labeled OPINIONLDR, consisting of four items measured on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5): "other farmers tend to look to me for advice; I consider myself to be a role model for other farmers; extension staff, crop advisers, and others involved in agriculture tend to look to me for advice, and my opinions matter in the local agricultural community." The Cronbach's alpha for this scale was 0.88. The research expectation is that all of these network-related variables will be positively related to adaptation practices and negatively related to maladaptation.

Control Variables

We include four variables to control for farmer age (AGE), education (EDUC), gender (GENDER), and GFS. A final variable (SUCCESSORIDENTI) is a binary measure of whether or not farmers had identified a successor who will eventually take over management of their farm operation (1 = yes). We consider this to be an indicator of a farm planning horizon that extends into the next generation of farmers, potentially impacting perspectives on adaptation.

Statistical Analysis

Our statistical analysis's main objective is to understand the factors that predict farmers' adaptive and maladaptive actions in response to climate change and weather extremes. As the response variables consist of ordered categories of a five-level increment scale, the cumulative logit model is appropriate (Simonff, 2003; Cappelleri et al., 2007). A detailed description of the cumulative logit model can be found in Simonff (2003). The cumulative logit model makes four important assumptions: (1) dependent variables should be ordinal, (2) one or more independent variables should be continuous, ordinal, or categorical, (3) there is no multicollinearity, and (4) proportional odds (Simonff, 2003). We ran a correlation matrix for all independent variables to test for any significant correlation between independent variables. We did not observe a significant correlation between any independent variables. To test for multicollinearity, we calculated Variance Inflation Factors (VIF). Variance Inflation Factors quantifies how much the variance is inflated (Simonff, 2003). Using the test of parallel lines, we checked whether the assumption of proportional odds was met or not (Simonff, 2003). All four assumptions were upheld. We fitted a cumulative logit model for dependent variables with five different levels of response. Let Yi denote the response measured on i individuals who have associated covariates Xi, i = 1,... K. The possible responses can be defined as Yi = (−2 if individual i chooses Major Decrease; −1 if individual i chooses Moderate Decrease; 0 if individual i chooses No Change; 1 if individual i chooses Moderate Increase; 2 if individual i chooses Major Increase).

Where Y_i = The probability that a randomly selected individual is in category j and is denoted by $P_r(Y = y_j)$. $P_{i,y_j} = P_r(Y \geq y_j)$ denotes the probability of a response in the category y_j or above, and the cumulative probabilities reflect the ordering in the response categories. Based on these cumulative probabilities, the incremental logit model can be written as

$$\log\left(\frac{p_{i,y_j}}{1-p_{i,y_j}}\right) = \alpha_j - \beta X_i.$$

RESULTS

We employed cumulative logistic regression to model factors affecting farmers' adaptive and maladaptive actions to climate change and extreme weather. Summary statistics for the independent variables included in the analysis are presented in **Table 1**. **Tables 3**, **4** summarize the model fits with a coefficient (B), the exponentiated coefficients [EXP(B)], also commonly referred to as odds ratios (Field, 2009) for four dependent variables for adaptive actions and three dependent variables for maladaptive actions to climate change and extreme weather.

Adaptive Actions

For each of the four adaptation practices, a majority of respondents reported either no change or an increase in adaptation actions (**Table 2**). Forty-one percent of farmers indicated that they had increased their use of no-till, 32% reported an increase in structural, in-field conservation practices such as grassed waterways and contour buffer strips, 27% increased their use of cover crops, and 22% increased structural, edge-of-field conservation practices such as buffer strips along streams. The proportion of farmers reporting decreases in the use of the practices ranged from 5% for cover crops to 3% for edge-of-field practices. Thus, the overall trend in the use of these adaptive practices was upward over the 10 years prior to the survey.

Use of Cover Crops

The cover crops model had the most robust predictive power, with 11 explanatory variables found to be statistically significant predictors of farmers' use of cover crops as adaptive actions in response to climate change and extreme weather, and a pseudo-R^2 of 0.36 (**Table 3**). Out of the four motivation factors, STEWARDMOTIV and WILDLIFEVALUES were significant, indicating that farmers with stronger stewardship and wildlife-related motivations and values were more likely to increase the use of cover crops in their farm operations. Two perceived capacity variables were significant predictors. AGRONCAPAC was positive, with farmers who viewed soil erosion and water quality impairment as difficult challenges being more likely to increase cover crops use. The negative coefficient for CROPINSURANCE indicates that farmers who believed that crop insurance and other programs would protect the viability of their farm operations regardless of weather variability were less likely to increase the use of cover crops. The two climate change attitudes scales, ADAPTATT and ADAPTPOLICY, were significant and positive. This indicates that farmers who had a positive opinion toward policies to incentivize planting of biomass and other carbon capture practices were more likely to increase the use of cover crops. All three network-related variables—receipt of cost-share (COSTSHARE) and involvement in watershed management groups (INVLVWATERSH), and self-rated opinion leader status (OPINIONLDR) were positive and significant predictors of increased use of cover crops. Among the control variables, age (AGE) had a significant negative relationship with the increase of cover crop use, while GFS was positive. The corresponding odds ratio statistics indicate that the likelihood of increased cover crop use associated with a one-unit increase in predictor variables ranged from 15% more for GFS to 2.16 times greater for cost-share. On the other hand, one-unit increases in CROPINSURANCE and AGE were associated with decreases in odds of 28% and 1.4%, respectively.

Use of No-Till

Three explanatory variables were significant and positive in the no-till model: stewardship motivations (STEWARDMOTIV), attitudes toward adaptation (ADAPTATT), and age (AGE) (**Table 3**). The odds ratios associated with these variables indicated that a one-unit increase in the stewardship motivations scale, the adaptations attitude scale, and in age corresponded to a 58%, 88%, and 1% greater likelihood of reporting increases in the use of no-till in response to weather variability (**Table 3**).

Structural In-field

Our results show that five different explanatory variables were significant, positive predictors of farmers' use of structural in-field practice such as buffer strips as adaptive actions in response to climate change and extreme weather impacts (**Table 3**). The one motivations item that was significant, although marginally so ($p = 0.07$), was WILDLIFEVALUES, and the corresponding odds ratio statistic indicates that a one-unit increase in the wildlife values scale corresponded to about a 24% greater likelihood of farmers reporting increased use of these practices. A single capacity-related variable, AGRONCAPAC, was significant, and the odds ratio indicated that a one-unit rise in the perceived difficulty of achieving soil erosion and water quality improvement corresponded to a 26% greater likelihood of increased structural in-field practices use. Similarly, the positive coefficient for ADAPTATT indicates that farmers with positive attitudes toward climate change adaptation were more likely to have increased use of such practices. The results also show that two of the network variables were significant. Farmers who had received cost share or technical assistance (COSTSHARE) were 84% more likely to report increased use of structural in-field practices, and farmers who rated themselves more highly on the opinion leader scale (OPINIONLDR) were more likely to increase the use of in-field practices. A one-unit increase in OPINIONLDR was associated with 33% greater odds of having increased practice use. Of the control variables, farmers' GFS was found to be a positive and significant predictor, with the odds ratio statistic indicating that a one-unit increase in GFS corresponded to 8% greater odds of increased use of structural in-field practices.

Structural Edge-of-Field

Four explanatory variables, WILDLIFEVALUES, ADAPATATT, COSTSHARE, and OPINIONLDR, were significant predictors of farmers' use of structural edge-of-field practices (**Table 3**). A one-unit increase in the wildlife values scale was associated with a 33% greater likelihood of increasing use of structural edge-of-field practices. Similarly, the odds ratio for ADAPTATT indicates that a one-unit increase in the attitudes toward climate change adaptation scale corresponded to a 94% greater likelihood of increasing use of edge-of-field practices. The two significant network-related variables, COSTSHARE and OPINIONLDR were associated with a 48% and 33% greater likelihood of increased use of edge-of-field practices as an adaptive response to climate change and extreme weather impacts.

TABLE 2 | Percentage distributions for adaptive and maladaptive actions (dependent variables).

Practices	Moderate decrease (%)	Major decrease (%)	No change (%)	Moderate increase (%)	Major increase (%)
Adaptive					
Use of no-till	2.5	2	53.7	22	19.8
Structural, in-field conservation practices such as terraces, grassed waterways, and contour buffer strips	1.7	0.7	66	23.3	8.3
Use of cover crops	3.2	1.6	68	14.7	12.5
Structural, edge-of-field conservation practices such as buffer strips along streams	2.1	0.9	75.1	15.3	6.6
Maladaptive					
Installation or renovation of agricultural drainage	1.6	1	51.8	34	11.6
Use of pesticides	7.7	1.4	59.4	26.2	5.4
Tillage	30.9	13.3	44.5	8.9	2.4

TABLE 3 | Factors that affect farmers' adaptive actions to climate change and extreme weather impacts.

Explanatory variables	Cover crops		No-till		Structural In-field (SIF)		Structural Edge-of-Field (SEoF)	
	B	Exp(*B*)	*B*	Exp(*B*)	*B*	Exp(*B*)	*B*	Exp(*B*)
TRUSTSCIENCE	0.097	1.102	0.071	1.073	−0.150	0.861	0.071	1.074
TRUSTAGRIBUSINESS	−0.115	0.891	0.078	1.081	0.143	1.154	−0.018	0.982
STEWARDMOTIV	0.396**	1.486	0.458***	1.582	0.191	1.210	0.219	1.244
REGMOTIV	−0.049	0.953	−0.036	0.965	−0.070	0.933	−0.021	0.979
SOCMOTIV	−0.183	0.833	−0.104	0.902	0.062	1.064	0.122	1.130
WILDLIFEVALUES	0.273*	1.314	0.041	1.042	0.212	1.237	0.284*	1.328
AGRONCAPAC	0.221*	1.247	−0.068	0.935	0.228*	1.256	0.109	1.115
ECONCAPAC	−0.189	0.828	0.009	1.009	−0.144	0.865	−0.188	0.828
FINCAPAC	0.012	1.012	−0.090	0.914	0.243	1.275	0.183	1.201
CROPINSCAPAC	−0.323**	0.724	0.049	1.050	0.025	1.026	0.017	1.017
CONCERN	−0.218	0.804	−0.072	0.930	0.015	1.015	−0.250	0.779
TECHNOOPTIMISM	−0.166	0.847	0.096	1.101	−0.112	0.894	−0.099	0.906
ADAPTATT	0.523*	1.688	0.633***	1.883	0.555**	1.742	0.664**	1.943
ADAPPOLICY	0.254*	1.289	−0.102	0.903	0.185	1.204	0.099	1.104
COSTSHARE	0.770***	2.159	0.209	1.232	0.609***	1.838	0.391*	1.478
INVLVWATERSH	0.195*	1.216	0.226	1.253	0.160	1.173	0.310	1.364
OPINIONLDR	0.466***	1.594	0.173	1.189	0.288*	1.334	0.289*	1.334
AGE	−0.014*	0.986	0.018**	1.018	0.008	1.008	0.003	1.003
GENDER	−0.032	0.969	0.265	1.304	0.504	1.656	0.507	1.660
EDUC	−0.070	0.932	0.082	1.085	0.060	1.062	−0.040	0.960
GFS	0.138***	1.148	0.002	1.002	0.084*	1.088	0.000	1.000
SUCCESSORIDENTI	0.174	1.190	0.004	1.004	0.311	1.364	0.060	1.062
Nagelkerke R^2	0.363		0.243		0.281		0.289	
Log likelihood	−714.389		−882.1		−681.4		−615.4	
AIC	1480.779		1816.2		1414.8		1282.8	
BIC	1602.317		1937.6		1536.5		1404.5	
Chi^2	4425.423		3431.8		3721.7		3828.4	

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Maladaptive Actions

Responses for the three maladaptive practices were mixed. A substantial percentage (44%) reported a decrease in the use of tillage, compared to 11% increasing and 45% no change (**Table 2**). Thus, although some farmers reported an increase in this soil degrading practice, on balance, respondents appeared to be

TABLE 4 | Factors that affect farmers' maladaptive actions to climate change and extreme weather impacts.

Explanatory variables	Tillage		Use of pesticides		Installation or renovation of AG drainage	
	B	**Exp(*B*)**	***B***	**Exp(*B*)**	***B***	**Exp(*B*)**
TRUSTSCIENCE	0.002	1.002	0.032	1.033	−0.167	0.846
TRUSTAGRIBUSINESS	0.119	1.126	0.171	1.186	0.130	1.139
STEWARDMOTIV	−0.389**	0.678	−0.280*	0.756	−0.059	0.943
REGMOTIV	0.029	1.030	0.310**	1.363	−0.076	0.926
SOCMOTIV	−0.029	0.971	−0.058	0.944	0.027	1.027
WILDLIFEVALUES	0.104	1.110	−0.282**	0.754	−0.159	0.853
AGRONCAPAC	0.009	1.009	−0.013	0.987	−0.010	0.990
ECONCAPAC	0.077	1.080	0.067	1.069	−0.220*	0.803
FINCAPAC	−0.087	0.917	−0.275*	0.759	0.153	1.165
CROPINSCAPAC	0.136	1.146	0.458***	1.581	0.034	1.035
CONCERN	0.201	1.222	−0.013	0.987	−0.343**	0.710
TECHNOOPTIMISM	0.058	1.059	0.038	1.039	−0.068	0.934
ADAPTATT	−0.492**	0.611	−0.002	0.998	1.423***	4.151
ADAPPOLICY	−0.154	0.857	0.091	1.095	0.065	1.067
COSTSHARE	−0.299*	0.741	−0.109	0.897	0.386**	1.472
INVLVWATERSH	−0.071	0.932	−0.036	0.964	−0.031	0.970
OPINIONLDR	0.070	1.072	0.249*	1.283	0.113	1.120
AGE	0.006	1.006	−0.004	0.996	0.013*	1.013
GENDER	−1.146***	0.318	0.420	1.522	0.514	1.673
EDUC	−0.008	0.992	0.027	1.028	0.175**	1.192
GFS	−0.085**	0.919	0.076*	1.079	0.189***	1.208
SUCCESSORIDENTI	0.145	1.157	0.132	1.141	−0.028	0.972
Nagelkerke R^2	0.266		0.211		0.289	
Log likelihood	−980.1		−810.8		−771.696	
AIC	2012.2		1673.6		1595.39	
BIC	2133.5		1795.2		1717.06	
Chi^2	3232.9		3028.1		5939.61	

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

moving away from tillage. On the other hand, 46% of farmers reported increases in the installation or renovation of agricultural drainage, and 32% reported an increase in the use of pesticides. Just 3% of farmers reported decreases in the use of agricultural drainage and 9% reported declines in the use of pesticides.

Tillage

Five explanatory variables, STEWARDMOTIV, ADAPATATT, COSTSHARE, GENDER, and GFS, were significant predictors of farmer's changes in the use of tillage in response to increasingly variable and extreme weather (**Table 4**). The coefficient of STEWARDMOTIV was significant and negative, indicating that farmers with greater stewardship ethics were less likely to increase tillage (or, in other words, more likely to decrease tillage) in their farm operations. The variables ADAPATATT and COSTSHARE were also negative predictors of change in use of tillage. The odds ratio statistics show that one-unit increases in the STEWARDMOTIV and ADAPTATT scales and receipt of COSTSHARE decreased the odds of an increase in tillage use by 33, 39, and 26%, respectively. The results showed that the coefficient of variable GENDER was significant and negative, indicating that female farmers were more likely to increase tillage in their operations as a response to climate change and weather extremes. Similarly, the negative and significant coefficient for GFS indicates that farmers with higher gross sales were less likely to increase the use of tillage on their farms.

Use of Pesticides

Our model shows seven explanatory variables, STEWARDMOTIV, REGMOTIV, WILDLIFEVALUES, FINCAPAC, CROPINSCAPAC, OPINIONLDR, and GFS, were significant predictors of change in the use of pesticides in response to increasing weather variability and extremes (**Table 4**). Among the motivation-related variables, stewardship motivations and wildlife values were negative and significant, and the corresponding odds ratio statistics indicate that a one-unit increase in both scales were related to a 24% lower likelihood of increased use of pesticides. On the other hand, the scale measuring regulation-related motivations for conservation practice use was a positive predictor of change in pesticide use, with a one-unit increase in the scale (indicating higher regulation motivations) corresponding to a 36% greater likelihood of increased use of pesticides. Two capacity-related variables were significant. The perceived financial and technical capacity scale (FINCAPAC) was a negative and significant predictor of change in use of pesticides, with a one-unit increase in FINCAPAC (higher perceived financial and technical capacity to cope with climate change) corresponding to a 24% decrease in odds of increasing use of pesticides. On the other hand, the positive coefficient for CROPINSCAPAC indicates that farmers who believed crop insurance and other programs would protect the viability of their farm operation regardless of weather variability were more likely (59% per unit increase) to increase the use of pesticides in their operations as a response to climate change and weather extremes. The positive coefficient for OPINIONLDR indicates that farmers who had higher scores on the self-rated opinion leadership scale were also more likely to increase the use of pesticides. Similarly, the positive coefficient for GFS indicates that farmers with high GFS were more likely to increase the use of pesticides in their farm operations as a response to climate change and weather extreme impacts.

Installation or Renovation of AG Drainage

The drainage model shows that seven explanatory variables, ECONCAPAC, CONCERN, ADAPTATT, COSTSHARE, AGE, EDUC, and GFS, were significant predictors of installation or renovation of ag drainage as actions in response to climate change and extreme weather impacts (**Table 4**). Out of the four perceived capacity variables, ECONOCAPAC, the measure of perceived lack of economic capacity to pursue conservation practice adoption (e.g., "pressure to make profit margins makes it difficult to invest in conservation practices"), indicated that higher "lack of capacity" scores were associated with a lower likelihood of increasing the installation or renovation of ag drainage as actions to climate change and extreme weather impacts. The scale measuring concern about the potential impacts of climate change (CONCERN) was significant and negative, suggesting that higher levels of concern were related to a lower likelihood of increases in drainage. The adaptation attitudes scale (ADAPTATT), on the other hand, was a strong positive predictor, with a one-unit increase in attitudes corresponding to a more than four times greater likelihood of increased installation or renovation of ag drainage. The positive and significant coefficient for COSTSHARE indicates that farmers who had received cost-share to fund conservation practices were about 47% more likely to increase the installation or renovation of ag drainage. Among the control variables, age, education, and GFS were positive and significant predictors of installation or renovation of ag drainage. The odds ratio statistics show that one-unit increases in AGE, EDUC, and GFS increased the odds of installation or renovation of ag drainage by 1%, 19%, and 21%, respectively.

DISCUSSION

Climate change is one of the most defining issues today, contributing to erratic precipitation levels, increased droughts, and other severe weather events worldwide. These extreme weather impacts are seen in every sector of the global economy. The far-reaching effects of climate change are clearly visible in the agriculture sector (Walthall et al., 2013; Arora, 2019; Zhang et al., 2020). The effects of climate change on agriculture could hinder meeting the growing food demands of the global population, which is expected to reach 9.7 billion by 2050 (Tamburino et al., 2020). To increase productivity, farmers are practicing intensive agricultural practices, including the application of fertilizers, herbicides, and tillage (Rabotyagov et al., 2014). But in the meantime, farmers are also changing or modifying practices in their farm operations in response to climate change and extreme weather to maintain or increase their farm productivity. But these practices are not always climate change friendly; they may fail to meet their objectives and may even increase vulnerability (Barnett and O'Neill, 2010). This unsuccessful adaptation is often termed "maladaptation" (Barnett and O'Neill, 2010; Magan, 2014). In order to minimize climate change and extreme weather impacts on agriculture, it is essential to consider farm practices that are directly under farmers' control. Farmers' perceptions and motivations affect their decisions to adopt different practices (Prokopy et al., 2008, 2019; Arbuckle et al., 2013a), and understanding factors associated with adaptive and maladaptive actions to climate change is key to reducing climate change impacts on agriculture. This discussion section focuses on results within each category of predictor (e.g., trusted information sources, conservation motivations, perceived risks), and examines patterns that emerged across the models regarding determinants of adaptation and mitigation practices.

Trusted Sources of Climate Information

Trust in major agricultural stakeholders, whether science-oriented public-sector entities or private-sector agribusiness interests, did not appear to influence farmers' changes in either adaptation or maladaptation practices in response to increasingly variable weather. Given that previous research on Iowa farmers had found these two types of entity to have positive and negative influences, respectively, on attitudes toward adaptation (and maladaptation) (Arbuckle et al., 2015), we were surprised that trust did not seem to influence actual behavior. However, Arbuckle et al. (2015) structural equation modeling analytical approach focused on the relationships between just four variables measuring trust, climate beliefs, and perceived risks and a two-item "support for adaptation" dependent variable that combined an adaptive practice (take additional steps to protect land) and a maladaptive practice (invest in drainage). Thus, the divergence in findings may be related to differences in model specification as well as our inclusion of many more potential predictor variables in this study. Further research may be needed to better elucidate the relationships between trust, attitudes, and actual behavior.

Conservation Motivations

Stewardship motivations and wildlife values were the most consistent predictors of behavior change of the four motivations-related variables, and among the most consistently significant variables overall. The stewardship scale, which comprised items such as "to maintain or improve soil health" and "to protect the land for the next generation" was strongly predictive of the two in-field adaptive management practices cover crops and no-till. The corresponding odds ratio statistic indicates that one unit increase in STEWARDMOTIV scale increases the likelihood of adoption of cover crops by 50% and no-till by 58% (**Table 3**). The wildlife motivations scale, composed of items such as "the presence of wildlife on my farm is important to me" and "farmers should improve wildlife habitat on their land" was a strong positive predictor of change in use of cover crops and in-field and edge-of-field structural practices such as buffer strips. Results for both of these variables make sense, given that the practices in question can fulfill the stewardship (e.g., soil health) and wildlife (e.g., habitat improvement) objectives (Blanco-Canqui et al., 2015; Schulte et al., 2017) embedded in the scales. Also important are the reverse results for these variables in the maladaptation models: stewardship motivations were negatively associated with increases in tillage, and both the stewardship and wildlife scales were significant negative predictors of increases in pesticide use. Thus, stronger stewardship and wildlife values may contribute to both increased adaptation and decreases in maladaptive behaviors. Considered together, these results suggest that climate change adaptation engagement strategies should focus on stewardship ethics, potentially with an emphasis on wildlife benefits of adaptation practices. These recommendations are in alignment with recent recommendations for soil and water conservation outreach strategies more generally (Zhang et al., 2016; Prokopy et al., 2019), adding evidence for increased focus on stewardship values in conservation programming.

Capacity and Efficacy

Results for the four capacity-related variables are more difficult to interpret. For the adaptation practices, farmers who rated soil and water conservation in corn-soybean production systems as a greater challenge (i.e., lower response efficacy) were more likely to have increased use of cover crops and structural in-field practices such as buffer strips. This result contrasts with studies that have found the opposite relationship, with, for example, lower ratings of capacity to address resource issues related to lower willingness to adopt cover crops (Burnett et al., 2018) or lower likelihood of adopting them (Lee et al., 2018). The only other capacity construct that was significant in more than one model was the variable measuring farmers' faith in crop insurance as a protective mechanism. The findings that farmers who had greater confidence that crop insurance would protect their farm operation were less likely to have increased use of cover crops and more likely to have increased use of pesticides align with our research expectations. As noted above, crop insurance coverage levels depend on rolling 10-year average yields; farmers who depend more on crop insurance may thus be less likely to risk annual yield over the short term through practices such as cover crops and more inclined to protect those yields through pesticide use. Several studies have provided insight into whether crop insurance and/or similar institutional and economic structures might influence farmers to employ practices that may have some short-term benefits but lead to potential long-term degradation (Stuart, 2018; Houser and Stuart, 2020; Mortensen and Smith, 2020). Our findings add to that body of evidence and point to a pressing need to conduct further research and policy analyses into potentially perverse relationships between structural factors such crop insurance and farmers' adaptive and maladaptive behaviors.

Perceived Risks

Both of the two perceived risk variables were poor predictors of adaptation and maladaptation actions, with only the CONCERN variable being significant in one model (installation or renovation of ag drainage). These results were surprising given that previous research has found strong and consistent positive relationships between concern about climate change and attitudes toward adaptation (Arbuckle et al., 2013a; Roesch-Mcnally, 2018) and negative relationships between attitudes toward adaptation and the *lack of concern* that generalized faith in human ingenuity (techno-optimism) represents (Gardezi and Arbuckle, 2020). As noted above regarding the trust variables, perhaps concern does not have a direct effect on actual behavior, but rather an indirect effect through attitudes, a relationship that the analytical approach employed here did not detect.

Attitudes Toward Adaptation

The adaptation attitudes variable was the most consistent and robust predictor of change in adaptive and maladaptive practices. The relationships were strongly positive for the adaptive practices, with odds ratios indicating that higher scores on the attitudes scale were associated with substantially higher likelihood of increases in conservation practice use. On the maladaptive hand, more positive adaptation attitudes were linked to reductions in use of tillage, but increased likelihood of drainage. As noted in the methods section, because some of the scale items were focused on precipitation, we anticipated a possible positive relationship, especially for drainage (Arbuckle et al., 2013b). Considered together, these results suggest that outreach and engagement strategies that focus on fostering positive attitudes toward conservation practices as adaptive responses to increasingly variable and extreme weather can be highly effective catalysts of behavior change. Specific to drainage maladaptation, the strong positive relationship between adaptation attitudes and the potentially maladaptive increases in drainage point to a potential opportunity for policy and programmatic intervention. Recent research (Castellano et al., 2019) indicates that the maladaptive properties associated with increased or renovated agricultural drainage can be substantially attenuated through practices such as wetlands and controlled drainage; our research points to a need to increase promotion of promotes these practices.

Conservation Networks

As a category, the variables measuring integration into (mostly) conservation-related social networks were also highly consistent predictors of adaptation actions, but not maladaptation. Having received cost-share or technical assistance with soil and water conservation, being involved in a watershed management group, and self-rated opinion leader status in agricultural networks were all strongly related to positive changes in use of cover crops and in-field and edge-of-field structural practices, but not no-till. Results were spotty and mixed for the maladaptive practices, with cost-share being associated with decreases in tillage but increases in drainage, and opinion leadership related to increases in pesticide use. That said, these findings indicate that on the whole these traditional predictors of conservation practice adoption are also influential when the behavioral response is specifically focused on climate change adaptation. As was the case with the motivations/identity variables above, our conservation network-climate change adaptation findings align with more general soil and water conservation practice adoption literature (Prokopy et al., 2019).

Farm and Farmer Characteristics

Except for gross farm income, which is a proxy for farm size, none of the four variables were consistent predictors of either adaptive or maladaptive actions. Of note is the lack of significance of the variable measuring whether or not a successor to the farm operation had been identified. The research expectation was that farms with plans for intergenerational transfer would be more likely and less likely to engage in adaptive and maladaptive practices, respectively, but this was not the case. Interestingly, gross farm income was positively related to two adaptive practices (three if you count the negative relationship with tillage) and two maladaptive practices. This is a finding that suggests that larger-scale farms are perhaps more subject to the contradictory treadmill of agriculture forces, also discussed in the capacity section above, that can induce farmers to pursue practices that are adaptive in the short-term but may have long-term and/or off-farm maladaptive properties (Houser and Stuart, 2020).

CONCLUSIONS

Farmers have always employed different adaptation strategies to prevent yield reductions due to weather variability, but climate change and the more variable and extreme weather it is engendering has made both adaptive action and avoidance of maladaptive behaviors more urgent (Takle and Gutowski, 2020). This study sought to improve understanding of the factors affecting farmers' adaptive and maladaptive actions. It is important to understand the drivers of both types of behavior, especially the maladaptive, given evidence that maladaptive responses can undermine long-term sustainability (Stuart and Schewe, 2016; Houser and Stuart, 2020; Mortensen and Smith, 2020). Our results provide insights into how variables that are commonly employed in studies of agricultural BMP adoption are associated with behavioral responses to increasingly variable and extreme weather in Iowa, USA. On the whole, our results indicate that many Iowa farmers are increasing their use of adaptive practices and decreasing use of maladaptive ones. However, many Iowa farmers are also increasing their use of pesticides and agricultural drainage, two maladaptive actions that can lead to major harms to common-pool resources such as pest management tools and water quality.

These insights into how different variables are associated with different types of adaptive and maladaptive behaviors can inform strategies that more effectively promote adaptation while discouraging maladaptation. In a sense, the findings that inform avoidance of maladaptive action are most interesting and important. For example, the findings that show a negative relationship between crop insurance and cover crop use are not unexpected given claims that this subsidized safety net program has led to less resilient agroecosystems (Mortensen and Smith, 2020), but they are nonetheless concerning given the ubiquity of crop insurance subscription in heavily agricultural states in the US Midwest (O'Donoghue, 2014). A number of analysts have proposed linking access to subsidized crop insurance to environmental performance (Yoder et al., 2021); our results point to a need for such reforms.

A second important maladaptation observation is related to agricultural drainage. Drainage use is nearly as ubiquitous as crop insurance in many areas of the US Midwest, and is a primary practice employed to address increasingly extreme precipitation; for example, in 2020, 42% of Iowa farmers indicated that they would be investing in drainage to prepare for increased precipitation (Arbuckle, 2020). Given the negative water quality impacts associated with increasing drainage, it is imperative that outreach focus on practices that might address those negative impacts, such as drainage water management and nutrient removal wetlands and buffers (Castellano et al., 2019). Our findings support Castellano et al.'s (2019, p. 918) proposed policy shifts to promote "a systems approach that integrates drainage, crop-soil processes, and nutrient loss reduction…systems that mitigate and adapt to climate change."

In conclusion, this research represents a step forward in addressing gaps in knowledge about the degree to which farmers are pursuing adaptive and potentially maladaptive practices, and what factors influence those behaviors. The evidence presented here points to significant increases in both types of change, at least among Iowa farmers. Extension and outreach implications include a need for expanded programming focused on developing stewardship ethics, with an emphasis on increasing positive attitudes toward multiple adaptation practices (e.g., programs such as Iowa Learning Farms, 2019). Given the current major shift in federal policy toward emphasis on climate change adaptation and mitigation, especially at the USDA (White House, 2021), our research highlights an urgent need for more research and extension to address the tension between short-term maladaptive decision factors and longer-term sustainability imperatives and to help avoid institutional and economic rigidity traps leading to soil and water degradation and long-term decline in agricultural productivity.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because Institutional Review Board human subjects research protections make it difficult to share primary survey data. Requests to access the datasets should be directed to arbuckle@iastate.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Iowa State University, Humans-Institutional Review Board (IRB). The patients/participants provided their written informed consent for participate in this study.

AUTHOR CONTRIBUTIONS

SU and JA conceived the idea for the manuscript and wrote the manuscript. JA designed the survey and collected the data. SU conducted the data analysis.

FUNDING

This research was supported by the C-CHANGE Iowa State University (ISU) Presidential Interdisciplinary Research Initiative (PIRI) and by the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, which was supported by USDA-NIFA and State of Iowa funds.

ACKNOWLEDGMENTS

The authors thank the IFRLP survey respondents for sharing their time and insights to make this study possible.

REFERENCES

Al-Kaisi, M. (2019). Managing wet and cold soils. *Integrated Crop Management News*. Available online at: https://crops.extension.iastate.edu/cropnews/2019/02/managing-wet-and-cold-soils (accessed May 17, 2021).

Arbuckle, J. G. (2020). *Iowa Farm and Rural Life Poll: 2020 Summary Report*. Ames, IA.

Arbuckle, J. G., Hobbs, J., Loy, A., Morton, L. W., Prokopy, L. S., and Tyndall, J. (2014). Understanding corn belt farmer perspectives on climate change to inform engagement strategies for adaptation and mitigation. *J. Soil Water Conserv.* 69, 505–516. doi: 10.2489/jswc.69.6.505

Arbuckle, J. G., Morton, L. W., and Hobbs, J. (2013a). Farmer beliefs and concerns about climate change and attitudes toward adaptation and mitigation: evidence from Iowa. *Clim. Change* 118, 551–563. doi: 10.1007/s10584-013-0700-0

Arbuckle, J. G., Morton, L. W., and Hobbs, J. (2015). Understanding farmer perspectives on climate change adaptation and mitigation: the roles of trust in sources of climate information, climate change beliefs, and perceived Risk. *Environ. Behav.* 47, 205–234. doi: 10.1177/0013916513503832

Arbuckle, J. G., Prokopy, L. S., Haigh, T., Hobbs, J., Knoot, T., Knutson, C., et al. (2013b). Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. *Clim. Change* 117, 943–950. doi: 10.1007/s10584-013-0707-6

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environ. Sustain.* 2, 95–96. doi: 10.1007/s42398-019-00078-w

Barnes, M. L., Wang, P., Cinner, J. E., Graham, N. A. J., Guerrero, A. M., Jasny, L., et al. (2020). Social determinants of adaptive and transformative responses to climate change. *Nat. Clim. Chang.* 10, 823–828. doi: 10.1038/s41558-020-0871-4

Barnett, J., and O'Neill, S. (2010). Maladaptation. *Glob. Environ. Chang.* 20, 211–213. doi: 10.1016/j.gloenvcha.2009.11.004

Beckie, H. J., Smyth, S. J., Owen, M. D. K., and Gleim, S. (2019). Rewarding best pest management practices via reduced crop insurance premiums. *Int. J. Agron.* 2019:9390501. doi: 10.1155/2019/9390501

Blanco-Canqui, H., Shaver, T. M., Lindquist, J. L., Shapiro, C. A., Elmore, R. W., Francis, C. A., et al. (2015). Cover crops and ecosystem services: insights from studies in temperate soils. *Agron. J.* 107, 2449–2474. doi: 10.2134/agronj15.0086

Brown, K., and Westaway, E. (2011). Agency, capacity, and resilience to environmental change: lessons from human development, well-being, and disasters. *Annu. Rev. Environ. Resour.* 36, 321–342. doi: 10.1146/annurev-environ-052610-092905

Burbi, S., Baines, R. N., and Conway, J. S. (2016). Achieving successful farmer engagement on greenhouse gas emission mitigation. *Int. J. Agric. Sustain.* 14, 466–483. doi: 10.1080/14735903.2016.1152062

Burke, M., and Emerick, K. (2016). Adaptation to climate change: evidence from US agriculture. *Am. Econ. J. Econ. Policy* 8, 106–140. doi: 10.1257/pol.20130025

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

Cappelleri, J. C., Bell, S. S., and Siegel, R. L. (2007). Interpretation of a self-esteem subscale for erectile dysfunction by cumulative logit model. *Drug Inf. J.* 41, 723–732. doi: 10.1177/009286150704100605

Castellano, M. J., Archontoulis, S. V., Helmers, M. J., Poffenbarger, H. J., and Six, J. (2019). Sustainable intensification of agricultural drainage. *Nat. Sustain.* 2, 914–921 doi: 10.1038/s41893-019-0393-0

Chatrchyan, A. M., Erlebacher, R. C., Chaopricha, N. T., Chan, J., Tobin, D., and Allred, S. B. (2017). United States agricultural stakeholder views and decisions on climate change. *Wiley Interdiscip. Rev. Clim. Chang.* 8:e469. doi: 10.1002/wcc.469

Doll, J. E., Petersen, B., and Bode, C. (2017). Skeptical but adapting: what Midwestern farmers say about climate change. *Weather. Clim. Soc.* 9, 739–751. doi: 10.1175/WCAS-D-16-0110.1

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., and Jones, R. E. (2000). Measuring endorsement of the new ecological paradigm: a revised NEP scale. *J. Soc. Issues* 56, 425–442. doi: 10.1111/0022-4537.00176

Field, A. (2009). *Discovering Statistics Using IBM SPSS Statistics*. North Amer: Sage.

Gardezi, M., and Arbuckle, J. G. (2020). Techno-Optimism and farmers' attitudes toward climate change adaptation. *Environ. Behav.* 52, 82–105. doi: 10.1177/0013916518793482

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., et al. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philos. Trans. R. Soc. B Biol. Sci.* 365, 2973–2989. doi: 10.1098/rstb.2010.0158

Gramig, B. M., Barnard, J. M., and Prokopy, L. S. (2013). Farmer beliefs about climate change and carbon sequestration incentives. *Clim. Res.* 56, 157–167. doi: 10.3354/cr01142

Halverson, J. B. (2021). The Iowa super derecho: catastrophe in the cornfields. *Weatherwise* 74, 22–28. doi: 10.1080/00431672.2021.1872988

Hatfield, J. L., Antle, J., Garrett, K. A., Izaurralde, R. C., Mader, T., Marshall, E., et al. (2020). Indicators of climate change in agricultural systems. *Clim. Change* 163, 1719–1732. doi: 10.1007/s10584-018-2222-2

Houser, M., and Stuart, D. (2020). An accelerating treadmill and an overlooked contradiction in industrial agriculture: climate change and nitrogen fertilizer. *J. Agrar. Chang.* 20, 215–237. doi: 10.1111/joac.12341

Howden, S. M., Soussana, J. F., Tubiello, N. F., Chhetri, N., Dunlop, M., and Meinke, H. (2007). Adapting agriculture to climate change. *Pro. Natl. Acad. Sci. U.S.A.* 104, 19691–19696. doi: 10.1073/pnas.0701890104

Iowa Learning Farms (2019). *Building a Culture of Conservation*. Available online at: https://www.iowalearningfarms.org/ (accessed March 5, 2021).

IPCC (2001). *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Integovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press.

IPCC (2007). *Climate Change 2007: Impacts, Adaptation and Vulner- Ability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press.

Jones, A. K., Jones, D. L., Edwards-Jones, G., and Cross, P. (2013). Informing decision making in agricultural greenhouse gas mitigation policy: a Best-Worst Scaling survey of expert and farmer opinion in the sheep industry. *Environ. Sci. Policy* 29, 46–56. doi: 10.1016/j.envsci.2013.02.003

Jørgensen, S. L., and Termansen, M. (2016). Linking climate change perceptions to adaptation and mitigation action. *Clim. Change* 138, 283–296. doi: 10.1007/s10584-016-1718-x

Lal, R. (2019). Eco-intensification through soil carbon sequestration: Harnessing ecosystem services and advancing sustainable development goals. *J. Soil Water Conserv.* 74, 55A−61A. doi: 10.2489/jswc.74.3.55A

Lee, D., Arbuckle, J. G., Zhu, Z., and Nowatzke, L. (2018). Conditional causal mediation analysis of factors associated with cover crop adoption in Iowa, USA. *Water Resour. Res.* 54, 9566–9584. doi: 10.1029/2017WR022385

Lengnick, L. (2015). *Resilient Agriculture: Cultivating Food Systems for a Changing Climate*. Gabriola Island, BC: New Society Publishers.

Loeb, N. G., Kato, S., and Wielicki, B. A. (2002). Defining top-of-the-atmosphere flux reference level for earth radiation budget studies. *J. Clim.* 15, 3301–3309. doi: 10.1175/1520-0442(2002)015<3301:DTOTAF>2.0.CO;2

Magan, A. (2014). Avoiding maladaptation to climate change: towards guiding principles. *Sapiens* 7:6. doi: 10.1108/09513501111119219

Mase, A. S., Gramig, B. M., and Prokopy, L. S. (2017). Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. crop farmers. *Clim. Risk Manag.* 15, 8–17. doi: 10.1016/j.crm.2016.11.004

Melillo, J. M., Richmond, T., and Yohe, G. W. (2014). *Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program.

Moore, L. S. (2021). Climate-friendly farming strategies can improve the land and generate income for farmers. *The Conversation.* Available online at: https://theconversation.com/climate-friendly-farming-strategies-can-improve-the-land-and-generate-income-for-farmers-157220 (accessed May 14, 2021).

Morris, C., and Arbuckle, J. G. (2021). Conservation plans and soil and water conservation practice use: evidence from Iowa. *J. Soil Water Conserv.* doi: 10.2489/jswc.2021.00166

Mortensen, D. A., and Smith, R. G. (2020). Confronting barriers to cropping system diversification. *Front. Sustain. Food Syst.* 4: 564197. doi: 10.3389/fsufs.2020.564197

Moser, S. C., and Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci. U.S.A.* 107, 22026–22031. doi: 10.1073/pnas.1007887107

Neset, T. S., Wiréhn, L., Klein, N., Käyhkö, J., and Juhola, S. (2019). Maladaptation in Nordic agriculture. *Clim. Risk Manag.* 23, 78–87. doi: 10.1016/j.crm.2018.12.003

Niles, M. T., Lubell, M., and Haden, V. R. (2013). Perceptions and responses to climate policy risks among california farmers. *Glob. Environ. Chang.* 23, 1752–1760. doi: 10.1016/j.gloenvcha.2013.08.005

O'Donoghue, E. J. (2014). *The Effects of Premium Subsidies on Demand for Crop Insurance.* Economic Research Report 178405, United States Department of Agriculture, Economic Research Service.

Plastina, A., and Edwards, W. (2017). *Proven Yields and Insurance Units for Crop Insurance*. Ames, IA. Available online at: https://www.extension.iastate.edu/agdm/crops/html/a1-55.html (accessed March 5, 2021).

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., et al. (2015). "Food security and food production systems," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. (Cambridge; New York, NY: Cambridge University Press), 485–534.

Prokopy, L. S., Floress, K., Arbuckle, J. G., Church, S. P., Eanes, F. R., Gao, Y., et al. (2019). Adoption of agricultural conservation practices in the United States: evidence from 35 years of quantitative literature. *J. Soil Water Conserv.* 74, 520–534. doi: 10.2489/jswc.74.5.520

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

Rabotyagov, S. S., Kling, C. L., Gassman, P. W., Rabalais, N. N., and Turner, R. E. (2014). The economics of dead zones: causes, impacts, policy challenges, and a model of the gulf of Mexico Hypoxic Zone. *Rev. Environ. Econ. Policy* 8, 58–79. doi: 10.1093/reep/ret024

Reimer, A. P., and Prokopy, L. S. (2012). Environmental attitudes and drift reduction behavior among commercial pesticide applicators in a U.S. agricultural landscape. *J. Environ. Manage.* 113, 361–369. doi: 10.1016/j.jenvman.2012.09.009

Reimer, A. P., Weinkauf, D. K., and Prokopy, L. S. (2012). The influence of perceptions of practice characteristics: an examination of agricultural best management practice adoption in two indiana watersheds. *J. Rural Stud.* 28, 118–128. doi: 10.1016/j.jrurstud.2011.09.005

Roesch-Mcnally, G. E. (2018). U.S. Inland pacific northwest wheat farmers' perceived risks: motivating intentions to adapt to climate change? *Environments* 5, 1–20. doi: 10.3390/environments5040049

Rogers, E. M. (2003). *Diffusion of Innovations*. 5th ed. New York, NY: Free Press.

Rosenzweig, C., and Parry, M. L. (1994). Potential impact of climate change on world food supply. *Nature* 367, 133–138

Schattman, R. E., Conner, D., and Méndez, V. E. (2016). Farmer perceptions of climate change risk and associated on-farm management strategies in Vermont, northeastern United States. *Elementa* 4, 1–14. doi: 10.12952/journal.elementa.000131

Scheraga, J. D., and Grambsch, A. E. (1999). Risks, opportunities, and adaptation to climate change. *Clim. Res.* 11, 85–95. doi: 10.3354/cr011085

Schlenker, W., and Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl. Acad. Sci. U.S.A.* 106, 15594–15598. doi: 10.1007/BF02365970

Schulte, L. A., Niemi, J., Helmers, M. J., Liebman, M., Arbuckle, J. G., James, D. E., et al. (2017). Correction: Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. *Proc. Natl. Acad. Sci. U.S.A.* (2017) 114:E10851 11247–11252. doi: 10.1073/pnas.1719680114

Simonff, J. S. (2003). *Analyzing Categorical Data*. New York, NY: Springer-Verlag. doi: 10.1007/978-0-387-21727-7

Singh, A. S., Eanes, F., and Prokopy, L. S. (2020). Climate change uncertainty among American farmers: an examination of multi-dimensional uncertainty and attitudes towards agricultural adaptation to climate change. *Clim. Change* 162, 1047–1064. doi: 10.1007/s10584-020-02860-w

Smit, B., and Skinner, M. W. (2002). Adaptation options in agriculture to climate change: a typology. *Mitig. Adapt. Strateg. Glob. Chang.* 7, 85–114. doi: 10.1023/A:1015862228270

Stuart, D. (2018). Climate change and ideological transformation in United States agriculture. *Sociol. Ruralis* 58, 63–82. doi: 10.1111/soru.12175

Stuart, D., and Schewe, R. L. (2016). Constrained choice and climate change mitigation in US agriculture: structural barriers to a climate change ethic. *J. Agric. Environ. Ethics* 29, 369–385. doi: 10.1007/s10806-016-9605-z

Takle, E. S., and Gutowski, W. J. (2020). Iowa's agriculture is losing its Goldilocks climate. *Phys. Today* 73, 26–33. doi: 10.1063/PT.3.4407

Tamburino, L., Bravo, G., Clough, Y., and Nicholas, K. A. (2020). From population to production: 50 years of scientific literature on how to feed the world. *Glob. Food Sec.* 24:100346. doi: 10.1016/j.gfs.2019.100346

Thompson, C. A. J., Helmers, M. J., Isenhart, T. M., and Lawrence, J. D. (2014). Reducing nutrient loss: science shows what works. *Agric. Environ. Ext. Publ.* 2014:223. doi: 10.31274/icm-180809-228

U. S. Department of Agriculture National Agricultural Statistics Service (2019a). *2017 Census of Agriculture*. Washington, DC.

U. S. Department of Agriculture National Agricultural Statistics Service (2019b). *2017 Census of Agriculture Iowa State and County Data*. Washington, DC. Available online at: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1_Chapter_1_State_Level/Iowa/iav1.pdf (accessed May 17, 2021).

USGCRP (2018). *Impacts, risks, and adaptation in the United States: Fourth National Climate Assessment, Volume II*. eds. D. R. Reidmiller, C. W. Avery, D. R. Easterling, K.E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart. Washington, DC. doi: 10.7930/NCA4.2018

Walsh, J. E., Overland, J. E., Groisman, P. Y., and Rudolf, B. (2011). Ongoing climate change in the arctic. *Ambio* 40, 6–16. doi: 10.1007/s13280-011-0211-z

Walthall, C. L., Hatfield, J., Backlund, P., Lengnick, L., Marshall, E., Walsh, M., et al. (2013). Climate change and agriculture in the United States: effects and adaptation. *USDA Tech. Bull.* 1935, i—186. doi: 10.1017/CBO9781107415324.004

White House (2021). *Executive Order on Tackline the Climate Crisis at Home and Abroad*. Available at: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/ (accessed May 18, 2021).

Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., Dokken, D. J., Stewart, B. C., and Maycock, T. (2017). *Climate Science Special Report: Fourth National Climate Assessment*, Vol. I. Washington, DC. doi: 10.7930/J0J964J6

Yoder, L., Houser, M., Bruce, A., Sullivan, A., and Farmer, J. (2021). Are climate risks encouraging cover crop adoption among farmers in the southern Wabash River Basin? *Land Use Policy* 102:105268. doi: 10.1016/j.landusepol.2020.105268

Zhang, L., Ruiz-Menjivar, J., Luo, B., Liang, Z., and Swisher, M. E. (2020). Predicting climate change mitigation and adaptation behaviors in agricultural production: a comparison of the theory of planned behavior and the Value-Belief-Norm theory. *J. Environ. Psychol.* 68:101408. doi: 10.1016/j.jenvp.2020.101408

Zhang, W., Wilson, R. S., Burnett, E., Irwin, E. G., and Martin, J. F. (2016). What motivates farmers to apply phosphorus at the "right" time? Survey evidence from the Western Lake Erie Basin. *J. Great Lakes Res.* 42, 1343–1356. doi: 10.1016/j.jglr.2016.08.007

Zinyemba, C., Archer, E., and Rother, H. A. (2021). Climate change, pesticides and health: considering the risks and opportunities of adaptation for Zimbabwean smallholder cotton growers. *Int. J. Environ. Res. Public Health* 18, 1–11. doi: 10.3390/ijerph18010121

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.