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Agricultural transformations: climate change adaptation and farmer decision making

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Agricultural transformations: Climate change adaptation and farmer decision-making

by

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ABSTRACT

Over the long-term, global climate change is projected to have negative impacts on agricultural productivity in the U.S. Corn Belt. Climate change will also exacerbate problems with soil loss through wind and water erosion in addition to environmental externalities associated with current land use practices, thus driving greater vulnerability of the Corn Belt agroecosystem. There is minimal research that examines how Corn Belt farmers will respond to climate change stressors and whether subsequent adaptive responses will alleviate or further exacerbate challenges in meeting production and conservation goals. This dissertation research explores farmer decision making in the context of climate change adaptation through the adoption and use of key management practices that can have soil and water conservation benefits. This research examines three distinct but connected studies that include qualitative, quantitative, and mixed methods analyses. Quantitative data include a survey of large-scale Corn Belt farmers (n=4,778) sampled from 22 six-digit Hydrologic Unit Code (HUC6) watersheds and secondary data from the 2012 Agricultural Census. Qualitative data were collected via in-depth interviews with 159 farmers across nine states in the Midwest (Iowa, Illinois, Indiana, Wisconsin, Minnesota, Michigan, Ohio, South Dakota, and Missouri).

Findings from the quantitative research suggest that farmers who believe they should adjust their practices to protect their farm from the negative impacts of increased weather variability are more likely to increase their use of no-till farming, cover crops, and tile drainage. Additionally, visiting with other farmers to observe their practices was positively associated with farmers increased use of the adaptive strategies examined. Famers with experience using no-till farming, cover crops, and tile drainage were also more likely to plan on increasing their use of these practices in response to climate

changes. However, farmers who report high levels of confidence in their current practices are less likely to change their use of these practices in response to climate change.

Through examination of in-depth interviews, I found that farmers are engaging in greater soil stewardship as a way to mitigate weather related risks. Findings suggest that farmers' shifting relationship to their soil resources may act as a kind of social-ecological feedback that enables farmers to implement adaptive strategies (e.g., no-till farming, cover crops) that build resilience in the face of increasingly variable and extreme weather. This was in contrast to emphasizing short-term tweaks to production (e.g., increased tillage in the spring) that may lead to greater vulnerability. Adoption of a soil stewardship ethic may also help farmers to resolve apparent tradeoffs between profitability in the short-term and field-level resilience over the long-term.

Finally, through a mixed methods analysis, I examined what influences farmers' use of extended crop rotations, as a measure of cropping system diversity, particularly in the context of climate change adaptation. Findings suggest that path dependency on the intensive corn-based cropping system of the U.S. Corn Belt limits farmers' ability to integrate more diverse crop rotations; yet, farmers in more diversified watersheds, those who farm marginal ground, and those with livestock are more likely to use extended rotations. Additionally, those farmers who currently use more diverse rotations are also more likely to see crop rotations as at risk mitigation tool in the context of climate change adaptation.

In total, this research offers a comprehensive analysis of farmer adaptive decision making through analysis of data on Corn Belt farmers' conservation behaviors and climate change adaptation intentions, which is of unprecedented size and scope.

CHAPTER 1.

INTRODUCTION

Anthropogenic climate change will fundamentally transform social and ecological systems (IPCC 2014; Brulle and Dunlap 2015). Climate change, as a form of social-ecological feedback (Collins et al. 2011), will ultimately encourage changes in social institutions to address impacts associated with climate disruption. Climate change impacts in coupled human and natural systems will be highly heterogeneous and will likely include "increasing conflicts over natural resources, social destabilization, population migration, and extensive adverse health consequences" (Brulle and Dunlap 2015:1). The willingness on behalf of political institutions to engage in global mitigation efforts is still quite limited despite the fact that they will be essential for reducing risks associated with climate change (Erhardt-Martinez et al. 2015). However, adaptations to experienced and projected climate changes are already occurring (Moser and Ekstrom 2010) and will need to continue even if mitigation efforts are widely implemented (IPCC 2014).

Agricultural production and food security is a critical foundation for social stability which will be affected by fluctuations in weather patterns due to changes in the climate, which will have variable impacts across regions and cropping systems (Howden et al. 2007). In general, there are concerns that climate change will hamper the world's ability to provide sufficient food for the global population (Hatfield et al. 2011). One agricultural region of particular interest is the U.S. Corn Belt. The Corn Belt is an incredibly productive agroecosystem, which produces over a third of the global supply of corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) commodities, primarily used for livestock feed (USDA- FAS 2016). Conventional land use in the Corn Belt is largely a system of intensive monoculture production of two crops which are highly dependent on external inputs of seeds and their attendant fertilizers and pesticides. This conventional agricultural system of production in the region is the product of a complex set of biophysical (e.g., soils, slope, topography, climate) as well as social, political, and economic forces (Atwell et al. 2010).

Conventional agricultural land use practices in the U.S. Corn Belt are largely responsible for the hypoxic zone in the Gulf of Mexico, a dead zone caused by high levels of phosphorous and nitrogen loading caused by runoff from agricultural fertilizers and sedimentation due to soil loss through wind and water erosion (Donner and Kucharik 2008; Broussard and Turner 2009). Additionally, agricultural land use practices in the region are also responsible for losses in wildlife habitat due to land conversion (Wright and Wimberley, 2013) and have led to problems with insect (Gassmann et al. 2011) and weed resistance (Ervin and Jussaume 2014) due in large part to the rapid adoption of genetically engineered insect and weed resistant corn and soybean seed technologies (Fernandez-Cornejo and Osteen 2015). Additionally, global climate change is expected to have negative impacts on crop production (Takle 2013; Chhetri et al. 2014; Gustafson et al. 2015), due to more extreme weather events, including heavier rainfall, increased flooding, and longer periods of drought (Melillo et al. 2014). These weather-related impacts are likely to increase weed, disease, and pest pressures (Hatfield et al. 2011), which may lead to greater agroecosystem vulnerability.

Decision making with regards to land use practices in the Corn Belt is driven, in part, through the choices that farmers make at the field-scale, which, in aggregate have impacts at the landscape-scale. Farmer adaptive decision making in response to a changing climate is temporally situated (e.g., short-term vs. long-term) and is made within the broader social, political, and economic system(s) that farmers operate within (Smit and Skinner 2002). Farmer decision making can reduce on-farm vulnerability, particularly by addressing problems associated with soil loss and degradation, through the adoption of soil and water conservation practices (e.g., no-till farming, cover crops, diversified rotations) (Lehman et al. 2015). Adoption of these practices can improve agroecosystem resilience (Kremen and Miles 2013) by increasing the production of a more diverse array of ecosystem services (i.e., provisioning, regulating, cultural).

The overall goal of my dissertation research was to explore farmer decision making in the context of climate change adaptation through the adoption and use of key management practices that can have soil and water conservation benefits. There is growing research that examines how farmers will respond to and make decisions in response to climate changes in the near and long-term (Arbuckle et al. 2013; Morton et al. 2015) yet further research is needed to understand adaptive decision making. This research effort also raises important questions for further exploration regarding whether subsequent adaptive responses taken by farmers will alleviate or further exacerbate challenges in meeting production and conservation goals.

My dissertation research combines quantitative, qualitative, and mixed methods analyses to build a more complete understanding of farmer decision making across the U.S. Corn Belt. We examine quantitative data from a survey of large-scale Corn Belt farmers (n=4,778) sampled from 22 six-digit Hydrologic Code Unit (HUC6) watersheds, including data from the 2012 Agricultural Census (Loy et al. 2013). Qualitative data were collected via in-depth interviews with 159 farmers across nine states (Iowa, Illinois, Indiana, Wisconsin, Minnesota, Michigan, Ohio, South Dakota, and Missouri) in the Corn Belt. Data collection methods approved by Iowa State University Office for Responsible Research's' Institutional Review Board as an exempt study (Appendix 3). Multi-scale research, using both qualitative and quantitative data, is needed to better understand the broader social, political, economic, and environmental context in which farmers make decisions (Stuart and Gillon 2013) as they operate within nested spatial and human-institutional scales (Jackson et al. 2010).

Thesis Organization

This dissertation is composed of three papers written for publication in scientific, peer reviewed journals. This chapter provides a general introduction to my dissertation topic. Chapter 2 is a quantitative analysis that examines what Corn Belt farmers' stated intentions are in response to climate change based on their current and projected use of three major production and conservation practices: no-till farming, cover crops, and tile drainage. Chapter 3 is a qualitative analysis, using Grounded Theory (Charmaz 2006), which explores the construct of soil stewardship and whether soil stewardship actions taken by farmers may help to reduce weather related risks while also helping to resolve tradeoffs between short-term economic goals of profit maximization with long-term proactive strategies to build climate resilience. Chapter 4 is a mixed methods study that combines survey and interview data to examine the influence of social, economic, and environmental factors on farmers' use of diverse crop rotations and to assess whether crop diversification is likely to be utilized as a climate change adaptation strategy in an intensive corn-based cropping system. Chapter 5 concludes with a synthesis of the findings across these three studies and provides recommendations for future research.

The survey data design and administration associated with this dissertation were collected as part of a much larger multi-state research effort designed to examine climate change impacts to Corn Belt agriculture and explore adaptive and mitigative strategies that could be implemented to create a more resilient agroecosystem (see Loy et al. 2013). The statistical and qualitative analyses, however, were solely prepared by the candidate. The design of the interview protocol and administration of the in-depth interviews was led by the candidate. The candidate and land grant university extension educators conducted the in-depth farmer interviews across nine states. Preparation of the text for all three papers developed as part of this dissertation was the responsibility of the candidate. Dr. J. Gordon Arbuckle and Dr. John C. Tyndall gave guidance and editorial advice on all chapters and will serve as co-authors on the final manuscripts. Additionally, my dissertation committee members (Drs. Lois Wright Morton, Lisa Schulte Moore, and Carmen Bain) provided substantive editorial comments on my research design, implementation, and presentation.

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CHAPTER 2.

WHAT WOULD FARMERS DO? ADAPTATION INTENTIONS UNDER A CORN BELT CLIMATE CHANGE SCENARIO

Paper submitted to *Agriculture and Human Values*

Gabrielle E. Roesch-McNally, J. Gordon Arbuckle, and John C. Tyndall

Abstract

This paper examines farmer intentions to adapt to global climate change by analyzing responses to a climate change scenario presented in a survey given to large-scale farmers (n=4,778) across the U.S. Corn Belt in 2012. Adaptive strategies are evaluated in the context of decision making and farmers' intention to increase their use of three production practices promoted across the Corn Belt: no-till farming, cover crops, and tile drainage. This paper also provides a novel conceptual framework that bridges a typology of adaptation with concepts that help predict intentionality in behavior change models. This conceptual framework was developed in order to improve our understanding of adaptive decision making in the context of agriculture. Additionally, this research effort examines key factors that influence whether a farmer intends to increase their current use of the practices evaluated given a climate change scenario. Twenty-two covariates are examined across three models developed for no-till farming, cover crops, and tile drainage. Findings highlight that farmers who believe they should adjust their practices to protect their farm from the negative impacts of increased weather variability are more likely to increase their use of each of the practices explored in response to climate change. Additionally, visiting with other farmers to observe their practices was positively associated with farmers' intentions to increase their use of the adaptive strategies examined. Famers with experience using no-till farming, cover crops,

and tile drainage were also more likely to plan on increasing their use of these practices in response to increased weather variability associated with climate change. However, farmers who report high levels of confidence in their current practices are less likely to plan on changing their use of these practices in response to climatic changes.

Introduction

Agricultural production in the U.S. Corn Belt accounts for the majority of the corn (*Zea mays L.*) and soybean (*Glycine max L.*) produced in the United States (USDA-FAS 2015). Further, this region is responsible for over a third of the global supply of corn and is the world's largest producer and exporter of soybeans (USDA-FAS 2015). While this commodity-driven system is very productive and yield per hectare has increased over the last half-century (Fuglie et al. 2007), global climate change is projected to drive greater weather variability and is expected to have a largely negative impact on crop yields in the region (Melillo et al. 2014). Yield decreases are expected due to increases in the severity and frequency of extreme weather events and associated outcomes such as increased disease and pest pressure (Chhetri et al. 2014; Hatfield 2014; Melillo et al. 2014). Overall, climate change related weather impacts are expected to hinder regional production goals not only through reduced yields (Hatfield 2014) but also by exacerbating negative environmental impacts of production, such as increased pollution from sediment loading and nutrient transport (Reilly et al. 2003; Donner and Kucharik 2008; Broussard and Turner 2009; Jordan and Warner 2010; Broussard et al. 2012).

To reduce the risks related to current and predicted changes in the Corn Belt, it is widely recognized that farmers throughout the region will need to adapt their farm systems to the effects of climate change to build greater resilience (Howden et al. 2007;

Arbuckle et al. 2013a). As such, vulnerability and resilience are linked concepts; vulnerability refers to a system's exposure to adverse impacts and its capacity to cope and adapt (IPCC 2014), whereas resilience is defined as a system's ability to respond and change "in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation" (IPCC 2014, p.5), which "may or may not succeed in moderating harm or exploring potential benefits" (Moser and Ekstrom 2010, p. 22026). Farmer adaptive decision making within the context of their farm business takes place on both short-term and long-term time frames and is in response to both climatic and non-climatic stimuli and the broader social, political, and economic system(s) that they operate within (Smit and Skinner 2002). Adaptation in this context is characterized by individual farmers attempting to manage agronomic conditions in their fields to minimize production and environmental risk, in part, in response to a changing climate regime.

Given the importance of farmer decision making, it is essential to understand how farmers might change their production practices in response to a changing climate. Yet there is very little research that examines how farmers might respond to climate change stressors (Howden et al. 2007; Rejesus et al. 2013). This study sought to answer the research question: how will climate changes, associated with weather variability, influence farmer adoption and increased use of key conservation and production practices? Our study examined farmer responses to a survey question that presented a realistic climate change scenario to nearly 5,000 large-scale corn farmers in the U.S. Corn Belt. These farmers assessed their intended use of specific practices that can serve to meet both production and conservation goals; for this analysis, we focus on three key practices: no-till farming[1], cover crops[2] and subsurface tile drainage[3]. No-till farming and cover crops have the potential to improve water quality and prevent erosion by mitigating nutrient leaching and reducing wind and water erosion (ISUEO 2014), while subsurface tile is an effective way to drain excess water and boost productivity in certain soil types (Oquist et al. 2007). The use of no-till farming and cover crops could be expanded across cropland in the Corn Belt given that in 2012 only an estimated 30% of cropland in the region was in no-till farming and just 3% in cover crops (NASS 2014c). In certain places across the Corn Belt, tile drainage is installed on most of the land that is suitable for the practice (e.g., Iowa and Illinois); however there are regions in the Corn Belt where additional tile drainage or improvements to drainage water management systems could provide crop yield benefits, and therefore, intensification and expansion of tiling is expected across the region (Sugg 2007).

The following section outlines the conceptual framework developed to better understand agricultural adaptation by integrating an adaptation typology with behavioral theories that examine intentions to change behavior. The methods section describes the data and analytical procedure used to analyze survey data. The results section examines the findings from three separate models that explore intentions to increase the use of no-till farming, cover crops, and subsurface tile drainage in addition to comparisons made across all models. The discussion section connects the results to the conceptual

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[1] The practice of no-till farming requires that farmers plant crops directly into the previous season's crop residue with minimal disturbance to the soil.
[2] Cover crops are plants grown in-between plantings of cash crops during fallow periods (e.g., cereal rye, *Secale cereale* planted during the winter).
[3] Subsurface tile drainage is "a conduit, such as corrugated plastic tubing, tile, or pipe, installed beneath the ground surface to collect and/or convey drainage water" (Schnepf and Cox 2008, p. 107). Tile drainage historically meant installation of clay cylinders used to drain excess soil moisture but these have largely been replaced by corrugated plastic tiles.

framework developed as part of this study. Finally, we provide a brief conclusion with outreach, research, and policy recommendations.

Conceptual Framework for Agricultural Adaptation

A conceptual model was developed (Figure 1) that facilitates the understanding of farmer adaptive decision making. The framework links a typology of adaptation developed to explain adaptive decision making (Smit et al. 2000), particularly in the context of agriculture (Smit and Skinner 2002), with a theoretical framework for examining behavioral intentions grounded in the Theory of Planned Behavior (TPB) (Ajzen 1991) and the Reasoned Action Approach (RAA) (Fishbein and Ajzen 2010). By linking these two conceptual frameworks together we are better able to understand intention to adapt to climate change in the agricultural context.

Smit et al. (2000) identify key factors that help to explain decisions regarding managing weather/climate risk, which include climate related stimuli, aspects of scale and responsibility, the form of adaptation, non-climatic factors/conditions, and finally evaluation of adaptation effects. The concept of climate-related stimuli refers to the form, timing, and severity of a given climate signal (Smit et al. 2000). Scale and responsibility refer to whom or what entity is adapting and at what scale, including the intent and purposefulness of the adaptation (autonomous or planned) as well as the timing and duration (anticipatory, concurrent, or reactive) (Smit and Skinner 2002). Our research focused on how farmers intend to change or maintain current management practices in response to changes in the climate signal, and the form of adaptive actions. Smit and Skinner (2002) identify four major forms of adaptation in the agricultural sector: technical development, government/insurance, farm production practices, and farm financial management. Our research rests primarily on farm production and conservation practices (i.e., no-till farming, cover crops and tile drainage) as the form of adaptation.

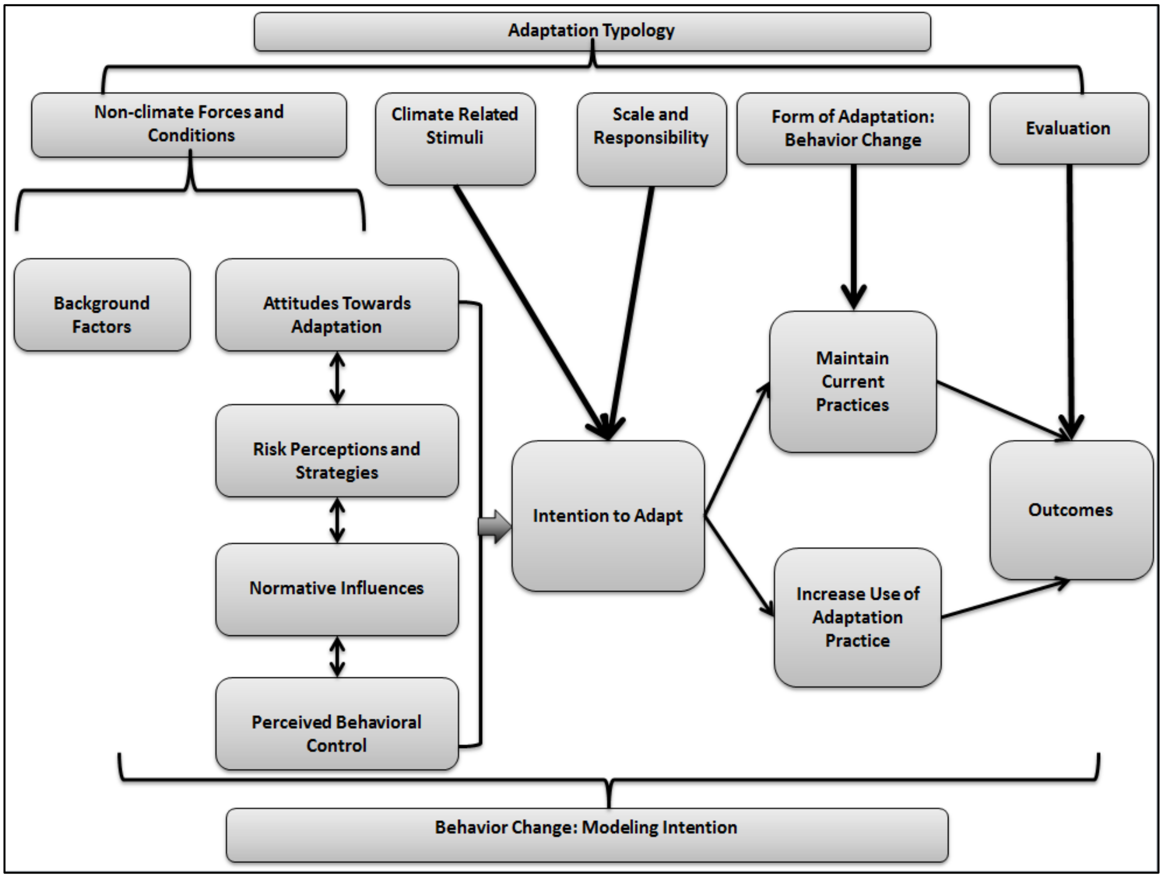

Fig. 1 This conceptual framework combines the "anatomy of adaptation" typology outlined in by Smit et al. (2000) with a modified framework drawing from the Theory of Planned Behavior (Ajzen 1991) and the Reasoned Action Approach (Fishbein and Ajzen 2010)

Smit et al. (2000) identify the importance of non-climatic forces and conditions in adaptation decision making. Indeed, many of the decisions farmers make are in response to non-climatic factors, which include factors associated with the broader ecological and socioeconomic context of agricultural production (Blesh and Wolf 2014). Multiple theories help explain the role of intention and how this influences changes in behavior, including two prominent theories outlined in the TPB (Ajzen 1991) and the RAA (Fishbein and Ajzen 2010). Such models have been used to explain agricultural and conservation decision making (e.g., Reimer et al. 2012a; Arbuckle and Roesch-McNally

2015). In Figure 1 we represent these concepts as attitudes towards adaptation, risk perception and strategies, normative influences, perceived behavioral control, and background factors.

The first category of non-climatic forces and conditions included in our conceptual model is *attitudes towards adaptation*. Attitudes are multidimensional and have been found to be important predictors of behavioral intentions, including intentions related to conservation practice adoption (Prokopy et al. 2008; Baumgart-Getz et al. 2012; Reimer et al. 2012b). Ajzen notes that attitudes should be measured directly in reference to a specific behavior and are defined as the “degree to which a person has favorable or unfavorable evaluation or appraisal of the behavior in question” (1991, p. 10). Additionally, there is evidence that farmers’ beliefs (described as necessary precursors to attitudes by Fishbein and Ajzen 2010) about the potential severity of climate impacts and causes of climate change can influence their support for adaptive and/or mitigative actions (Howden et al. 2007; Arbuckle et al. 2013b; Hyland et al. 2015).

The second category for non-climatic forces and conditions is *risk perceptions and strategies*. In general, farmer perceptions of the potential risks associated with increased weather variability due to climate change have been shown to influence their support for adaptation (Arbuckle et al. 2013b). Actual physical vulnerability associated with experiences of extreme weather has been shown to increase the perception of risks associated with climate change (Brody et al. 2008) in addition to other political and social values (Cutler 2015). Environmental risks have also helped to explain the adoption of cover crops, no-till, and increased use of tile drainage in the U.S. Midwest (e.g., Morton et al. 2015). Generally, perceived risks have a strong and positive relationship with support for public responses and individual behavioral intentions to address climate change impacts (O'Connor et al. 1999; Zahran et al. 2006; Arbuckle et al. 2013b; Hyland et al. 2015). Farmers also employ a number of risk management strategies to mitigate both weather-related and financial risks associated with their agricultural production systems. Rejesus et al. (2013) found that farmers are likely to employ a diverse set of risk management strategies to deal with extreme weather, which can include diversifying crops, use of crop insurance, modifying lease arrangements, and retiring from farming. Specifically, crop insurance is a key risk management tool currently used by many farmers across the Corn Belt, particularly as a way to protect their farm operations from catastrophic crop losses caused by extreme weather events (NASS 2014a). Additionally, greater diversification of cropping systems can help explain farmer adoption of conservation practices (Saltiel et al. 1994; Singer et al. 2007; Arbuckle and Roesch-McNally 2015) and is also considered an important strategy for building greater resiliency in response to more extreme weather (Jordan and Warner 2010; Lin 2011).

The third category examined in our conceptual framework is the concept of *normative influences*. Specifically, decision making is considered a social process, influenced by community norms, whereby individuals enlist others, often those in their social network, to help them make specific management decisions (Pannell et al. 2006). Social networks are important predictors of farmer transitions to sustainable agricultural and conservation-oriented practices (Coughenour 2003; Carolan 2006; Atwell et al. 2009; Blesh and Wolf 2014; Nelson et al. 2014). Additionally, norms also influence what constitutes a 'good farmer', which is a social construct laden with values and aesthetic preferences (e.g., ‘a freshly tilled field is beautiful’) (Burton 2004). Ideas about what constitutes a good farmer can have a normative influence on farmers and in some cases can actuate key conservationist identities (Schneider et al. 2010; McGuire et al. 2013), which can impact a farmer’s decision to use or increase their use of certain conservation practices (Arbuckle 2013; Hyland et al. 2015).

The fourth category that is included in our conceptual framework is the notion of *perceived behavioral control*. Many studies on environmental decision making have illustrated that perceived behavioral control (PBC), or the confidence that an individual has in their ability to perform certain activities or achieve certain outcomes (Ajzen 1991), has a positive influence on behavioral intentions (Schwartz and Howard1981; Ajzen 2002). PBC has also been found to influence decision making specifically in regards to agricultural management practices (Reimer et al. 2012a). A high level of perceived behavioral control has also been found to be negatively associated with farmers’ concern about and support for adaptive actions in light of climate change (Arbuckle et al. 2014).

Finally the category of *background factors* includes a number of farmer and farm characteristics that have been used to explain conservation practice adoption. Factors that have been found to be more or less consistently influential include education, age, income, farm size, and off-farm income (Soule et al. 2000; Pannell et al. 2006; Knowler and Bradshaw 2007; Prokopy et al. 2008; Baumgart-Getz et al. 2012). However, the sign and effect of each of these characteristics are not always consistent, which may have to do with variation in the types of practices analyzed and the confluence of other factors discussed above. Additionally, habits, or behaviors practiced regularly, improves the fit of behavioral change models (Klöckner 2013) and past/current practices can be an important variable for understanding adoption of agricultural conservation practices in particular (Wilson et al. 2014).

Smit et al. (2000) included the evaluation concept in their typology of adaptation in order to highlight the importance of measuring outcomes associated with adaptive actions, which can enable an assessment of whether adaptive actions reduce or increase vulnerability. Evaluating the spatial and temporal impacts of adaptation decision making is a complex process because adaptation decisions are made by individual actors who may experience benefits and/or losses as a consequence of their decisions while these same decisions, in aggregate, may lead to different, and potentially negative, effects at the landscape or watershed scale. Farmers are likely to evaluate the outcomes of their action at the field and farm scale (e.g., improved drainage due to installation of tile drains). However, this evaluation is distinct from a more landscape-scale evaluation of the impacts of multiple actions taken by farmers and their aggregate impacts at spatial and temporal scales.

Methods

Survey data

Survey data were collected through a stratified random sample of Corn Belt farmers across 22 six-digit Hydrologic Code Unit (HUC6) watersheds that cover a large proportion of 11 contiguous Corn Belt states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota and Wisconsin (Arbuckle et al. 2013a). The sample frame consisted of 103,126 larger-scale corn producers, defined as farm operations that manage more than 32 ha of corn and generate a minimum of US$100,000 of gross sales. The US Department of Agriculture (USDA) Census of

Agriculture “Master List” of farmers was used to develop the sample frame because it is the most up-to-date and comprehensive list of U.S. farmers. Across the 11 states sampled, these farms represented 78% of the total cropland hectares farmed and 27% of total farms with cropland (NASS 2009).

The survey was mailed in February 2012 to 18,707 farmers using a three-wave mailing process where the survey was mailed, then a reminder postcard was sent, followed by a final survey sent to non-responders (Arbuckle et al. 2013a). A sample size of 4,778 was achieved with an effective response rate of 26%. Comparisons of respondents to non-respondents based on a range of farmer and farm attributes (e.g., age, farm size, hectares in different crops, number of livestock) indicated no meaningful differences between respondents and non-respondents, providing no evidence of a non-response bias and indicated that our sample is representative of the eligible population of large-scale farmers in the Corn Belt region (Arbuckle et al. 2013a). Sampling weights were developed to account for differences in response probability at the watershed level and were applied to the entire dataset before statistical analyses were performed (see Loy et al. 2013).

Climate change scenario

The survey instrument was designed as part of a project focused on climate change beliefs and mitigative and adaptive strategies of farmers in the Corn Belt. The specific question used for this analysis asked how farmers might change their practices given a climate change scenario. Respondents were asked to consider this text: “Suppose the following scenario were to happen in the near future: Violent storms/extreme rain events will become more frequent, particularly in the spring; More extreme rain events will increase likelihood of flooding & saturated soils; Periods between rains will be longer, increasing likelihood of drought; and Changes in the weather patterns will increase crop insect, weed & disease problems." This scenario was followed up with the question: "If you knew with certainty that these conditions would occur, would the following practices on the cropland you own and rent decrease, increase, or stay the same?" Farmers were then provided with a list of practices that are considered to be potentially effective adaptation actions.

Analytical approach

We use a binary logistic regression to analyze farmers' stated intent regarding the use of no-till farming (Model 1), cover crops (Model 2) and tile drainage (Model 3) on land that they own (Table 1), in response to the climate change scenario.

Table 1 Descriptive statistics for the three models examined as part of this study. Each variable was measured as a binary response (0=Stay the same, 1=Increase).

Model	Variable	Question	N	Mean	SD
Model 1	No-till farming	Would use of this practice stay the same or increase, given the climate change scenario?	3281	0.34	0.47
Model 2	Cover Crop	Would use of this practice stay the same or increase, given the climate change scenario?	2704	0.36	0.48
Model 3	Tile drainage	Would use of this practice stay the same or increase, given the climate change scenario?	3374	0.57	0.49

Variables

The conceptual framework outlined in Figure 1 was employed to guide the selection of variables included in each of the three models that were assessed. Twenty-two covariates (see Table 2) were included in the three models examined. These covariates are organized by conceptual category, in alignment with Figure 1, which characterize non-climate forces and conditions relevant to farmer adaptation. These include attitudes towards adaptation, risk perceptions and strategies, normative influences, and perceived behavioral control as well as background factors associated with farmer characteristics. These data conform to the assumptions of logistic regression with the exception of two variables, measuring hectares in crop insurance and gross farm revenue, which were transformed using the natural log in order to correct problems with right skewed non-normal data.

Three variables were included that measure attitudes towards adaptation (I Adapt, Farmers Adapt, and Uncert NoAdapt) and one variable to measure climate change beliefs (CCharm) (Table 2). These include variables measuring farmers' attitudes toward taking additional steps to protect their farmland from increased weather variability (I Adapt), beliefs about whether it is important that farmers, in general, adapt to climate change to ensure long-term success of U.S. agriculture (Farmers Adapt), and belief that that there is too much uncertainty about climate change to justify adaptive action (Uncert NoAdapt). A fourth variable was included to measure farmer beliefs that their operation will be harmed by climate change (CC harm).

We include six variables that measure risk perceptions and strategies (Table 2). Four variables were included that measure the degree of concern that farmers have regarding potential negative weather-related outcomes: increased flooding (Flooding), longer periods of drought (Droughts), more frequent extreme rains (Extreme Rains), and soil erosion (Erosion). We also include two variables that measure risk management strategies that farmers employ, including a variable on whether farmers are diversifying into other forms of production/different crops as a way to manage weather related risks

(Diversification) and a variable that measures how many hectares a farmer has insured through federal crop insurance (Crop Insurance).

Three variables are included in our models that measure normative influences (Table 2). Two variables measure the latent construct of a conservationist identity (Stewardship) and a more production-oriented identity (Productivist). Farmers were asked to rate a suite of survey items meant to describe what attributes constitute a ‘good farmer’ (Burton 2004). Responses to these questions were used to construct the Stewardship and Productivist variables by using a confirmatory factor analysis (Appendices). We also include a variable that measures the importance of visiting with other farmers (Visit Farmers) as another normative influence on farmer intentions.

Two variables are used to measure the concept of Perceived Behavioral Control (PBC). The first variable measures how confident farmers are that their current practices will be able to effectively mitigate the impacts associated with increasing weather variability (Confidence). The second variable assesses how confident farmers are in their knowledge and skills to deal with weather-related threats to their farm (Knowledge & Skills).

Finally, four variables were included in the model that measure key characteristics (e.g., background factors) at the farmer and farm-level. These included age (Age), highest level of education (Education), the value of farm sales (Farm Revenue) and finally, the percent of highly erodible land that was planted to crops in 2011 (Erodible Land). Three additional variables were included that measure farmers’ current use of the practices examined, including their use of no-till farming (No-till), cover crops (Cover Crops), and tile drainage (Tile Drainage).

Table 2 A total of 22 covariates were included in the models. Descriptive statistics are presented (mean, and SD). The name of the variable, the associated question/statement from the survey and the scale that the variable is measured on are also presented

Variable Category	Variable	Question/Statement	Measure	Mean	SD
Attitudes Towards Adaptation	I Adapt	I should take additional steps to protect the land I farm from increased weather variability	Five point scale	3.47	0.80
	Farmers Adapt	It is important for farmers to adapt to climate change to ensure the long-term success of U.S. agriculture	Five point scale	3.56	0.86
	Uncert NoAdapt	Too much uncertainty about the impacts of climate change to justify changing my agricultural practices and strategies	Five point scale	3.67	0.93
	CC Harm	My farm operation will likely be harmed by climate change	Five point scale	2.98	0.78
Risk Perceptions and Strategies	Flooding	Concern about increased flooding	Four point scale	1.92	0.84
	Droughts	Concern about longer dry periods and drought	Four point scale	2.67	0.87
	Extreme Rains	Concern about more frequent extreme rains	Four point scale	2.48	0.90
	Erosion	Concern about increased soil erosion	Four point scale	2.26	0.80
	Diversification	Diversifying into other forms of production/different crops as a way to manage weather related risks	Binary response (no=0, yes=1)	0.10	0.30
	Crop Insurance	Crop insurance hectares	Continuous	238	282
Normative Influences	Productivist	Confirmatory Factor Score (see Appendix A)	Continuous	0.00	0.51
	Stewardship	Confirmatory Factor Score (see Appendix A)	Continuous	0.00	0.69
	Visit Farmers	It is important for me to visit other farms to look at their practices and strategies	Five point scale	3.32	0.88
Perceived Behavioral Control	Knowledge & Skills	I have the knowledge and skills to deal with any weather-related threats to the viability of my farm operation	Five point scale	3.35	
	Confidence in Practices	How confident are you in your current practices given a climate change scenario?	Four point scale	2.86	0.73
Background Factors	Age	Age	Continuous	55.94	11.01
	Education	Highest level of education	Ordinal Scale (1=some formal ed., 6=Grad. school)	3.24	1.33
	Farm Revenue	Farm revenue from sales	Continuous	463,412	674,736
	Erodible Land	Percentage of highly erodible farmed land, in 2011, which was planted to crops	Continuous	22.52	39.04
	No-till	Currently uses no-till	Binary response (no=0, yes=1)	0.60	0.49
	Cover Crops	Currently uses cover crops	Binary response (no=0, yes=1)	0.22	0.42
	Tile Drainage	Currently has land that is artificially drained through tile or other methods	Binary response (no=0, yes=1)	0.77	0.42

Results

The results of three logistic regression models have some similarities yet there are clear differences with regards to the significance and effect of the independent variables on each dependent variable explored in all three models. The first results presented (Table 3) provide basic descriptive statistics that characterize what "increase" means for each of the models to contextualize the results. Then the results from each of the analyses are presented, including a model developed for no-till farming (Model One), cover crops (Model Two), and tile drainage (Model Three). Each model is discussed separately to examine the results associated with each of these practices in addition to a section that makes comparisons between all of the models. In Table 4, we present information on the estimated coefficient, the standard error, level of significance, and the odds ratio (Exp(b)) for each model, in addition to model fit statistics. An odds ratio of 1 (even odds) indicates that the independent variable has no influence on the dependent variable. For significant variables, a number over 1 suggests that the independent variable has a positive relationship with the dependent variable and the inverse is true for a number below 1.

Understanding potential adaptation

This analysis focuses on predicting adaptive responses to climate change, measured as farmers' stated intentions to increase use of selected production and conservation practices. In all the models, independent variables measuring whether farmers are currently using the practices are included as it is expected that current practices will have an influence on what farmers would do in response to climate change. It is useful, however, to understand what "increase" in practice usage means in the context of our analysis. For no-till farming, 66% of farmers indicated that they would maintain their current management practices, while 34% would increase their use of no-till farming (see Table 3). Among those who indicated that they would increase their use of no-till farming, 26% would increase their current use while 8% would adopt the practice anew. For cover crops, 36% of farmers would increase their use of the practice, with 23% of those farmers adopting the practice for the first time. Finally, for tile drainage, very few farmers who did not already use the practice indicated that they would adopt the practice, but 53% of those who currently have drainage would intensify or expand tile coverage in response to increased weather variability associated with climate change. Note, however, that the focus of the analysis is on intended action, moving from the status quo (stay the same) to increased use.

Table 3 Percentage of farmers surveyed who plan on staying the same or increasing their use of each practice based on whether they currently use the practice or whether they plan to adopt the practice for the first time

	Stay the Same	**Percent**	**Increase**	**Percent**
No-till farming	Would Not Use	22%	Would Adopt	8%
	Currently Use	44%	Would Increase Use	26%
	Total	66%	*Total*	34%
Cover Crops	Would Not Use	48%	Would Adopt	23%
	Currently Use	16%	Would Increase Use	14%
	Total	64%	*Total*	36%
Tile drainage	Would Not Use	12%	Would Adopt	4%
	Currently Use	31%	Would Increase Use	53%
	Total	43%	*Total*	57%

Model one: Increasing the utilization of no-till farming

Three of the variables from the attitudes towards adaptation category were statistically significant predictors in the no-till farming model (Table 4). The variable measuring whether farmers believe that they should personally take action to protect their land from increased weather variability, *I Adapt*, had a highly significant ($p<0.001$) and positive relationship with intentions to increase no-till farming. The variable measuring uncertainty (*Uncert NoAdapt*) ($p<0.05$) had the opposite effect, such that farmers who believe there is too much uncertainty about climate change to justify changing their practices were less likely to increase their use of no-till farming. The *CC Harm* variable, or those farmers who believe that their farm will be negatively impacted by climate change, had a positive relationship ($p<0.05$) with increasing the use of no-till farming.

One variable measuring risk perceptions and strategies and another variable assessing normative influences were statistically significant predictors of No-till farming adaptation intentions. The variable measuring concern about increased erosion, *Erosion*, had a highly significant ($p<0.001$) and positive relationship with the intention of increasing the use of no-till farming. The normative influence of visiting other farmers, *Visit Farmers*, also had a positive and significant effect ($p<0.05$).

One variable measuring perceived behavioral control and one variable measuring background factors were also significant predictors of adaptation intentions regarding no-till farming. *Confidence in Practices* had a highly significant ($p<0.001$) and negative relationship with intentions to increase the use of no-till farming. However, the current use of no-till farming, *No-till*, had a positive and significant ($p<0.05$) relationship with improving the odds that a farmer would increase their use of no-till farming in response to greater weather variability due to climate change.

Model two: Increasing the use of cover crops

One of the variables measuring attitudes towards adaptation and two variables assessing risk perceptions and strategies were significant in predicting adaptation intentions in the cover crops model (Table 4). The variable measuring support for taking individual adaptive actions, *I Adapt*, was highly significant ($p<0.001$) with a positive relationship with intention to increase use of cover crops. The variables measuring concern about increased risks associated with *Extreme Rains* ($p<0.05$) and increased *Erosion* ($p<0.001$) both had a positive relationship with intentions to increase the use of cover crops.

Two variables measuring normative influences and one variable measuring perceived behavioral control were significant in the cover crops model. A *Stewardship* identity was highly significant ($p<0.001$) and positively associated with intentions to increase the use of cover crops. *Visit Farmers*, or the importance of networks, also had a positive and highly significant ($p<0.001$) relationship with plans to increase the use of cover crops in response to more extreme weather. However, the variable *Confidence in Practices* had a negative and significant relationship ($p<0.01$) with intention to increase the use of cover crops.

Three background factors are significant predictors of intention to use cover crops. *Age* had a significant ($p<0.01$) negative relationship and *Education* had a highly significant ($p<0.001$) and positive effect on whether a farmer intends to increase their use of cover crops. Finally, the variables measuring farmers' current use of *Cover Crops* and *No-till* both had highly significant ($p<0.001$) and positive relationships with intention to increase the use of cover crops.

Model three: Increasing the use of tile drainage

Two measures for assessing attitudes towards adaptation are positive and significant ($p<0.01$) in the tile drainage model (Table 4), with the variables *I Adapt* and *Uncert NoAdapt* increasing the odds of a farmer increasing or intensifying tile drainage on their farms given the climate change scenario. Additionally, four variables from the risk perceptions and strategies category were significant in the tile drainage model. The variable measuring concerns about *Flooding* was highly significant ($p<0.001$) and had a positive relationship with the likelihood of farmers installing more subsurface tile. The *Extreme Rains* variable was also significant ($p<0.01$) and positively associated with the likelihood of installing more tile drainage; however, the perception of drought risk (*Droughts*) ($p<0.01$) decreases a farmer's intention to install more drainage. An increase in the number of hectares that are insured (*Crop Insurance Hectares)* ($p<0.05$) improves the odds that a farmer intends to increase their use of tile drainage.

One variable measuring normative influences and one variable assessing perceived behavioral control were significant ($p<0.01$) in the tile drainage model. *Visit Farmers* increases the odds that a farmer will increase their use of tile drainage. The variable *Confidence in Practices*, which measured farmers' confidence in their use of current practices to reduce weather related risks, was negatively associated with intentions to increase the use of tile drainage.

All three variables in the background factors category were highly significant ($p<0.001$) in the tile drainage model. *Age* and *Farm Revenue* both have a positive relationship with intention to install more tile drainage. The current use of *Tile Drainage* had an expectedly positive relationship with improving a farmers intention to use more tile drainage, with a very large odds ratio (Exp(B) 4.97) which suggests a very powerful relationship between the current use of tile drainage and intentions to increase or intensify the use of this practice given expected climate changes.

Table 4 Twenty-two covariates presented for all three models, No-till farming (Model 1), Cover crops (Model 2) and Tile-drain (Model 3). For each variable in every model we include logit coefficients, ± S.E. in parentheses and the log odds (Exp(B)). Hosmer and Lemeshow values and Psuedo-R^2 are presented for each model

Variable Category	**Variables**	**No-till farming (Model 1)**	**Exp(B)**	**Cover Crop (Model 2)**	**Exp(B)**	**Tile drainage (Model 3)**	**Exp(B)**
	Intercept	-2.39 (1.01)*	0.09	-3.53(1.15)**	0.03	-5.56(1.02)***	0.00
Attitudes Towards Adaptation	**I Adapt**	0.28(0.07)***	1.32	0.26(0.08)***	1.30	0.20(0.06)**	1.23
	Farmers Adapt	0.07(0.06)	1.07	-0.10(0.07)	0.90	0.11(0.06)	1.11
	Uncert_NoAdapt	-0.12(0.06)*	0.89	-0.06(0.07)	0.94	0.18(0.06)**	1.19
	CC Harm	0.17(0.07)*	1.19	0.02(0.08)	1.02	0.05(0.06)	1.05
Risk Perception and Strategies	**Flooding**	0.02(0.06)	1.02	-0.07(0.06)	0.93	0.26(0.06)***	1.29
	Droughts	-0.03(0.06)	0.97	-0.07(0.07)	0.93	-0.18(0.06)**	0.84
	Extreme Rains	-0.01(0.06)	0.99	0.15(0.07)*	1.17	0.17(0.06)**	1.19
	Erosion	0.2(0.06)***	1.22	0.25(0.07)***	1.28	0.09(0.06)	1.10
	Diversification	0.2(0.14)	1.24	0.22(0.16)	1.24	0.09(0.15)	1.10
	Crop Insurance Hectares	0.00(0.02)	1.00	0.0(0.02)	1.02	0.03(0.02)*	1.03
Normative Influences	**Productivist**	-0.08(0.1)	0.92	-0.21(0.11)	0.81	0.10(0.1)	1.10
	Stewardship	0.11(0.08)	1.12	0.29(0.09)***	1.48	-0.01(0.07)	1.00
	Visit Farmers	0.11(0.06)*	1.11	0.23(0.06)***	1.26	0.14(0.05)**	1.16
Perceived Behavioral Control	**Knowledge & Skills**	0.07(0.06)	1.07	0.01(0.07)	1.01	0.06(0.06)	1.07
	Confidence in Practices	-0.39(0.07)***	0.67	-0.33(0.08)**	0.72	-0.20(0.07)**	0.82
Background Factors	**Age**	0(0.00)	1.00	-0.01(0.01)**	0.99	-0.02(0.00)***	0.98
	Education	0.05(0.03)	1.05	0.13(0.04)***	1.14	0.05(0.03)	1.06
	Revenue	0.02(0.07)	1.02	0.13(0.07)	1.14	0.21(0.06)***	1.24
	Erodible Land	0(0.00)	1.00	0(0.00)	1.00	-0.00(0.00)	1.00
	No-till	0.28(0.11)*	1.33	0.81(0.11)***	2.26	-0.01(0.10)	0.99
	Cover Crops	0.1(0.11)	1.10	0.49(0.11)***	1.63	-0.04(0.11)	0.96
	Tile Drainage	-0.15(0.11)	0.86	-001(0.12)	0.99	1.60(0.13)***	4.97
	Hosmer and Lemeshow (p-value)	7.47(0.49)		7.38(0.50)		2.27(0.97)	
	Nagelkirke's Psuedo-R^2	0.09		0.19		0.19	
	*p<0.05; **p<0.01; ***p<0.001						

Model comparison

There are clear commonalities between each of the models examined (Table 4); however differences exist, suggesting that factors driving the intention to increase the use of no-till farming, cover crops, and tile drainage, given the climate change scenario, are unique to the practice. The main similarities between all the models include three key findings. First, farmers who had positive attitudes towards adaptation and believe that they should take additional steps to adapt to increased weather variability on their farm, *I Adapt*, indicated that they would increase their use of all three practices explored. Conversely, farmers who express high levels of perceived behavioral control expressed through their confidence in current practices (*Confidence in Practices)* are less likely to increase their use of any of the practices explored. Additionally, the background factor of current practices, measuring current use of *No-till*, *Cover Crops,* and *Tile Drainage*, are significant and positively associated with plans to increase the use of each of these practices in their respective models. In other words, if they were using a given practice, farmers were more likely to report that they would increase their use in response to climate change impacts. Five variables were not significant in any of the models, which included *Farmers Adapt, Diversification, Productivist, Knowledge & Skills,* and *Erodible Land*.

There are also important similarities between significant covariates when comparing each of the models separately. For example, a comparison of the no-till farming model and the cover crops model shows that high risk perceptions for weather related risks, specifically the variable *Erosion*, had a positive and significant relationship with intentions to increase the use of both no-till farming and cover crops given the climate change scenario. When comparing the no-till farming model with the tile drainage model, we find that *Uncert NoAdapt*, as a measure of attitudes towards adaptation, had a positive and significant relationship with intentions to increase the use of tile drainage yet the converse was true for no-till farming, with a negative and significant relationship. Finally, when comparing the cover crops model with the tile drainage model we found a few commonalities, including concerns about *Extreme Rains*, as a measure of risk perception, and the importance of visiting other farmers, *Visit Farmers*, as a normative influence. Both of these variables improve the likelihood that a farmer would increase their use of cover crops and tile drainage. *Age*, as an important background factor, decreases the likelihood that a farmer will plan on increasing their use of both cover crops and tile drainage.

Discussion

These findings illustrate that a third to half of all Corn Belt farmers that were surveyed intend to change their practices in response to projected climate changes. Clearly the effects of extreme weather will influence how farmers respond to climate change (Rejesus et al. 2013). However, non-climatic forces and conditions also influence what farmers intend to do in response to a changing climate (Smit and Skinner 2002).

Generally, attitudes towards adaptation matter. In particular, the variable measuring whether farmers think that they should take additional steps to protect the land that they farm, *I Adapt*, was critical for explaining intention to increase the use of all three practices. Farmers are adapters; this is what they do in the context of maintaining viable farm systems (OECD 2012; Arbuckle et al. 2013c), and in particular, those who see it as their responsibility to protect their farm from weather related risks are more likely to engage in adaptive strategies. The significance of this variable emphasizes the importance that farmers place on individual responsibility to protect *their* land from increased weather variability; however, the variable measuring whether, collectively, farmers should take additional steps to protect farmland from increased weather variability, *Farmers Adapt*, was not significant in any of the models. This highlights that farmers are indeed open to taking personal action to adapt to climate related risks on their farm. However, there may be difficulty in marrying this individualistic approach with efforts to design purposeful and collaborative adaptation strategies (Howden et al. 2007).

Across all models, at least one variable in the category of risk perceptions and strategies was an important predictor of intentions to increase the use of no-till farming, cover crops, and tile drainage. In particular, concerns about excess water or risk of soil erosion were significant in all three models. The perception of weather-related risks has been found to be a critical driver in motivating farmers to shift their production and conservation practices, particularly in relation to climate change adaptation (Arbuckle et al. 2013c; Hyland et al. 2015).Our findings support a similar connection, found by Brody et al. (2008), between positive attitudes towards adaptation and higher levels of perceived risks associated with extreme weather, which has an influence on what farmers intend to do in response to climate change.

Farmers who had higher levels of confidence that their current agricultural practices and strategies were sufficient to reduce weather related risks were less likely to indicate that they would increase their use of any of the practices explored. These findings are important to note as other research has suggested that PBC has a direct impact on intention to change behaviors (Klöckner 2013) and therefore suggests that greater confidence in current practices may discourage adaptive actions. Farmers who reported a high level of confidence in their current practices were distinct from farmers who had a higher perception of weather related risks because these farmers were more likely to increase their use of the practices of interest given projected climate changes. Farmers manage risks through a range of management decisions, not all of them examined here (Rejesus et al. 2013), so there may be factors that are driving confidence that we do not adequately capture (e.g., connectivity to markets, low debt-to-asset ratio). High levels of confidence may present a barrier to making necessary farm-scale changes in response to more extreme and variable weather (Arbuckle et al. 2014); at least to the degree that it inhibits the use of critical adaptive strategies.

The importance of visiting other farmers to observe their practices is an important factor influencing intentions to increase the use of no-till farming, cover crops, and tile drainage. Visiting other farmers to observe what practices they use on their farms has been found to be important in the adoption of a number of farm production practices (Rogers 1995; Coughenour and Chamala 2000; Coughenour 2003; Pannell et al. 2006; Reimer et al. 2012a) and can facilitate important social learning necessary for adopting conservation practices (Pannell et al. 2006; Blesh and Wolf 2014). These findings suggest that building adaptive capacity among farmers will be effectively facilitated, in part, through building more networks among farmers so that they can observe particular practices of interest before experimenting on their own farms.

Finally, the background factors associated with farmers' current use of no-till farming, cover crops, and tile drainage was a strong predictor of propensity to increase the use of each of the adaptive strategies examined in this study. In other words, the findings suggest that farmers who were more familiar with these practices were more likely to believe that increased use would be an appropriate adaptive response in the context of a changing climate. Given that the three practices are effective adaptive management practices (Morton et al. 2015) this suggests that perhaps greater emphasis on current adoption of these practices could have a positive impact on future adaptation. However, the impacts associated with these practices and the subsequent evaluation of those impacts will depend on the spatial and temporal context in which the evaluation occurs.

Evaluating adaptive strategies

It is beyond the scope of this paper to evaluate the potential multi-scale impacts of the increased use of the practices explored. Nevertheless, it is critical that we acknowledge the complexity of assessing impacts, even with the production practices (i.e., no-till farming, cover crops, and tile drainage) examined in this study. For example, researchers should be cognizant that while the practices discussed in this paper are promoted/adopted for their beneficial properties, each of these practices may have associated maladaptive properties, which will ultimately reduce the "effectiveness of purposeful adaptation action and policies across sectors" which is a challenge for achieving "effective adaptation in practice" (Adger et al. 2005, p. 97). Maladaptation can be defined as "actions taken to avoid or reduce vulnerability to climate change that impacts adversely on, or increases vulnerability of other systems" (Barnett and O'Neill 2010, p. 211). For example, no-till farming and cover crops have been shown to be helpful in reducing some of the negative externalities associated with corn and soybean production; however cover crops, which require chemical burn down or mechanical removal via tillage may lead to greater use of pesticides in the long run (Hoorman 2009) and no-till has been shown, in some cases, to increase nitrogen leaching (Constantin et al. 2010). Tile drainage is considered a standard practice in corn and soybean producing regions of the Corn Belt, however, tile drainage also has maladaptive properties, particularly because it has been found to contribute to high nitrate concentrations in the Mississippi River and concomitant issues with hypoxia (Goolsby et al. 1999; Oquist et al. 2007), which may be further exacerbated due to more extreme storm events associated with climate change.

These adaptive practices may suggest, in some cases, a situation where farm-level resilience may be contrary to resilience at the landscape-scale, where increased use of a particular practice leads to reduced vulnerability at the field and farm-level but actually stimulates greater vulnerability in the larger agroecosystem. Indeed, beneficial adaptations at the individual level may lead to negative consequences that hinder others' ability to adapt (Adger et al. 2005; Nelson et al. 2007).Overall, these instances suggest that there are potential maladaptive properties associated with the practices examined in this study and the case may be that simple tweaks to the current cropping system may not be enough to fundamentally bring about a resilient agroecosystem (Atwell et al. 2011).

Broader implications

There is clear evidence that the Corn Belt is already experiencing more weather variability (Arritt 2016), which suggests that those involved in agricultural research and outreach must encourage farmers to implement adaptive actions on their farms. The findings from this study highlight the opportunity to engage with farmers who are generally confident in their ability to adapt and are willing to take steps to respond to more extreme weather, particularly through efforts that appeal to "farmers' confidence and their capacity to adapt" (Morton et al. 2016, p. 7). Given that farmers' current use of specific conservation practices help to predict what they intend to do in response to a changing climate, it will be important to actively engage farmers in efforts to expand the use and adoption of critical soil and water conservation efforts *now* in anticipation of more variable and extreme weather events. Study findings also highlight the importance of farmer networks in expanding the use and adoption of adaptive strategies, suggesting that development of robust farmer networks that allow farmers to observe and experiment with practices will be important for climate change adaptation. This builds on existing knowledge that has highlighted the importance of farmer networks, which have been critical in the adoption soil and water conservation practices in the farming community (Pannell et al. 2006).

Conclusion

Findings from this study, which examines Corn Belt farmer survey data of unprecedented size and scope, suggests that both climatic and non-climatic factors and conditions will influence farmers' adaptive intentions. Indeed, farmer decision making in the context of climate change adaptation will be based on a diverse array of biophysical, political, economic, and cultural factors. This study highlights the opportunity to engage with farmers, who are confident in their ability to adapt and are generally willing to take steps to mitigate weather related risks on their farms, by clarifying and promoting the practices that will reduce climate related risks at both the field and landscape-scale. Climate change adaptation efforts in the agricultural sector will ultimately need to be linked to a broader set of policies and targeted efforts that build more capacity for purposeful adaptation designed to respond to long-term changes in the climate (Howden et al. 2007). Therefore, engaging with corn and soybean farmers will be a critical way to enhance adaptive capacity in the Corn Belt.

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Appendix

A confirmatory factor analysis was conducted to develop productivist and stewardship identity constructs. The survey question was measured on a 5 point Likert scale (1=Strongly Disagree, 5=Strongly Agree). The survey question and the standardized factor loadings are provided. A partial information estimator was used to develop the factor scores due to the ordinal nature of the response variables.

Factors	**Question/Statement**	**Standardized Factor (Lamda) Loading**
Productivist Identity	A good farmer is one who has the highest yields per hectare	0.584
	A good farmer is one who gets their crops planted first	0.564
	A good farmer is one who has the highest profit per hectare	0.605
	A good farmer is one who has the most up-to-date equipment	0.677
	A good farmer is one who uses the latest seed and chemical technology	0.679
	A good farmer is one who maximizes government payments	0.537
Stewardship Identity	A good farmer is one who considers the health of streams that run through or along their land to be their responsibility	0.700
	A good farmer is one who minimizes erosion	0.743
	A good farmer is one who minimizes nutrient runoff into waterways	0.759
	A good farmer is one who thinks beyond their own farm to the social and ecological health of their watershed	0.771
	A good farmer is one who maintains or increases soil organic matter	0.759
	A good farmer is one who minimizes the use of pesticides	0.583

	A good farmer is one who manages for both profitability and minimization of environmental impact	0.758
	A good farmer is one who scouts before spraying for insects/weeds/disease	0.660
	A good farmer is one who puts long-term conservation of farm resources before short-term profits	0.672
***Fit statistics for confirmatory factor model with two latent constructs (Productivist Identity and Conservationist Identity): Chi-square fit index (0.380, d.f. 89, p-value >0.995); RMSR value 0.0523; AGFI value 0.963). All indicate good fit, including no standardized residuals over 1.96.**		

CHAPTER 3.

SOIL STEWARDSHIP: BRIDGING SHORT-TERM REACTIVITY AND LONG-TERM PROACTIVE STRATEGIES FOR CLIMATE RESILIENCY

A paper to be submitted to *Rural Sociology*

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Abstract

There is growing concern that increased soil degradation and soil erosion in highly productive areas of the Corn Belt will hamper regional productivity over the long-term. In addition to concerns about soil degradation and soil loss due to erosion, there is a concern that global climate change will lead to greater soil loss with negative impacts on crop productivity. In this article we examined in-depth interviews with farmers (n=159) from nine Corn Belt states. Using Grounded Theory, a “soil stewardship” construct was identified, which exemplifies how farmers are thinking about building long-term sustainability of their farming operation in light of more variable and extreme weather events. Findings suggest that farmers’ shifting relationship to their soil resources may act as a kind of social-ecological feedback that enables farmers to implement adaptive strategies (e.g., no-till farming, cover crops) that build resilience in the face of increasingly variable and extreme weather, in contrast to emphasizing short-term tweaks to production that may lead to greater vulnerability. Further, greater soil stewardship might help farmers to resolve the apparent tradeoff between profitability in the short-term and field-level resilience over the long-term. Focusing on the message of managing soil health to mitigate weather-related risks and preserving soil resources for future generations may provide a pragmatic solution for helping farmers to re-orient their farm production practices, which would have soil building and soil saving at their center.

Introduction

In recent years, high prices for corn and soybean commodities across the U.S. Corn Belt, driven in part by increased demand for corn-based ethanol (Bain and Selfa 2013), has induced the conversion of marginal lands into row crop production, particularly on land that is considered Highly Erodible (HEL) (Claassen et al. 2011; Morton et al. 2015; Wright and Wimberly 2013). Indeed, there are rising concerns that erosion is on the increase in highly productive agricultural regions such as the U.S. Corn Belt and in many instances exceeds the estimated tolerable rate of soil loss (11.2 Mg ha^{-1}) (Cox et al. 2011; Cruse et al. 2012). These trends are concerning because healthy soil resources are critical for productive agricultural systems and poor management of soil resources carries a social cost, particularly due to excessive sedimentation and water quality impairment (Montanarella 2015; Morton et al. 2015). Further, there is growing concern that global climate change will increase the frequency of extreme rain events and intensify soil erosion problems with subsequent impacts on agricultural productivity (Cruse et al. 2012; Melillo et al. 2014; Morton et al. 2015).

Globally, there is a growing awareness that preserving soil resources and enhancing soil quality will help to reduce agricultural systems' social and ecological vulnerability to climate change impacts (Lal 2014; Melillo et al. 2014; Morton et al. 2015). Soil quality, often referred to as soil health, is defined as "the fitness of the soil to carry out biological production and environmental protection functions within specified land use, landscape, and climate boundaries" (Harris et al. 1996: 61). To address the degradation of soil resources, global agricultural conservation efforts have begun to focus on soil health and erosion prevention as a way to build greater resilience across agriculturally productive regions. These efforts are evidenced in the Food and Agricultural Organization's commitment to the work of the Global Soil Partnership as well as the development of the nascent Intergovernmental Technical Panel on Soils (see Montanarella 2015). In the U.S., these efforts are being actively promoted across agriculturally-productive regions in the U.S. through the Soil Health Initiative, which is an education and outreach campaign sponsored by the U.S Department of Agriculture's Natural Resources Conservation Service (NRCS 2015).

Managing for healthy soils often requires the adoption of Best Management Practices (BMPs), such as no-till farming and cover crops (Lehman et al. 2015), which can carry near-term costs for farmers with benefits that accrue over the long-term. Indeed, healthy soils are built over long-periods of time (Amundson et al. 2015), which can improve soil moisture and nutrient retention due to better aggregate stability which enhances permeability and subsequent infiltration (Gaudin et al. 2015). Improvements to soil health can translate into long-term economic benefits for farmers (NRCS 2015); however, the value of improved and/or retained soil is often not directly assessed in the context of short-term economic decision making made at the farm scale (Cruse et al. 2012). Therefore, tension exists, across agriculturally productive regions, between short-term economic goals of minimizing costs (profit maximization) and efforts to preserve and enhance soil resources for long-term resilience[4] (Cruse et al. 2012). In other words, farmers often have to make seasonal decisions that emphasize the economic viability of their farm operation, which may be counter to achieving longer-term soil health goals.

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[4] In general, resilient cropping systems are "able to retain yield potential and recover functional integrity (produce food and feed) when challenged by environmental stresses" (Gaudin et al., 2015, p.1).

Through this research effort we sought to answer the following questions: How do farmers approach managing their soil resources to sustain their farming operation and adapt to weather related risks?; and, how are farmers' efforts to enhance and preserve soil temporally situated (i.e., short-term interests vs. long-term management goals)? In this article we use Grounded Theory (Charmaz 2006) to examine in-depth interviews with farmers (n=159) from nine Corn Belt states. Farmers were asked questions regarding their motivations for adopting and utilizing soil and water conservation practices (e.g., no-till farming and cover crops) as well as probing their adaptive responses to increased weather variability. Through analysis of the farmer interviews, the construct of "soil stewardship" emerged as a way to explain how some farmers are enhancing their soil resources as a way to adapt to more variable and extreme weather. We further examined how farmers are engaging in soil stewardship as a way to bridge short-term reactivity to seasonal weather variability with proactive management of their soil resources in order to build long-term resilience of their farm operation.

Background

Soil stewardship as social-ecological feedback

In coupled human and natural systems, such as farming, people and nature interact "reciprocally and form complex feedback loops" (Liu et al. 2007:1513). Farmers learn from and respond to their farming environment (e.g., soils, topography, and climate) through this social-ecological feedback. This compliments Freudenberg et al.'s (1995) assertion that the social and biophysical worlds are conjointly constituted illustrating a dynamic interplay between the social and natural world; whereby the biophysical world is shaped by social processes and in turn, social phenomena are shaped by the biophysical world.

Farmer management decisions impact their soil resources, and their soil resources constrain and facilitate management decisions through a kind of social-ecological feedback. For example, farmer observations of highly erodible soils on their farm can encourage them to use no-till farming or cover crops to reduce erosion problems (Romig et al. 1995). Additionally, farmers' adoption of new practices can facilitate a new "relationship" with their soil resources that allow them to observe and experience their soil in new and different ways. Coughenour (2003) found that with the adoption of no-till farming, some farmers began to develop a new appreciation for soil resources. This new "relationship" with the soil enabled these farmers to shift their identity from a more productivist orientation, with an emphasis on short-term profitability (Arbuckle 2009; Burton 2004; McGuire et al. 2013), to what he identifies as "practical agroecologists working with the soil and plant environments." (2003:295). Coughenour (2003) found that through this newly activated identity, farmers sought new ways to balance both profitability and conservation.

Lambin and Meyfroidt (2010) argued that this social-ecological feedback can manifest in farmer decisions to change their farming practices as a result of experiencing degradation of their soil resources and other on-farm ecosystem services. Indeed, we have seen that concerns about soil conservation can be a strong driver for farmers' adoption of agricultural BMPs (Arbuckle and Roesch-McNally 2015; Atwell et al. 2009; Ervin and Ervin 1982; Gould et al. 1989; Knowler and Bradshaw 2007; Reimer et al. 2012; Roesch-McNally et al. In review). Increased weather variability, with greater erosivity potential due to large storm events, may increase the intensity of this feedback loop (see Collins et al. 2011), which may cause farmers to respond by emphasizing practices that enhance their soil resources as a way to reduce weather related risks (Knutson et al. 2011). Farmers may tweak, adapt, or transform their farm production practices to minimize risk and vulnerability associated with soil losses (Hatfield and Morton 2012).

Tweak-adapt-transform

Adaptation approaches can include a range of practices and adjustments that farmers take "based on short-and long-term production and conservation goals" to mitigate weather related risks (Morton et al. 2015:811). Adaptation strategies available to farmers can be considered within the social-ecological frame (see Figure 1) of Tweak-Adapt-Transform (Atwell et al. 2011). This research conceptualizes the Tweak-Adapt-Transform framework as a continuum of strategies implemented by farmers as a way to reduce weather related risks, which lead to outcomes (from vulnerability to resilience), at the field-scale.

Farmers can make "tweaks" to their production systems, in response to increased weather variability, that more-or-less maintain their current production system. These tweaks might include increased tillage in response to cool and wet spring weather, which may provide economic benefits to farmers over the short-term, by allowing earlier planting of key cash crops, but over-time might degrade soil resources (Morton et al. 2015). These tweaks are likely to lead to greater vulnerability over time through the degradation of on farm soil resources in particular.

Farmers are also able to "adapt" their systems via a form of social ecological feedback in order to build greater resiliency by addressing on-farm impacts (e.g., erosion) and off-farm environmental impacts (e.g., sedimentation), by adopting BMPs (e.g., reduced tillage, cover crops, and diversified rotations). These proactive adaptive management strategies are expected to assist farmers' efforts to reduce weather related risks on their farms through the incorporation of practices that modify row-crop production in ways that may also lead to greater soil and water conservation with field and landscape-scale benefits.

Farmers can also "transform" their farm operation as a way to purposefully adapt to climate change. This transformation might include the extensive incorporation of perennial systems, which moves beyond monoculture production of annual row-crops to the integration of perennial-based systems, more diverse polycultures and/or greater crop and livestock integration. These purposeful adaptation strategies would ultimately enhance the provision of a more diverse array of ecosystem services that would build longer-term resilience of the agroecosystem at field and landscape scales.

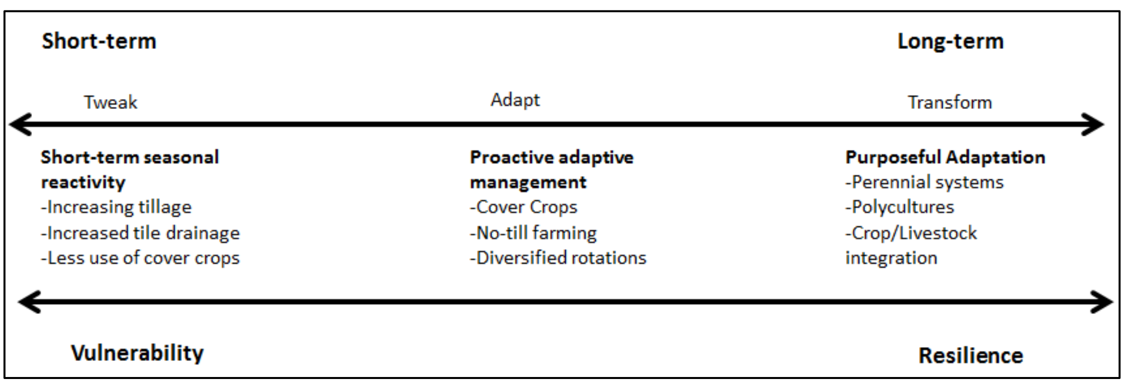

Figure 1. This conceptual model builds on the Tweak-Adapt-Transform framework (Atwell et al. 2011) by conceptualizing it along a continuum of potential climate change adaptation strategies and outcomes.

Data and Methods

Interviews with Corn Belt farmers were conducted as part of a multi-state research effort designed to explore adaptive and mitigative strategies that could be implemented across the U.S. Corn Belt to decrease agriculture's vulnerability to the impacts of climate change. Semi-structured in-depth interviews were conducted with 159 farmers across nine states: Illinois (9), South Dakota (14), Missouri (16), Ohio (18), Indiana (20), Iowa (20), Minnesota (20), Michigan (20), and Wisconsin (22). The region as a whole has been experiencing greater extreme weather events, including heavy rain events and periods of drought (Pryor et al. 2014), and farmers were interviewed during a historically wet 2013 growing season following the 2012 drought, which affected a large portion of the U.S. Midwest. Farmer participants are larger-scale commodity producers who primarily raise corn and soybeans. Participants were purposively recruited as part of the land grant extension and affiliated agricultural conservation networks in each state. Farmers who tended to be more conservation oriented and early adopters of conservation practices were specifically recruited because the research team wanted to learn from individuals who had some exposure and experience with key conservation practices (e.g., no-till, cover crops, precision agriculture) and who may have surmounted barriers when adopting these practices; however, it is not assumed that these farmers are necessarily at the cutting edge of conservation practice use on their farms, only that they have some experience using conservation practices in their corn and soybean cropping system.

Interviews with farmers lasted between 45-90 minutes, following a semi-structured interview protocol with follow-up questions designed to probe motivations and expand on topics that emerged out of the in-depth interviews. The interview protocol was composed of four sections that covered perspectives on the use of conservation practices (with an emphasis on reduced tillage, cover crops, and diversified rotations), experienced weather variability, beliefs about climate change, trusted information sources, and attitudes about sustainability (See Table 1). The interview protocol was extensive and not all portions of the interviews were examined as part of this study. Analysis of the in-depth interviews focused on farmers' discussion of soil health and erosion prevention and their reported strategies for reducing weather related risks.

Table 1. **Interview protocol used to guide in-depth interviews with Corn Belt farmers.**

Thematic Area	Interview Questions
Conservation practices	• Could you describe your nutrient management system? Including your main motivations for managing nutrients the way you do? • What tillage do you use on these fields and what were your motivations for using them? What are the primary benefits of your tillage approaches? And are there any challenges associated with these tillage approaches? Where do you get information on these methods? • If you use cover crops, when did you start using them and what were your motivations for starting? What species do you use? What are the primary benefits of your cover crop approach? Are there challenges associated with using cove crops on these fields? Where do you get your information on cover crops? • *IF* Farmer does not use cover crops then they were asked if they had ever used them and why they stopped using them as well as whether they would consider using them in the future. • Have you ever heard of drainage water management? If so, what do you think about it? • Have you ever heard of nitrogen sensors? If so, what do you think about them? • What, if any, practices do you implement differently on land you own as opposed to land you rent?
Weather Variability	• Over the past five years or so, have you experienced any extreme weather that has adversely affected your farm operation? • Have these weather events changed your management practices at all? If so, how? • There have been a lot of discussions lately about global climate change and its potential impacts on agriculture. What are your opinions about climate change and its potential impacts on your farm operation? • *IF* Farmer thinks that climate change is occurring ask: What do you think are the causes of climate change and who do you think is responsible for addressing the challenges associated with it? • *IF* Farmer doesn't think that human or naturally caused climate change is happening AT ALL then ask: What types of information, conversations, or other resources have shaped your current thoughts on climate change?
Trusted Sources of Information	• Who do you look to for information on conservation management practices? Can you give me a sense of what these particular organizations/agencies do specifically that make you more willing to take their advice or technical expertise? • What can extension, government, or the private sector do to assist further development of conservation practices on your farm? • What types of programs or policies do you think might assist you participating in more conservation programs or implementing new/different management practices?
Sustainability	• Can you describe what long-term, on-farm sustainability means to you? • Let's think about your marginal field right now, or other marginal areas on your whole farm, and consider other uses that might be of value or interest to you. Would you ever consider changing your current cropping system on this field and if so, what are the types of things you have considered doing with this land? • As you think about your business and the lifestyle of farming, what is it that you most want researchers and perhaps government agencies to understand about the long-term goals you have for your farming operation?

Interviews were digitally recorded and transcribed verbatim with analysis conducted in NVivo 10. Interview transcripts were examined using Grounded Theory[5] following an open, axial, and selective coding procedure (Charmaz 2006). Theoretical memos, which are an integral tool for conducting qualitative analyses using Grounded Theory (Charmaz 2006), were written throughout the coding process in order to build conceptual density of key concepts. Each category was explored to validate the findings and to ensure reliability, by assessing the power of the category to explain the phenomenon of interest, the usefulness of the category and broader patterns within and between different categories (Charmaz 2006). These categories were examined by writing theoretical memos and coding/recoding interviewee responses to ensure that farmer quotations provided conceptual richness and accurately reflected the broader meaning of the category without too much overlap between different categories. As Prokopy (2011) suggests, direct quotes are included in the findings section to illustrate key concepts and assure transparency.

During the preliminary coding process, a coding typology was developed based on the available literature on how farmers assess soil health properties. Soil assessment categories based on the work of Romig et al. (1995) and Gruver and Weil (2006), include: soil organic matter, soil moisture, compaction, infiltration, soil testing, presence of earthworms and beneficial insects, texture, soil color and crop performance/yield. However, later coding efforts built on how farmers think about, and manage for, soil health, particularly in the context of increased weather variability. Specifically, discussions regarding soil health and erosion prevention were not a primary focus of the interviews but rather they emerged out of the discussions with the farmers as they

[5] Theoretical sampling was not used as part of our sampling methodology as utilized in some GT studies.

volunteered information about their approach to conservation and their response to weather-related events on their farm; therefore this particular study is grounded in the emergent concepts that developed out of conversations with farmer participants. A primary construct of “soil stewardship” was developed through this analysis. The soil stewardship construct has four sub-categories, which include managing weather related risks, preserving soil for the future, the neighbor effect and temporal tradeoffs. These subcategories are used to organize our findings.

Findings

Farmer participants were similar to farmers in the Corn Belt region. However, on average, participants had fewer cropland hectares, with an average of 281 hectares, compared to the region[6]. Most interview participants grossed between US$250,000-$500,000 and almost all had at least some college education. Around a third had cattle in their operation. In terms of conservation practices, the majority of participants had adopted some form of reduced tillage to minimize soil disturbance and leave crop residue for soil protection, either by using conservation tillage or no-till farming, or a combination of both. Over fifty percent were experimenting with cover crops to some extent. These rates of reduced tillage and cover crops are higher than those estimated for the region as a whole.[7]

Soil stewardship

The soil stewardship construct was developed through the iterative coding process outlined in the methods section. This construct is conceived of as a soil stewardship ethic

[6] The Economic Research Service estimates that the midpoint acreage is greater than 445 hectares, which has steadily been increasing in the U.S. Corn Belt due to consolidation of the farming industry.
[7] Based on Ag Census data for 2012, for the states where farmers were interviewed, on average, 3% of total cropland was in cover crops and around 25% in conservation tillage and 28% in no-till (NASS 2012). Many farmers use a combination of conservation tillage and no-till on their cropland.

which was constructed by examining the ways that farmers articulated the benefits of soil preservation, through erosion prevention, and soil enhancement, through improvements in soil health, particularly in the context of reducing weather related risks on their farms. Subcategories were developed in order to examine what elements constitute this soil stewardship ethic; these subcategories include: managing weather related risks, preserving soil for the future, the neighbor effect, and temporal tradeoffs (Table 2).

The subcategory of “managing weather related risks” represents the ways in which farmers are adopting or increasing their use of conservation and management practices to improve soil health and reduce erosion as a strategy for mitigating weather related risks. The “preserving soil” subcategory exemplifies the ways in which farmers are protecting their soil resources, primarily through erosion prevention, for future generations. “The neighbor effect” subcategory emerged out of conversations with farmers who described how they approach their management practices differently in contrast with neighboring farms. Finally, the subcategory of “temporal tradeoffs” illustrates how farmers articulate the tension between short-term profit-oriented goals and long-term soil conservation objectives. Overall, our findings suggest that there is a clear relationship between a soil stewardship ethic and expressed commitment to managing soil resources to reduce on-farm vulnerability, particularly in the context of more extreme and variable weather.

Table 2. Sub-categories for the soil stewardship construct are presented along with the total number of farmers (out of 159 farmers in total) who discussed elements coded for in the subcategory, a general description of subcategory, and typical quote that illustrates the subcategory.

Soil Stewardship Subcategory	No. of interviewees	Description	Typical Quote
Managing weather related risks	65	Enhancing soil resources, often discussed as improving soil health; include strategies to adapt to weather related risks, with tensions between management tweaks vs. adaptive strategies to improve soil	Even a few of the fields that we own, the lighter ground, we do more no-till on that, might be part of the reason we got and switched to a no-till drill for the beans. [We are] trying to conserve some moisture, kind of thinking ahead a little bit, without disturbing the soil, and help build a little organic matter too. (WI farmer)
Preserving soil	48	Thinking about erosion prevention and protecting the soil base, particularly for future generations, farmland transfer and for ensuring agricultural productivity for feeding society	If we were to farm this land that we've been given…to us for the next 100 years, as it has been farmed and cultivated for the previous 100 years, then we are going to diminish this natural resource that we've been blessed with… I think that, as stewards of the soil, we should prioritize on making that [soil], making that a very important thing. (IN Farmer)
The neighbor effect	19	Observations of soil erosion, water movement on neighboring farms; broadly discussing soil impacts to the area after large wind and rain events	Well I look at his [field] and I look at mine. I mean, if I notice his, I look a little bit more at mine cause I can see what's going on. So that's what brings your attention to things. (IA farmer)
Temporal tradeoffs	13	Direct contemplation of the challenge of reconciling short-term goals of profitability with long-term goals of conservation	Well it's always economics. And that's followed by land stewardship. You know, you have to be a good steward of the soil because that's what pays the bills. If we destroy the soil, you know, that's short-term and it's not going to be replaced. I mean, economics is always first. Conservation is right there with it, of course. (WI farmer)

<u>Managing weather related risks</u>

Farmers' experience of more extreme weather events had caused some to shift their production practices to focus on soil health and erosion prevention. Farmers' experiences of extreme weather events were variable across regions and between farms. For example, some farmers did quite well during the 2012 drought due to timely rains experienced in their area, coupled with high crop prices, while some farms had catastrophic crop losses. Multiple farmers discussed ways that they had shifted their production practices, to enhance soil resources, due to experiences of extreme rain events and drought. Two farmers discussed changes they had made to their tillage regime in response to different weather extremes,

> The springs of '10 and '11 were quite wet, large rain events, and we are seeing more erosion, more dirt moving than we should see on some of those fields so we are trying to move to a system, a strip till system for corn on corn that we can get comfortable with using on this highly erodible land. (IL farmer)
>
> We, historically, have been conventional tillage. This year, I have switched almost all the acres to no-till, thinking it was going to be dry. I'd been thinking about it for about 5-6 years but I'm a little slow to act on it, I guess. (SD farmer)

Many of the farmers interviewed discussed the benefits of reducing tillage or shifting to no-till farming as a way to improve soil health and reduce erosion with the added benefit of mitigating weather related risks. Additionally, utilization of cover crops was another practice viewed as having soil health and erosion prevention benefits that farmers, many of whom were beginning to experiment with cover crops, suggested might help them to create a farm operation that is more resilient to more extreme weather events. The importance of these practices for reducing weather related risks are articulated in the following quotes from a Michigan and an Iowa farmer:

> We seem to be having these extremes from one year to the next. Like this year it was way too wet. Last year, it was plenty dry. The year before that, it was cold and wet, initially, and then it got too dry after that. I guess you just need to be flexible. Obviously, you can't do anything about the rain but, if you don't work your ground to death and you leave residue on the ground. No-tilling [farming is] what you're going to [do to] conserve more moisture than if it's wide open and getting baked by the sun. (MI farmer)
>
> You're trying to think ahead and say, how can I make that soil more resilient or able to handle the stresses that might, whether it's a dry stress or too much rain or something like that, you know? By having that structure and those roots there [from using cover crops] and holding on to that soil and maybe, hold on to more nutrients through [the winter]. (IA farmer)

Farmers often discussed the importance of improving soil health in order to reduce weather related risks. Specifically, many farmers discussed how their use of BMPs have enhanced the health of their soils by improving infiltration rates during periods of heavy rain and maintaining soil moisture during drought. Typically, farmers discussed these as benefits of reduced tillage and no-till farming. These quotes from a Minnesota and a Wisconsin farmer highlight that emphasis,

> That's another factor that I feel I have an advantage with the no-till and strip till is it's just a way to manage the water that we're given. You know, with the better soil, anything I can do to maximize the infiltration and keep the water on my ground instead of running off down the ditch. (MN farmer)

> Well, I just think, through the years, we've just gone to the point of trying to maximize all the moisture that's available. In other words, through the reduced tillage, through the no-till, just trying to make efficient use of what we have and not opening up the ground any more than what we have to, trying to utilize moisture the best we can. (WI Farmer)

Additionally, some farmers expressed that improving soil health, through adoption of cover crops, might help to address some of the negative impacts of larger storm events. This is articulated by a farmer from South Dakota, who said, “I would guess that [climate change] means bigger rainfall events so the impetus to keep soil in place and to do cover crops is probably going to be something that we're going to have to pay much more attention to.”

A number of farmers clearly recognize the benefits of reducing tillage. However, some have actually moved to more intensive tillage in response to cooler and wetter springs. These farmers discussed increasing their tillage, particularly in the spring, to get the ground dried out enough to plant. This is illustrated by a farmer from Iowa, who said,

> So, you know, the ground's got to be dry to do no-till and then sometimes the ground just don't dry out unless you, you know, scratch it up a little bit. So you know there are pros and cons of [no-till]... Like last year when it was so dry, no-

> till was a pretty smart thing to do. And then, you know, so you'll have years where you just got to do what you got to do.

While many farmers acknowledge the soil health and conservation benefits of reducing tillage, some have found it tricky to implement on their farms due to the management impact of more extreme weather events (e.g., late spring planting due to more frequent rain events), as well as underlying biophysical factors associated with their on-farm soil resources. This illustrates the ways in which some conservation goals may be in conflict with a farmer's need to get a crop established and guarantee good yields for the season. As a farmer from Missouri put it, "I tried to no-till and some of our soils are just really wet and heavy and they don't warm up in the spring and I've just found that the deep tillage, over the years, you certainly get a yield bump from the tillage because you're loosening the soil." In this way, these farmer sentiments illustrate a tension between building soil resources, via improvements in soil management practices, and short-term, seasonally reactive tweaks that they make to address the negative impacts of weather events.

The managing weather related risks subcategory of the soil stewardship construct highlights a tension that farmers have experienced between tweaking their production systems in response to seasonal weather variability and adapting their systems for more proactive management in the context of more extreme weather. Indeed, some farmers are tweaking their production systems in order to react to seasonal weather primarily through increased tillage as a way to reduce weather related risks and maintain profitability. Yet other farmers are adapting their systems through the use of soil and water conservation practices, such as reduced/no-till farming and cover crops, in an effort to enhance their soil resources and reduce weather related risks.

Preserving the soil for the future

Farmers were asked about their perspectives on what long-term sustainability means to them. This question provided insight on how farmers define sustainability for their operations, given that the term can take on multiple meanings depending on the context and audience. Nearly a third of the farmers talked about the importance of preserving the land, or their "ground," particularly for the benefit of future generations, evidenced in a few key quotes:

> But I guess, morally, the sustainability is to keep doing the best of our ability for good stewardship of the soil for the next generations… we need to be careful and preserve it [soil] for next generations and leave our legacy behind. (MO farmer)

> I'll probably have grandchildren and we want to keep that water supply good for them. And also to keep the soil [in] good condition so that the generations from now can still produce food that they're going to need. (IA Farmer)

Thus, soil preservation is viewed as a connection between a farmers' current operation and future generations. While this was often referred to in the context of preserving their farmland for grandchildren or others who might inherit the farm, there were broader discussions about the importance of maintaining the agricultural land base for the production of food and feed for the benefit of society more broadly.

Interview participants also discussed the long-term nature of preserving soil, noting that reducing soil erosion and improving soil health assists them in thinking about the productivity of their land over time, not just on a seasonal basis, as the following quotes demonstrate:

> Well, I guess the way I look at it is if my farm, if the ground I farm is going to be sustainable for the long-term, you know, it's got to be able to maintain its productivity and increase its productivity and the most important thing for me is you can't do that without the soil and I need to take care of the soil. (MN farmer)

> But long term, I mean, you have to be aware of what you're using in the soil and take care of it. I mean you can't just let it all wash away. You have to keep it in a good state of fertility. (IL farmer)

The subcategory of preserving soil for the future illustrates that many farmers acknowledge that that preserving and enhancing soil resources is a long-term project. Farmers are clearly drawing linkages between preserving soil through erosion prevention and enhancing soil health with broader goals for maintaining productivity on their farm over the long-term. These farmers articulated that soil is not just another input for their row-crop production system but rather soil forms the foundation of a productive farming operation that will sustain them, and generations, to come.

<u>The neighbor effect</u>

Throughout the course of the interviews, farmers referenced the actions of their neighbors in relation to their own. In the context of soil stewardship, farmers often discussed their neighbors' tillage regimes and the ways in which the impacts of big weather events influenced their approach to soil conservation. In some cases, farmers were disappointed with how their neighbors appear to treat their soil resources. This was articulated by farmers who noted:

> You know there are times you get those huge rains and, you know, when you drive around and you see guys who are just totally disregarding it, that just have a disaster. And then even the people who are trying hard, can lose a little dirt but, yet, you know, I think it's [soil preservation] got to be something that's constantly in the back of your mind, you know. (IA farmer)

> You know, last week or the week before when we had that big rain, you know, you can look at all these ditches and see all the mud and everything going down through there and you're thinking, you know, if them guys had just been out there and left it alone, you wouldn't have all that running down through there like that, that color [running brown]. (IN farmer)

Through these sentiments expressed by farmers, one gets the sense of the very public nature of farming, whereby actions taken on the landscape, particularly those that lead to erosion, are highly visible to the community and neighbors. There is a sentiment of blame and frustration among some of farmers who see and experience the consequences of actions taken on surrounding land:

> I just get tired of cleaning my ditches out when I'm the guy below the neighbor and all this silt's coming down here in the spring, you know. He's always complaining about is, oh, he got a hard rain. Well, we all got a hard rain, you know. (IN farmer)
> I mean, our neighbor, he works his ground every year. Half of it's a sand knoll. Why he works it is absolutely beyond me. I can look up and see it and it's just blowing across onto my field. I should send him a thank-you note for the topsoil. (MI farmer)

In many cases, observations of neighbors and other cropland in their community inspired a farmers' confidence in their own conservation practices and ethics, which they might articulate as being "better" for the soil in comparison to what certain neighbors were doing. Many referenced these comparisons as a rationale for their use of no-till farming. These farmers used their observation of neighbors' practices to affirm their own conservation efforts. However, many of these farmers also expressed a challenge with reconciling that their practices are different than their neighbors, particularly when it came to getting out in the fields early in the spring, where many of the farmers who practice no-till farming wait longer to get out in the field than their neighbors because tillage will dry out and warm up soils more quickly than no-till.

Some farmers also suggested that their neighbors simply are not willing to allow the benefits of conservation practices (e.g., reduced tillage) to accrue to the soil, which they suggest has driven some of their neighbors to revert back to more intensive management (e.g., increased tillage). This is illustrated by a South Dakota farmer, who said, "So they'll [neighbors will] no-till for two or three or four years and then they'll till. And then you get all that organic matter decomposing and they say, see. I do a much better job with tillage." This farmer argued that because the benefits of no-till accrue over a longer period of time that many farmers are not willing to "wait" to experience the benefits and thus revert back to more intensive tillage. In other words, these farmers who are articulating a soil stewardship ethic caution that there is a temporal component to improving soil resources, which suggests that it takes time to observe and appreciate the benefits of conservation practices as they manifest in soil improvement.

The subcategory of the neighbor effect illustrates that farmers acknowledge the public nature of the farming enterprise; after all, farmers are able to observe their own and others' actions on the land with obvious impacts, such as erosion and drainage problems, that are difficult to hide from public view. These farmers acknowledge that observing neighboring farmers' mismanagement of soil resources have provided a signal to them to re-orient their own production practices to better steward their soil resources or, at times, these observations serve to reinforce farmers' beliefs that their current approach to managing soil resources (e.g., reduced or no-till) is superior to that of their neighbors. Typically these observations occur after experiences of extreme weather (e.g., flooding, big rains) events that impacted the broader farming community in a given region.

<u>Temporal tradeoffs</u>

Several farmers described tensions between their goals of maximizing short-term productivity and maintaining soil health and productivity over the long-term. Quotes such as this one from a farmer who has prioritized long-term soil stewardship goals over short-term productivity articulate their thoughts about this tension:

> You know, if you're focused on maximizing production, you might not necessarily be doing what's best for the soil, short- term. But I think, you

> know, I'm kind of leaning towards what's best for the soil…If I take care of the soil in the short-term, long-term, my yields will reflect that. (MN farmer)

Another farmer described how he wrestles with the difficulty of achieving long-term soil stewardship goals given the short-term impetus to make a profit:

> To get to the long-term, we have to get through the short-term to turn the profit. That has to be there to get us through the short-term. Long-term, I'm a little bit conflicted on that. Absolutely, well, [what] I'm not conflicted on is, absolutely, we have to save our soil. If we lose our soil, we have nothing to work with. (MO farmer)

This quote articulates the struggle that exists for farmers who, in many cases, feel they need to maximize profits on a yearly basis, while also trying to achieve their goals of taking care of their soil resources. As a Wisconsin farmer who primarily uses no-till farming but has shifted to fewer rotations and more corn-corn rotations summed it up, "the bottom line is you got to do, whatever makes you the most money, taken the fact that you want to keep the soil in good health, you know, as far as erosion and such but the market will dictate."

While there is a tension between the short-term profit imperative and long-term sustainability concerns, many farmers appear to be bridging the short- and long-term by drawing connections between yield and healthy soils. For example, as a Michigan farmer expressed, "organic matter, which gives you better soil tilth, which gives you the microbial activity, which gives you the better soil health, better soil structure, better yields, more money." Emerging from these farmer sentiments is the idea that an ethic focused on preserving and enhancing soil health may drive a reorientation towards a longer view of landscape-level change, articulated by a South Dakota farmer who said,

> I truthfully don't believe that 100 years from now that people will continue to till in the form that they do, I think their productivity will probably start to taper off

> or just pop for them. Where people with more reduced tillage and no-till will probably just continue to increase their yields. So, you know, I'm trying to think long-term.

Whether increasing no-till farming across the entire Corn Belt would achieve what this farmer suggests, in terms of ever-increasing yields, is unclear; however, his sentiment highlights the idea that, through specific management practices that emphasize enhancement of soil health, farmers are trying to harmonize their short-term yield and profit-oriented goals with longer-term goals of sustaining soil resources for the long-term.

The subcategory of temporal tradeoffs illustrates the ways that farmers have, or are trying to resolve tensions between short-term goals of profitability and long-term goals for conservation. Many of these farmers expressed that soil provided a fundamental connection between on-farm profitability, after all, soil forms the basis of productive agricultural systems, and their vision for the long-term sustainability of their farm operation.

Discussion

These findings suggest that many farmers in the Corn Belt are managing their farm operations by cultivating a soil stewardship ethic in response to increasingly variable and extreme weather. The data show that some farmers are making slight *tweaks* to their systems, such as increasing tillage or tile drainage, to respond to weather-related risks while other farmers are *adapting* their systems, through proactive management (e.g., increased use of no-till farming and cover crops), guided by a social-ecological feedback, to build more resilient operations over the long-term. These results complement Coughenour's (2003) findings that farmers, through their adoption of no-till farming, began to see the soil differently, as a living and dynamic system that they need to manage and work with, rather than simply viewing it as another input to their system of production. The findings also support prior research that has found that land managers respond to social-ecological feedbacks on their farms, which can cause land managers to alter land use practices to improve ecosystem services provision on their farm (Lambin and Meyfroidt 2010).

Many of the farmers interviewed also noted that observing soil degradation on their own farm and on neighboring farms, typically following extreme weather events, had inspired them to change their management practices. This suggests that soil stewardship provides an opportunity to redefine normative ideas about what makes a 'good farmer' (Burton 2004) and may help to redefine what good farming practices are (Quinn et al. 2015). Additionally, our work reinforces the finding that soil health and soil erosion can be perceived as both a reflection of personal identity and social identity (e.g., how neighbors view their actions), which can enable farmers to make management changes on their farm (e.g., no-till farming) (Schneider et al. 2010).

This soil stewardship ethic may be an emergent property of a conservationist identity that is facilitated through a social-ecological feedback. Farmers' efforts to address temporal tradeoffs through greater soil stewardship may help them to resolve tensions between productivist and conservationist identities (Coughenour 2003; McGuire et al. 2013). In his study of no-till farming, Coughenour (2003) found that farmers' values regarding soil resources shifted over time, which fostered a change in farmer identity towards a more conservationist orientation. Our research suggests that greater soil stewardship has forced farmers to think about soil in the long-term, potentially leading them to make connections between conserving land for future generations and integrating soil conservation as a proactive business strategy (Ryan et al. 2003).

Our findings also suggest that some farmers are struggling to reconcile production-oriented goals that demand profitability on a yearly basis with longer-term goals for soil preservation and enhancement. Indeed, political and economic factors, such as policy and markets, can drive farmers towards greater exploitation of their natural resources over the short-term, despite the benefits that might accrue to them over the long-term from greater soil conservation (Ashby 1985). Farmers are thus incentivized to emphasize annual profitability, particularly in an era of decreasing marginal returns, due to increases in seed and chemical costs (NASS 2014) and historically high rental rates (Secchi et al. 2008). Maintaining annual profitability may be increasingly challenging due to the volatility of commodity markets and increased variability of weather (NOAA 2011), where efforts to improve soil resources may be perceived as difficult to achieve in the context of decreasing marginal returns, particularly if these changes carry additional costs to farmers.

The adoption of a soil stewardship ethic may be one way to help farmers shift along a continuum of tweak, adapt, and transform on their farms. Figure 1 outlines the tweak, adapt, transform framework (Atwell et al. 2011) along a continuum of approaches that farmers can take that can either drive greater vulnerability or build resilience. Our findings suggest that some farmers are “tweaking” their production systems in terms of short-term seasonal reactivity to experienced weather on their farms while most are discussing their attempts at “adapting” their system to be more resilient to increasingly extreme and more variable weather through the concretization of a soil stewardship ethic.

The soil stewardship ethic is likely situated on the “adapt” section of the continuum with an emphasis on proactive adaptive management through the use and adoption of reduced/no-till farming and cover crops. A few of the farmers interviewed were pushing more for a transformation of the current system of production, driving them closer to the “transform” side of the continuum with an emphasis on purposeful adaptation. Most farmers, however, did not discuss the use of practices that would be considered a radical departure from intensive row-crop production of corn and soybean in favor of a more “transformative” agricultural system that incorporates more perennial systems, polycultures or crop/livestock integration.

The results of this research indicate that efforts to engage farmers in conversations about soil stewardship may be an effective pathway for building more resilient farming systems. The NRCS implemented their Soil Health Initiative in 2012 (NRCS 2015) with the goal of encouraging farmers to maintaining healthy and productive soil resources, through the use and adoption of no-till farming, cover crops, and more diverse crop rotations. The findings from this research provide empirical evidence that suggests that the NRCS and other global initiatives are building programs that are likely to be received well by farmers. Emphasizing soil stewardship may enable farmers to engage in practices that will foster more resilient agricultural systems, particularly in the era of climate change (Cruse et al. 2012). While many farmers in our study emphasize a soil stewardship ethic as a way to mitigate extreme weather, assessing whether adapting their farm operations by increasing the use of conservation practices will actually lead to broader scale transformation should be further investigated. In this vein, interdisciplinary research should build farmer and scientist partnerships to develop programs that will "monitor, assess, and build healthy soil" (Romig et al. 1995:236) particularly as it relates to mitigating weather-related risks.

Conclusion

Through in-depth interviews with farmers across nine Corn Belt states, we examined how farmers respond to weather related risks and specifically, how they alter management practices in response to increased weather variability and projected climate change. Our findings illustrate a potential resolution, via soil stewardship, to the apparent tradeoff between short-term seasonal reactivity and proactive management with a focus on building long-term resilience through the use of soil and water conservation practices. Focusing on the message of managing soil health to mitigate weather-related risks and preserving soil resources for future generations may provide a pragmatic solution for engaging farmers in strategies that re-orient their farm production practices, which have soil building and soil saving at their center.

The climate is changing and more farmers may need to adopt adaptive practices that are more transformative than using no-till farming and cover crops; these transformative practices might include crop and livestock integration and greater field-level cropping systems diversity (Hatfield et al. 2014). A transformation in agricultural production highlights the need for a more multifunctional agriculture that will deliver agricultural goods (e.g., food, fuel, fiber) and other ecosystem services (e.g., carbon sequestration and water quality improvements) to society (Robertson and Swinton 2005; Jordan and Warner 2010). Therefore, further efforts should examine whether the development of a soil stewardship ethic might lead to greater resilience to climatic changes, which allow for innovation and transformation that will to lead to more desirable social-ecological outcomes (Folke 2006).

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CHAPTER 4.

CROP DIVERSIFICATION IN THE U.S. CORN BELT: A MIXED METHODS ANALYSIS

A paper to be submitted to *Global Environmental Change*

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Abstract

Cropping system diversity can help build greater resilience by suppressing insect, weed, and disease pressures while also mitigating effects of extreme and more variable weather. Little is known about what factors most influence a farmers' decision to use more diversified crop rotations in the US Corn Belt, particularly in the context of a changing climate. This study uses a parallel convergent mixed methods approach, using a multi-level analysis of survey data from 4,778 farmers, and qualitative analysis of 159 in-depth interviews with Corn Belt farmers. Analyses were conducted to answer questions regarding what factors influence farmers' use of extended crop rotations in intensive corn-based cropping systems and to explore whether farmers in the Corn Belt might use extended crop rotations in response to climatic changes. Findings suggest that path dependency associated with the intensive corn-based cropping system in the region limits farmers' ability to integrate more diverse crop rotations. However, farmers in more diversified watersheds, those who farm marginal ground, and those with livestock are more likely to use extended rotations. Additionally, farmers who currently use more diverse rotations are also more likely to plan to use crop rotations as a climate change adaptation strategy. If more diverse cropping systems are desired to reduce negative impacts from climate change and enhance the multifunctionality of agroecosystems then further efforts must be made to facilitate more diverse crop rotations in the U.S. Corn

Belt by adjusting policy and economic incentives that presently discourage cropping system diversity in the region.

Introduction

Corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) commodities, which are largely produced in the U.S. Corn Belt, constitute the most economically valuable agricultural export produced in the United States (USDA-ERS 2014). This Corn Belt agroecosystem is primarily managed to produce corn and soybean commodities through a corn-soybean rotation or continuous corn planting. Over the past thirty years, this region has consistently had the lowest crop diversity when compared to other regional U.S. cropping systems (Aguilar et al., 2015). This is part of a long-term trend of increased row crop acreage and farm size with less land devoted to diversified cropping systems (MacDonald et al., 2013), with ongoing conversion of grassland, pasture, and marginal lands for increased crop production (Claassen et al., 2011; Lark et al., 2015).

This intensive production system in the U.S. Corn Belt has environmental consequences. Specifically, agricultural land use in the Corn Belt is the primary cause of the hypoxic zone in the Gulf of Mexico, which is an oxygen-depleted area caused by runoff of nitrogen and phosphorous fertilizers and sedimentation due to wind and water erosion (Donner and Kucharik, 2008; Broussard and Turner, 2009). Additionally, changes in land use and land cover, primarily losses of grasslands, wetlands, and other perennial systems for conversion to intensive row cropping has decreased the availability of wildlife habitat in the region (Wright and Wimberley, 2013). Further, climate change projections for the region, which include more extreme and variable weather (e.g., heavier rainfall, increased flooding, and drought events) (Melillo et al., 2014), are likely to exacerbate water quality challenges due to increased sediment loading and fertilizer runoff (Broussard and Turner, 2009; Broussard et al., 2012). Climate change impacts in the region are also likely to have negative impacts on yields of key commodities produced in the region, including corn and soybean (Hatfield et al., 2014)

One way to combat some of the challenges associated with this intensive row crop production in the region is to diversify the crop rotation. Cropping systems diversity, through the use of extended rotations, can balance multiple goals of “productivity, profitability, and environmental health” (Davis et al., 2012, p. e47149). Extended rotations can include any crop used to diversify the corn-soybean rotation (e.g., small grains, alfalfa, hay, cover crops) integrated over the course of multiple years (from 2-7 years). Over time, extended rotations can also build agroecosystem resilience by reducing insect, weed, and disease pressures (Lin, 2011) in addition to reducing the need to purchase external synthetic inputs (Davis et al., 2012). In general, resilient cropping systems are “able to retain yield potential and recover functional integrity (produce food and feed) when challenged by environmental stresses” (Gaudin et al., 2015, p.1).

There are some key findings from existing literature that highlight what influences farmers’ decisions to use extended crop rotations in highly specialized agricultural regions. In their study of the Western Corn Belt, Cutforth et al. (2001) found that the slope of farmland (as a proxy for marginal land) and farmers' positive attitudes towards cropping system diversity were positive drivers of crop rotations while net household income had a negative influence on farmers’ use of crop rotations. Livestock integration can also influence a farmer’s decision to use diversified rotations (Knutson et al., 2011); particularly if those diversified rotations include the use of cover crops (Singer et al., 2007; Arbuckle and Roesch-McNally, 2015). Farmers may also use extended rotations to preserve and enhance soil resources (Davis et al., 2012; Lehman et al. 2015) and reduce climate related risks (Reidsma et al., 2010; Knutson et al., 2011).

Bradshaw et al.'s (2004) study of the Canadian Prairie region examined farm-level adoption of extended crop rotations and explored the likelihood that farmers would adopt greater crop diversification in response to climate change. They identified barriers to farmers' use of diversified crop rotations as a climate adaptation strategy, which includes the compounding effects associated with non-climatic risks and opportunities, the challenge of dealing with what they term "inter-periodic variability" (the difference between weather and climate), and the heterogeneity of decision-making and behavior at the farm-scale. They argue that crop diversification, as a climate change adaptation strategy, is unlikely to occur due to the increasingly prevalent trends towards specialization at both the farm and regional scale. This research builds on these findings by exploring what influences and constrains farmers' use of extended crop rotations in the Corn Belt and whether farmers will take actions to diversify in the context of increased weather variability.

In this research effort we examine three questions regarding the use of diversified crop rotations in the U.S. Corn Belt: what factors influence the use of extended rotations among farmers in intensive corn producing watersheds?; what are the challenges of integrating extended rotations into corn-based cropping systems?; and, how might increased weather variability, associated with global climate change, influence farmer decisions to use diversified rotations in their cropping systems? This study employs a parallel convergent mixed methods approach that includes a multi-level analysis of farmer survey responses (n=4,778), coupled with Agricultural Census data aggregated at the six-digit Hydrologic Unit Code (HUC6) watershed-level (NASS 2014a), and qualitative analysis of in-depth interviews (n=159). The following section examines drivers of specialization in the Corn Belt and how this has disincentivized cropping system diversity in the region. The methods section includes a description of data and analytical procedure used to conduct qualitative and quantitative analyses. The discussion and conclusion section provides a discussion of relevant findings across data sources and explores future areas for research.

Treadmill of Production

The Corn Belt is trending towards greater homogeneity at the field and landscape scale, with an emphasis on maximizing production of corn and soybean crops (Lark et al., 2015) as part of a market for undifferentiated global commodities, which is paired with a concomitant loss of crop and livestock integration with a decreased need for diverse livestock feed and forage (Stuart and Gillon, 2013). There is an expansion of row crop production on marginal lands and a general trend towards less diversity (Aguilar et al., 2015), including losses to hay ground, pasture and livestock production (Wright and Wimberley, 2013). This trend is associated with a productivist paradigm of agricultural production (e.g., agro-industrialisation (McMichael, 2009); high-yield production regime (Carolan and Stuart, 2016)), which operates within a neoliberal context following a market-driven logic, reinforced by government policy, orienting modern agricultural systems towards capital accumulation (McMichael, 2009). This productivist paradigm manifests in a trend towards more consolidated and specialized systems of production that require economies of scale and attendant equipment, seeds, and chemicals.

This productivist paradigm in the Corn Belt follows the logic of the treadmill of production, which emphasizes the goals of boosting yields and increasing the production of a select group of commodities (Cochrane, 1958; Levins and Cochrane, 1996). In an effort to increase production and cut costs, farmers must adopt new technologies, such as improved seed varieties and attendant chemicals that require more specialized farm equipment and greater reliance on external inputs often leading to economies of scale to reduce marginal costs and increase profits (Gould et al., 2004). However, as more farmers increase the supply of agricultural commodities overall revenue tends to be reduced and the profit margins associated with production tend to go down. This ultimately leads to a "double squeeze" in agricultural production, where farmers face diminished revenues for their product coupled with higher input costs (e.g., equipment, seeds, chemicals, fertilizers) (Fuglie et al., 2007, p. 3). Across the U.S. Corn Belt farmers have experienced declining marginal returns and increased costs, particularly due to historically high rental rates (Secchi et al. 2008) and high input costs (NASS 2014b).

A number of factors have driven this system towards greater homogeneity, including environmental factors such as water availability, soil type, topography (Bowman and Zilberman, 2013), and sociopolitical factors such as government commodity program payments (Broussard et al., 2012), crop insurance (Bowman and Zilberman, 2013; MacDonald et al., 2013), biofuel policies (Donner and Kucharik, 2008; Bain and Selfa, 2013; Aguilar et al., 2015; Fausti, 2015), and the increased financialization of commodity markets (Clapp, 2012). Additionally, research and technology investments tend to favor economies of scale and have facilitated greater specialization of cropping system technology, including seed and associated chemical technologies (Vanloqueren and Baret, 2009; Lin, 2011) with increased size and efficiency of machinery with less demand for rural labor (Gould et al., 2004). This intensive agricultural production system "remains strongly reinforced by agricultural markets, legislation, and agribusiness companies that greatly profit from the current system" (Stuart and Gillon, 2013, p. 322) and is reinforced by the predominant view that monoculture production systems are inherently more productive than more diversified systems (Lin, 2011).

Actors, including farmers, make decisions contingent upon the prevailing logic and beliefs, norms, values, and practices that guide the institution of which they are part of (Feunfschilling and Truffer, 2014); further, farmers are influenced by the broader structure of the farming institution in the Corn Belt, which largely operates within the productivist paradigm. This productivist paradigm is "stabilized through various lock-in mechanisms, such as scale economies, sunk investment in machines, infrastructure, and competencies" (Geels, 2011, p. 25). These lock-in mechanisms, associated with path dependency, make it very difficult for farmers to shift production systems. Path dependency "occurs when a particular technological innovation becomes dominant and self-reinforcing…excluding competing and possibly superior alternatives," which can make systems less resilient to change over time (Chhetri et al. 2010:895).

Farmer decisions to diversify, by including small grains or re-integrating livestock in their farming operations, can be difficult due to losses in rural market infrastructure such as rail lines (Brown and Schulte, 2011) and local market access. Despite these constraints, farmers illustrate agency within the productivist paradigm through their "creative improvisation and real time management of variability and stochastic events in social, technical or ecological realms" (Crane et al., 2011, p.180). However, farmer agency should be considered as a form of 'embedded agency' whereby farmers are "constrained, but also enabled by institutional structures, which in return, are socially [re]constructed by them" (Fuenfschilling and Truffer, 2014, p. 776). Farmers are limited in their ability to influence systemic change or wield power more broadly within the context of agricultural and economic policy because the "macro-scale historical, socioeconomic, and political context" of the region has driven the current resource allocation and landscape design (Blesh and Wolf, 2014, p. 4). Indeed, shifting production practices, even if these changes are not radical transformations of the current production system, can be difficult because managing farms differently can be "risky, challenging, and rare" (Blesh and Wolf, 2014, p. 4).

Methods

The study utilized a mixed methods approach, using a parallel convergent design for data collection and analysis (Fig. 1). A parallel convergent design allows researchers to collect "different but complementary data on the same topic" (Morse, 1991, p. 122). In this study, survey and interview data are examined using separate statistical and qualitative data analysis procedures, then findings are merged in the discussion section to compare and contrast results from these different data sources (Creswell and Clark, 2011). The methods section outlines the quantitative and qualitative data and analysis in separate sections examined below.

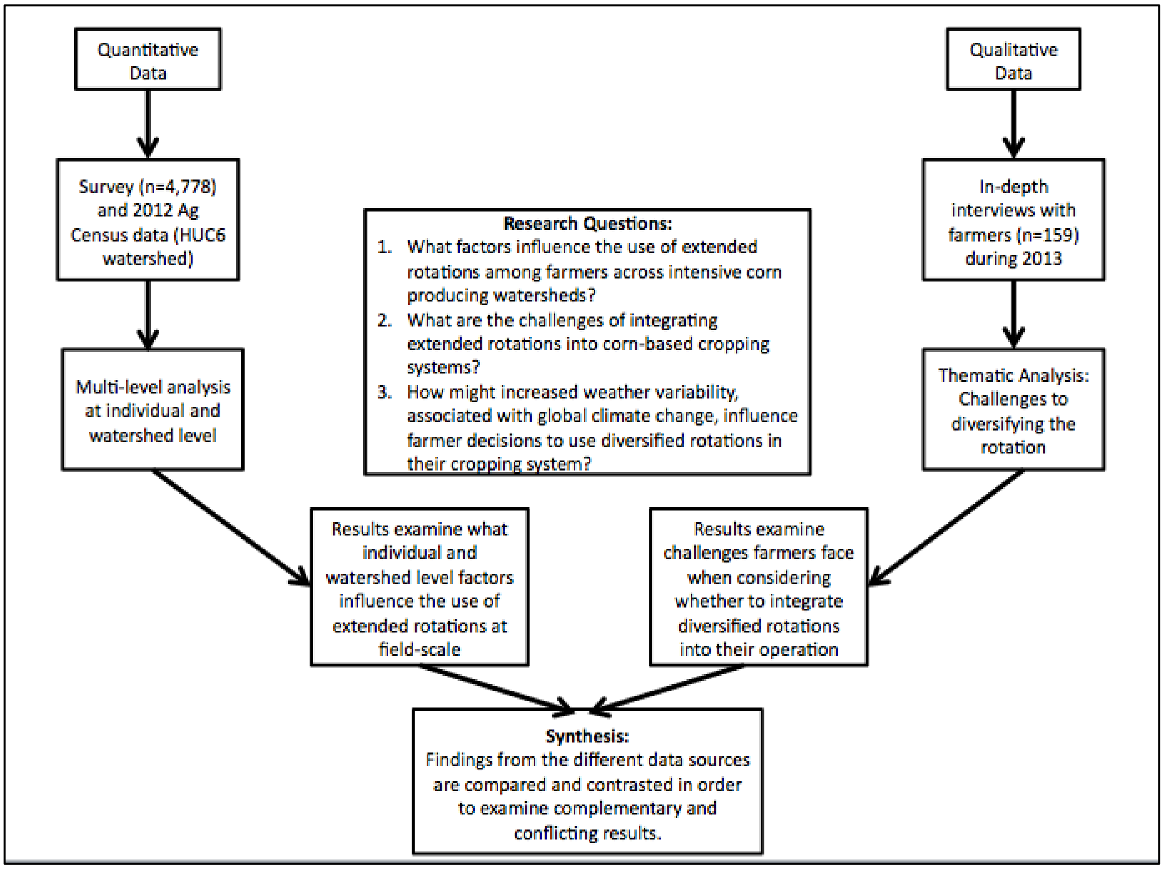

Fig. 1 Mixed methods analysis follows a parallel convergent approach, combining separate qualitative and quantitative data sources and analyses.

Quantitative data and analysis

Survey data

Survey data were collected through a random sample survey of Corn Belt farmers that was stratified across 22 HUC6 watersheds covering more than half of corn and soybean production in the United States (Appendix A). The US Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) Census of Agriculture sample frame was used (USDA, 2012), which provided the most complete and up-to-date list of farmers available in the U.S. The sample population was larger-scale corn producers, defined as farms that operate more than 80 acres of corn and generate a minimum of $100,000 U.S.D. in gross sales. The 22 watersheds cover a significant portion of eleven

Corn Belt States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin) and are classified as "major crop areas" for corn and soybean according to the USDA (1994).

The survey was administered in February 2012 using a three-wave mailing process. The survey was mailed to 18,707 farmers, followed by a reminder postcard, with a final survey sent to non-responders (Arbuckle et al., 2013a). A sample size of 4,778 was achieved with an effective response rate of 26%. A non-response bias analysis was conducted at the watershed level comparing respondents and non-respondents and no meaningful differences were detected (Loy et al., 2013). This suggests that there is no systematic bias between those who responded and those who did not thus our results can be generalized to the population of larger-scale corn farmers in the Corn Belt (Arbuckle et al., 2013a). Sampling weights were developed to account for the probability of selection and response at the watershed level and were applied to the entire dataset before statistical analyses were performed (Loy et al., 2013). Additional data were taken from the 2012 Census of Agriculture, which were aggregated at the HUC6 watershed-level (NASS, 2014a).

Quantitative analysis

Multi-level modeling (MLM) was employed because it allows for the partitioning of variance in hierarchically nested data (i.e., individual and watershed-level data) (Snjiders and Bosker, 2012). The model includes two-levels of variables, measured at the individual farmer-level (level-one) and watershed-level (level-two) that help to explain the variability between individuals across twenty-two HUC6 watersheds. For this analysis, individual data are nested within watershed-level data, therefore all independent variables at level-one (farmers) are centered about their means (i.e., centered within context) to allow for ease of interpretation of intercept values and predictors (Hofmann and Gavin, 1998; Enders and Tofighi, 2007). In this way we are able to specify that level-one units (farmers) are nested within level-two units (watersheds). The dependent variable is a binary response variable; therefore, we use a hierarchical generalized linear model (HGLM)[8] to account for the non-normal error distribution associated with dichotomous data (Snjiders and Boskers, 2012). Overall, model assumptions are met; however, three variables were log transformed due to heteroscedasticity in the residuals (Table 1).

The MLM is constructed to examine a dichotomous dependent variable, Diversified Rotations, by including eleven level-one (individual farmers) variables and four level-two (watersheds) variables (Table 1). The dependent variable Diversified Rotations represents whether or not a farmer uses diversified rotations in their farming operation. In the study survey, farmers were asked whether they currently use diversified rotations, such as small grains, forages, or other crops on land they farm. Extended crop rotations, in a corn-based cropping system, are defined here as any crop used to diversify the corn-soybean rotation, which can include small grains, alfalfa, hay/grasses, or cover crops. These additional crops used in the rotation can be integrated over the course of many years (crop rotations in a corn-based cropping system are typically based on 2-4 year rotations but can be integrated over longer periods of time) (Strock and Dalzell, 2014).

[8] We utilized the Proc Glimmix procedure in SAS 9.3 (Ene, 2015) and used the Laplace approximation to account for the non-normal nature of the dependent variable (Snjiders and Boskers, 2012). We specify an unrestricted covariance structure (TYPE=UN) to limit the restrictions placed on these data.

Level-one variables

Two variables were included to measure farmer identity, Productivist and Stewardship, to examine the role that identity has on farmers' use of diversified rotations. These variables were constructed, using confirmatory factor analysis (Appendix B), to measure the latent construct of a Productivist and Stewardship identity. Farmers rated a set of items meant to describe what constitutes a 'good farmer' (Burton, 2004; McGuire et al., 2013). Items measuring the Productivist construct were based on agreement with survey questions that suggested that a good farmer is one who focuses on high profits/ha, those with the most up-to-date equipment and seed/chemical technologies, and those who maximize government payments. The Stewardship construct was developed using contrasting survey questions, which included statements that a good farmer was someone who focuses on water quality, soil health, and erosion prevention, chemical use reduction, and environmental stewardship. We expected that a farmer with a productivist identity would be less likely to use diversified rotations with the converse being true for farmers with a stewardship identity.

Three variables were included to measure different ways that farmers might diversify their economic risks, including All Cattle, Crop Insurance and Corn Markets (Table 1), which might affect their use of extended crop rotations. The All Cattle variable was used to indicate the influence of having cattle on whether or not farmers have more diversified rotations as the presence of livestock has been found to be an important driver for greater on-farm diversity because of a need for diverse feed and forage (MacDonald et al. 2013). Another variable was included to measure the total number of hectares that were insured using federal crop insurance (Crop Insurance) because farmers' use of crop insurance to minimize financial and weather related risks might serve as a disincentive for more diverse agricultural production systems (MacDonald et al., 2013). Finally, we included a total count for the number of corn markets (Corn Markets) that farmers produce corn for (including commodity, ethanol, livestock, specialty, seed, and other) as a way to assess market diversification (Morton et al., 2015).

Two variables, Water Concern and Highly Erodible Land (HEL) (Table 1), were included in the model to assess relationships between environmental factors and farmers' use of diversified rotations. We created the Water Concern variable as a summated scale created from four survey questions regarding the level of concern for specific weather events associated with too much water, which include concerns about increased flooding, extreme rain events, increased saturation, and erosion. Perceived risks associated with extreme weather events can influence farmers' management decisions (Knutson et al., 2011) and actions taken in response to climate change (Brody et al., 2008; Arbuckle et al., 2013b). The percent of a farmer's HEL cropland that they reported to farm during 2011 was also included as an environmental factor that might be positively associated with the use of more diverse rotations because land designated as HEL can erode at excessive rates due inherent soil properties (NRCS, nd) and may be more vulnerable to erosion during extreme weather events (Morton et al., 2015).

Two variables, Diversify_Adapt and Alt. Markets, were employed to evaluate the relationships between farmers' attitudes towards diversifying crop rotations to reduce climate related risk (Table 1). The first variable (Diversify_Adapt) measured whether or not, given a realistic climate change scenario developed for the region, farmers would increase their use of diversified rotations. Additionally, farmers were also asked whether they agree that profitable markets for small grains and other alternative crops should be developed as a climate change adaptation tool (Alt. Markets).

Table 1 Eleven level-one independent variables were included in the multi-level analyses. The variable, the associated question/statement from the survey and the scale that the variable is measured on are also presented, along with information on data source(s). Descriptive statistics include mean and standard deviation (SD).

Variable	**Description**	**Scale**	**Mean**	**SD**	**Source**
Dependent Variable					
Diversified Rotations	Farmer uses diversified rotations that include small grains, forages, or other crops on land they own and/or rent	Binary response (0=No, 1=Yes)	0.46	0.5	a
Independent Variables					
Individual (level-one) variables					
Productivist	Confirmatory Factor Score (see Appendix B)	Continuous Scale	0.00	0.51	a
Stewardship	Confirmatory Factor Score (see Appendix B	Continuous Scale	0.00	0.69	a
All Cattle	Count for all Cattle & Calves *	Continuous Scale	80.94	392.73	b
Crop Insurance	Crop insurance hectares*	Continuous Scale	240.79	282.47	b
Corn Markets	Number of crop markets farmers produce corn for (includes options for commodity, ethanol, livestock, specialty, seed, other)	Nominal Scale	1.95	0.82	a
Water Concern	Summated scale measuring concern about water related risks (flooding+ extreme rains+ increased saturation+ increased erosion/4)	Four point scale (1=Not Concerned, 4=Very Concerned)	2.22	0.69	a
HEL	Hectares of highly erodible land that was planted to crops in 2011-based on the percentage of HEL that farmers reported to farm *	Continuous Scale	84.98	244.03	a, b
Diversify_Adapt	Intention to use diversified rotations or not given a climate change scenario	Binary response (0=Stay the same, 1=Increase)	0.20	0.40	a
Alt. Markets	Profitable markets for small grains and other alternative crops should be developed to encourage diversified crop rotations in order to address potential changes in climate.	Five point scale (1=Strongly Disagree, 5=Strongly Agree)	3.61	0.78	a
Education	Highest level of education	Ordinal Scale (1=Less than high-school, 6=Graduate degree)	3.27	1.32	a
Farm Revenue	Gross farm revenue from sales (USD)*	Continuous Scale	$457,014	$653,461	b

* Final model used natural log transformation for variable due to non-normal, right skewed data
a. Data from survey of Corn Belt farmers across eleven states in U.S. Corn Belt in 2012 (Loy et al., 2013)
b. Data from NASS Census of Agriculture (NASS, 2014a)

We included farmer education level (Education) and gross farm revenue (Farm Revenue) as control variables that might influence whether a farmer uses diversified rotations. Both education and farm revenue have been found to be significant control variables in studies of farmer decision making (Knowler and Bradshaw, 2007; Prokopy et al., 2008; Baumgart-Getz et al., 2012). Specifically, higher farm revenues were found to negatively influence on-farm diversification (Cutforth et al., 2001).

Level-two variables

A cropland diversity index (CDI) (Table 2) was developed to quantify the diversity of cropland at the watershed-level, following the method outlined by Broussard et al. (2012)[9]. For the construction of the CDI we use Agricultural Census data including the total cropland area of six different crops, which include: corn, soybeans, small grains (incl. wheat, oats, barley, and rye), vegetables, fruits/nuts, and all other crops (NASS, 2014a). The equation used to develop the CDI was

$$\text{CDI} = 1 - \sum_{i=1}^{6} \frac{Crop_i^2}{Cropland^2}$$

where CDI is a measure of cropland diversity for each watershed, the numerator, *Crop*, was the number of hectares of a specific crop type *i* within each watershed, and the denominator, *Cropland*, was the number of total hectares for all cropland in that watershed. A CDI score represents the probability that two randomly selected but adjacent hectares of land would be planted to different crops. A CDI score of 0 represents a zero chance that two adjacent hectares would have different crops as compared to a

[9] Broussard et al. (2012) use a modified Simpson's Diversity Index (Simpson, 1949) and use relevant cropland hectares for: barley, corn, cotton, hay, oats, rice, sorghum, soybeans, and wheat.

CDI of 1, which would mean a 100% chance of two hectares having different crops on adjacent hectares.

A second variable was included to measure the trend of the land coming out of pasture and grassland and shifting into crop production (Change in Cropland Pasture). This variable was constructed using Agricultural Census Data based on the percent change between 2002 and 2012 in total land designated as “cropland pasture.” The USDA defines cropland pasture as land in long-term crop rotation, which can also include hectares of crops that are hogged or grazed but not harvested. Additionally, land designated as cropland pasture could presumably be cropped without making land improvements (NASS, 2014a).

A third variable was developed (Marginal Soils) to assess whether the proportion of land in a watershed that is considered marginal might drive greater crop diversity at the farm level. This variable represents the percentage of the watershed that would be considered marginal. Marginal lands are determined by using the Natural Resource Conservation Services (NRCS) land capability class system with classes 1-4 considered arable and classes 5-8 as mostly suitable for pasture or rangeland. This variable was computed by summing the land capability class acreages for classes ≥4 for each county and creating a proportion of all marginal hectares in the county (Loy et al., 2013). Median values were then computed for the watershed.

Given that crop diversification can be considered to be a climate change adaptation strategy, a variable measuring the relative incidence of extreme weather at the watershed-level was included (Daily Precip). Daily Precip is a measure of extreme daily precipitation. Heavy precipitation events are counted as any day when the daily precipitation exceeded the 99th percentile of daily precipitation for a given month. We consider the proportion of days with precipitation exceeding the 99th percentile for the five-year period 2007–2011, which would be expected to be 0.01 by chance (Loy et al., 2013).

Table 2 A total of 4 level-two (HUC6 watersheds) independent variables were included in the multi-level analyses. The name of the variable, the associated description and the scale that the variable is measured on are also presented, along with information on data source(s). Descriptive statistics include mean and SD.

Variable	**Description**	**Scale**	**Mean**	**SD**	**Source**
CDI	Cropland Diversity Index	Probability	0.63	0.06	b
Change in Cropland Pasture	Percent Change from 2012 as compared to 2002 in total land in cropland pasture.*	Continuous	81.39	4.84	b
Marginal Soils	Percent of the watershed that would be considered marginal.	Continuous	0.17	0.16	d
Daily Precip.	Median values for extreme daily precipitation developed for each watershed.	Continuous	0.01	0.00	e

* All percent changes in cropland pasture were negative indicating that across each watershed there was a net decrease in total cropland pasture in 2012 when compared to 2002.
b. Data from NASS Census of Agriculture (NASS, 2014a)
d. Data for each county from SSURGO database (Loy et al., 2013)
e. Variable constructed using the National Weather Service Cooperative Observer data archive (Loy et al., 2013)

Qualitative data and analysis

Qualitative data were collected through semi-structured in-depth interviews with 159 farmers across nine states: Illinois (9 interviews), South Dakota (14), Missouri (16), Ohio (18), Indiana (20), Iowa (20), Minnesota (20), Michigan (20), and Wisconsin (22). Interviews were conducted during the spring and summer of 2013, which was a very wet cropping season, following a severe drought during the 2012 growing season, which follows the trend of more extreme weather experienced in the region (Pryor et al., 2014). Interviewees were large-scale farmers who primarily raise corn and soybeans. Participants were purposively recruited as part of the land grant extension and affiliated agricultural conservation networks in each state. A primary rationale for recruiting these farmers was to reach individuals who had some experience or familiarity with diversified rotations as well as other conservation practices (e.g., no-till, cover crops) and who may have surmounted barriers associated with these practices.

The interview protocol was developed as part of a multi-state research effort designed to examine climate change impacts to Corn Belt agriculture. For this study, we focused primarily on farmer responses to questions about crop diversification in the context of increased weather variability and whether they would consider diversifying their production system, primarily on land that they consider to be marginal (Table 3). Marginality was not defined for farmers; however, it was typically discussed as land that was less suitable for corn-soybean production because of diminished productivity and/or greater soil erosion potential. We focused our analysis on the conversations that related to farmers' consideration of diversified rotations.

Table 3 Select interview questions examined as part of this analysis.

Thematic Area	**Interview Questions**
Weather Variability	• Over the past five years or so, have you experienced any extreme weather that has adversely affected your farm operation? • Have these weather events changed your management practices at all? If so, how?
Diversity	• Let's think about your marginal field right now, or other marginal areas on your whole farm, and consider other uses that might be of value or interest to you. Would you ever consider changing your current cropping system on this field and if so, what are the types of things you have considered doing with this land? • Would you ever consider growing other row crops, fruits/vegetables, or converting marginal cropland to pasture for livestock?

The interviews were digitally recorded and transcribed verbatim. Analysis of interview transcripts was conducted in NVivo 10. Our analytical procedure utilized an iterative coding method following an open, axial, and selective coding procedure (Corbin and Strauss, 1990). Through an iterative coding procedure aimed at exploring constraints and possible facilitators of more diverse crop rotations, the data were eventually coded into two primary categories, which include "path dependency" and "rethinking the rotation." Further examination of these categories is explored in the results section. Theoretical memos were written throughout the coding process in order to explore the relationships between categories and to develop conceptual richness (Charmaz, 2006). As suggested by Prokopy (2011), direct quotes are included in order to increase transparency.

Results

Quantitative analysis

Utilizing a random intercepts model following a procedure to construct a MLM, we found that a few key level-one variables are associated with farmers' use of diversified rotations in their farming operations (Table 4). This random intercepts model allows for watershed variation in whether farmers use diversified rotations while introducing farmer-level and watershed-level variables that help to explain why differences might exist between farmers' use of diversified rotations across the 22 HUC6 watersheds. We assessed a best fitting model that explains most of the unexplained variation between watersheds (Appendix C). We found that farmers with cattle in their operations and those who farmed more HEL/ha were more likely to use diversified rotations. Those farmers who had positive attitudes towards diversified rotations as a climate change adaptation strategy were also more likely to use extended rotations on the land that they farm. The only negative relationship at the first-level of analysis is the relationship between farm revenue and a farmers' likelihood of using diversified rotations. In other words, farmers with higher revenues were less likely to use extended rotations on their farm.

Two-variables at the watershed-level were significant, including CDI and Change in Cropland Pasture. These results suggest that the presence of diverse cropping systems in a watershed, as measured in the CDI, had a very strong and positive influence on whether individual farmers use diversified rotations. However, the converse is true for

Change in Cropland Pasture, with a negative influence on whether farmers use extended rotations on their farm. This means that, as more land designated as Cropland Pasture is converted to crops, the less likely a farmer will have diversified rotations in their operation.

Table 4 Fixed effects are presented for the best fitting model, entries show parameter estimates (logit coefficients) and standard errors (SE).

Fixed Effects Model (n=2316)		
Variables	**Coefficients**	**SE**
Fixed Effects:Level-1		
Intercept	0.29**	0.10
Productivist	-0.18	0.10
Stewardship	0.04	0.07
AllCattle	0.34***	0.02
Crop Insurance	-0.01	0.02
Corn Markets	0.11	0.06
Water Concern	-0.04	0.07
HELOR	0.07**	0.02
DiversifyAdapt	0.36**	0.12
Alt. Markets	0.43***	0.07
Education	-0.04	0.04
Farm Revenue	-0.24**	0.07
Fixed Effects: Level-2		
CDI	5.92**	2.17
Change in Cropland Pasture	-0.08***	0.02
Marginal Soils	0.57	0.94
Daily Precip	63.62	46.67
***p<.05, **p<.01, ***p<.001**		

Qualitative analysis

Farmer interview participants were broadly similar to farmers in the Corn Belt region. However, on average, participants had fewer cropland hectares, with an average of 281 hectares, compared to the region.[10] Most farmers grossed between US$250,000-$500,000 and almost all had at least some college education. Around a third had cattle in their operation. Many of these farmers had some diversity in their farms (e.g., inclusion of wheat or alfalfa in the rotation or woodlots and conservation reserves) but on the

[10] The Economic Research Service estimates that the midpoint acreage for farms in the U.S. is greater than 445 hectares, with the largest increases in farm size occurring in the U.S. Corn Belt. The average farm size estimates for the Corn Belt is approximately 192 hectares but this number is misleading due to the large number of small farms that are not actually managing the majority of cropland area.

whole, these farmers were recruited because they produce corn and soybean as a large percentage of their operation.

The two categories developed through the qualitative analysis are *Path Dependency* and *Rethinking the Rotation* (Table 5). Path dependency reflects a system that has become “dominant and self-reinforcing” (Chhetri et al. 2010, p. 895) where integration of alternative crops can be difficult because the technological trajectory of the conventional agricultural industry reinforces and perpetuates a corn-corn and corn-soybean rotation with attendant markets, technology, and infrastructure. The path dependency category has four sub-categories that were coded under the broader category of path dependency because they represent different ways that path dependency has manifested in farmers’ consideration of more diverse crop rotations. These subcategories include lack of markets, loss of livestock, high land costs, and responses to weather related risks.

The second theme explored is the concept of rethinking the rotation, where farmers discuss the benefits of extending the rotation despite the fact that they feel constrained by the current system of production in the region. In the context of the interviews, farmers discussed extending the rotation through their use of specific crops, including cover crops (30), hay/other grasses (28), small grains (27), wheat (24), and alfalfa (20) (the number of farmers discussing each crop type included in parentheses), in addition to more general discussions about the need for a “third or fourth crop” in the rotation.

Table 5 Key qualitative categories/subcategories are presented with the total number of farmers discussing the item (out of 159 farmers), a category description and an illustrative quote.

Category/Subcategory	**No. of farmers discussing**	**Description**	**Quote**
Path Dependency	100	Discussions of the ways that the corn-based system predominates, which limits adoption of diverse crop rotations	We used to rotate, years ago, with oats. Our potato rotation was potatoes, oats, and alfalfa. And the alfalfa, we would plow down…But [now] we just don't. And corn is king, unfortunately. (WI farmer)
-Lack of markets	61	Discussions of how markets are a major limiting factor in extending the crop rotation	Well, if small grains were more competitive and viable, I would put those in the rotation. Beyond that, you know, maybe a little more conservation minded but, right now, they don't compete. They just don't compete. Even soybeans don't compete right now. That's why you see so much corn. (MN farmer)
-Loss of livestock	24	Discussions of the ways that livestock have disappeared from farms or from regional cropping systems in general	We farrowed to finish, too. And we were better off financially and from an environmental standpoint in just taking care of our resource that we'd been given…Now, you live or die by two crops. And, ultimately, I don't feel that this is sustainable. (WI Farmer)
-High land costs	19	Discussions about the high costs of land, particularly rented land which has driven farmers to produce more corn and soybean due to historically high prices	I only own 40 acres and the rest of it is all rented and so much of it is, you know, the landlord has to be on board for that. So I have one piece right now that there's a corner that I cannot get into almost every single year. I cannot plant it cause it's too wet and I approached him about, hey, let's just put an acre into CRP here. And he goes, oh, no, we don't need to do that. You know? So he'd rather get my [money for] an acre of rent on that one from me. (MN farmer)
-Weather related risks	12	Farmers discussing diversifying the crop rotation specifically as a response to more variable and extreme weather	Oh, climate [change]… I'm more excited about it. I mean, I'm planting barley…and, you know, do I double crop? If I can take advantage of the change in climate, that's great. I'm trying to experiment and find out how to do that. (IN Farmer)
Rethinking the rotation	42	Farmer discussions of interest in changing their crop rotation, despite not always having a clear idea about what the rotation might be	A long-term goal of mine would be diversity…I was having a hard time thinking of another crop to grow on my marginal land. Well is there some kind of diversity that I haven't even have thought about for my farm that would make it productive? (OH Farmer)

Path dependency

Through the in-depth discussions with farmers, many of them touched on the notion of path dependency and how it manifests in ways that constrain their ability to integrate more crop diversity in their farm systems. Farmers often discussed that diversifying their crop rotation was in conflict with what they saw as a trend towards increased specialization with an emphasis on structural drivers that facilitate corn-corn and corn-soybean rotations. Many farmers noted that they had grown up in a very different system of production, as expressed by an Iowa farmer who contrasted the current system of big equipment and animals in confinement with "the diversified ag which I grew up on, with the couple hundred acres and diversified, hogs, cows, that kind of stuff." Path dependency affects the ways that farmers think about the economic viability of alternative crops. This is clarified in a statement made by a South Dakota farmer,

> People respond to the economics of things. And so, you know, why is wheat grown in more arid areas. You know? It's because of the economics of that area, their cost of land, their cost of input and things of that sort. And so, in some ways, you'd like to use more crops in the rotation. From a pure economic sense, I'm probably using more crops in the rotation than I should. You know?

However, farmers were also interested in diversifying their crop rotation as a way to mitigate financial risks, expressed by a farmer from Wisconsin who said,

> Monoculture cropping systems, I do believe will, invariably, fail. And we need to have more research into diversifying our cropping mix. When you look at the European model of farming, it's so much different than [ours]… But a lot of European farms are very well diversified... I mean, that they're revenue sources are multiple compared to the standard corn/soybean farmer in the United States who has two shots at income.

This farmer expressed an important reflection on the limitations of the current cropping system that privileges corn and soybean commodity production that has real economic impacts on farmers' ability to generate diverse streams of revenue from their farm operation.

This discussion of path dependency manifested in many aspects of the in-depth interviews with farmers, with specific focus on the way path dependency affects the availability of diverse markets that farmers are able to access, whether or not they choose to integrate livestock, how they make decisions in the context of high land costs, and finally, path dependency has affected the ways that farmers respond to increased weather variability on their farms.

Lack of markets

Many farmers discussed the lack of markets for alternative crops that would be used to extend their rotation. One South Dakota farmer noted, that "Actually, I would love to grow other crops. I mean, I would love to have more than two crops in rotation." However, this farmer noted that limited markets and lack of economic profitability prevented them from growing other crops. Multiple farmers noted that markets for wheat, canola, and hay had disappeared from their region. One farmer from Minnesota said, "I would consider alternative crops. I've tried wheat. Unfortunately, our market here's almost nonexistent…Plus, wheat doesn't return as much as corn and soybeans." In this way, many farmers talked about the alternative markets as possibilities but typically noted that they are not economically viable, especially with high prices for corn and soybeans.

While lack of markets, in general, was typically discussed in the context of barriers to extending the rotation, some farmers were very specific about the potential for biomass (e.g., poplars, switchgrass) markets, which are currently very limited. This point is well articulated by an Indiana farmer who said, “I don't see a market for the things that I can use that farm for in a one-year cash flow term that would be beneficial to me or my family at this time. Now there may be things down the road with cellulosic ethanol, you know?” A number of farmers expressed interest and expectations for a future cellulosic (e.g., wood or grass-based feedstock) ethanol market that would allow for more diverse crop rotations yet most did not believe these markets were currently available, at least in the short-term. This is articulated by a Michigan farmer who said, “If switchgrass came into effect and we were growing it and baling it and hauling it into a place to have it turn into an energy source, I would do it if it's profitable. But currently, it's not there.”

Loss of livestock

Around half of the farmers who discussed the theme of path dependency focused specifically on the loss of crop/livestock integration as a large reason why there are fewer crops in their rotation and less pasture in their operation or in the region as a whole. Farmers typically discussed how their farm had once had livestock but they often describe that they are now just “crop farmers” and indicated an unwillingness to go “back in time.” Others noted that more diversified rotations would be more feasible if they still had livestock in their operation. This is expressed by a farmer from Illinois who said that some of their land “used to be pasture but, the profitability of livestock and the [financial] risk of livestock has just been increasing so much that, you know, that the livestock part of it has disappeared.” Another connected theme that came out of the discussion of loss of livestock was the idea that once farmers had improved their land (e.g., through tile drainage, irrigation) for crop production that it was no longer suitable for livestock production. This is articulated by a Michigan farmer who said, “We have a beef [feeding] operation… I have daughters that wanted me to turn some of this land into pasture but I don't tile [drain] ground to turn it into pasture."

Some farmers' noted that through specialization and loss of crop/livestock integration, they have lost some of their financial resilience, according to a Wisconsin farmer, "We farrowed to finish, too. And that we were better off financially and from an environmental standpoint in just taking care of our resource that we'd been given…Now, you live or die by two crops. And, ultimately, I don't feel that this is sustainable." Farmers consistently expressed the challenge of making diverse rotations in an era where "corn is king" across the region and therefore livestock integration no longer made much financial sense in their operation.

<u>High costs of land</u>

Farmers occasionally brought up high costs of production as limiting their use of extended rotations. In particular, the high cost of land was most commonly discussed in relation to markets for cropland rental (sometimes referred to as "cash rents"). Farmers suggested that the crop produced on their rented land needs to be profitable on a yearly basis in order to pay cash rents. This is emphasized by an Iowa farmer who said, "Rent keeps going up and [you] can't afford to put hay ground on rented ground." This is further affirmed by a farmer from South Dakota who expressed a desire for a more diversified crop system but the barrier of high land costs, accompanied by the challenge of limited markets, constrains his choices,

> I would like to include a small grain crop in the rotation so I can better use cover crops. But, at this point in time, I don't think that that's practical from an economical point of view. I mean, we look at our land costs and, you know, the cost of buying land and the returns from the different crops and so on and, frankly, the other way I've considered it is, and I haven't done it, but [is to] go to a monocrop… to a continuous corn [system].

The conversation about high costs of land, in some cases, was tied directly to the conversation about what landlords might want to see on their rented ground. This often led farmers to focus on maximizing annual profits/hectare, which can facilitate a corn-corn rotation because of the historically high prices for corn commodities in recent years. A farmer from Illinois, when discussing his rental ground, said that “you push the pencil and do the math on your corn and, you know, in most cases, corn on corn on dark dirt usually pencils out to be the way to go”, when he was trying to articulate the tension between profitability and what he thinks may be better for the land that he farms. This farmer was actually talking about trying to integrate soybeans into his rotation but felt that corn-corn was the most economically sound choice. In this way, farmers may want to extend their rotation yet they find that they face financial challenges if they shift too far away from a corn-corn or corn-soybean rotation.

<u>Responding to weather related risks</u>

A smaller group of farmers discussed diversified rotations as a viable strategy for responding to increased weather variability. Often farmers discussed this in the context of changing climate patterns, where they envision a time where they will be producing different crops, according to an Illinois farmer, “maybe I'll start [growing] wheat. You can't grow wheat here now…Maybe [in the future] we'll be growing more wheat. Maybe the climate will change.” However, a number of them discussed minor modifications that they had made due to recent weather events, including planting soybeans instead of corn due to the late spring rains or planting wheat during dry years. In general, increased weather variability did not appear to influence farmers to shift their production far beyond the corn-soybean system. Most farmers noted that increased weather variability might encourage them to plant soybeans instead of corn in certain years, according to a Wisconsin farmer who said, “we might have a few more beans in the rotation so that we [have] less acres of continuous corn.”

Overall, very few farmers discussed extended crop rotations as a way to minimize climate related risks, focusing instead on soil and water conservation practices that they might use to maintain the profitability of their current system. However, the use of cover crops was a clear strategy for diversifying the rotation and conserving soil resources that some farmers saw as a way to integrate greater diversity in their cropping mix while also mitigating risks from more extreme weather events. According to a South Dakota farmer, extreme weather events are encouraging them to think more about integrating cover crops, particularly if they can help protect their soil resources, “I would guess that means bigger rainfall events so the impetus to keep soil in place and to do cover crops is probably going to be something that we're going to have to pay much more attention to.”

Rethinking the rotation

Farmers discussed the need for moving beyond the corn-soybean rotation and lamented the fact that diversified cropping systems had largely disappeared. Some reflected on the fact that specialization has not always been a good thing for the health of farmland, particularly with impacts on soil resources, as explained by an Iowa farmer,

> I think that our intense cropping situation has more of an adverse effect on our conservation than anything else. Growing up, everybody had livestock and there was a lot more hay and oats and things like that to…[which helps to] keep the soil where it belongs.

Many of the farmers who value diversity already have more diversified rotations but many were discouraged by the fact that the current system is overly focused on corn and soybean commodities, according to a Minnesota farmer, “I'd like to see more crops in a rotation. I'd like to see more food-producing crops rather than commodity crops that are not necessarily used directly for food." In general, farmers who discuss benefits of diversity also articulated the challenge of making tradeoffs with the benefits of crop diversity and profitability. According to a Michigan farmer, "I think that [more diverse rotations] would be a helpful thing to this farm but, acres per dollars, that type of thing, right now [with the low] profit margins and so…we're bringing in more [land] with the corn-soybean rotation."

Some farmers found that integrating a more diverse rotation would help them to achieve broader conservation goals for their farms, noting that more diversified rotations have multiple benefits. However, a number of farmers struggled to determine an alternative crop that might work in their rotation. According to an Iowa farmer, determining how to integrate more diversified rotations without livestock is challenging to resolve,

> If I was starting over again…I would probably go back to more of a 3-way rotation. Years and years ago, like I told you, we used to have a lot of hay and oats. And most livestock guys still have that same system. I always thought that if we had like corn, beans, and wheat or something like that to help break up the cycle more, that it would be better for the environment. But what's that third thing going to be? Third or fourth thing? There are people out there that do that. But, what should I say, unless you're a livestock person, then you're not going to probably break up your rotation to that extent.

A number of farmers realize that the corn-based cropping system is flawed, particularly a system of continuous corn production that has done away with rotations altogether. Some farmers argue that this intensive monoculture system causes environmental and economic challenges but most are uncertain about potential alternatives and whether they could diversify their cropping system and still maintain productivity and profitability of their farm enterprise. A farmer from Ohio expressed this challenge well,

> A long-term goal of mine would be diversity. Just like there, I was having a hard time thinking of another crop to grow on my marginal land. Well, you know, is there some kind of diversity that I haven't even have thought about for my farm that would make it productive?

Farmers expressed an interest in diversifying their rotation yet they struggled with identifying viable crop alternatives. Some farmers found it difficult to imagine greater cropping systems diversity in their corn-based cropping system despite a general interest in extending their rotation.

Discussion and Conclusion

This study sought to better understand what social, economic, and environmental factors, at the individual and watershed-scale, influence the use of extended rotations. We found that a number of farmers in more diversified watersheds and those with livestock are more likely to use diversified rotations. Additionally, farmers who see diversification as an important risk mitigation tool in the context of climate change were more likely to use diversified crop rotations. Farmers also discussed how path dependency on the current corn-soybean cropping system and subsequent trends towards increased specialization has presented multiple challenges. Yet, farmers in the Corn Belt appear to value the benefits of extended rotations yet are limited in their ability to find economically viable alternative crops to include in their rotation. Finally, farmers who see diversification as an important risk mitigation tool in the context of climate change were more likely to use diversified crop rotations on their farms.

Findings suggest that watershed-scale diversity matters. In particular, the significance of the Cropland Diversity Index suggests that as more individuals within a watershed have greater crop diversity, the more likely it is that an individual farmer will use extended rotations. However, it is unclear as to what precisely is driving this. Greater diversity at the watershed level may facilitate extended crop rotations due to the presence of alternative markets (e.g., small grains or more livestock). However, environmental factors, such as topography, slope, soils and climate, may also be driving regional differences. The quantitative analyses yielded information about the influence of highly erodible land on the likelihood of farmers using more diversified rotations; however, the qualitative results illuminate the reality that many farmers have found ways to make marginal land (e.g., HEL) more productive for corn-soybean production through changes to their management practices (e.g., adding tile drainage or implementing conservation practices). Cutforth et al. claim that "ecological constraints are more important than economic and social constraints [in predicting the use of extended rotations] at the landscape or watershed scale of the agricultural system" (2001, p. 174). Our findings, however, suggest that while environmental factors are important, path dependency associated with the dominant productivist system of agriculture in the region, which influences economic and social institutions, also constrains a farmer's ability to diversify their crop rotation.

Findings, particularly from the qualitative analysis, suggest that many farmers value the benefits of a more diversified crop rotation but structural constraints make integrating diversity more difficult. Both analyses affirm the importance of livestock in facilitating the use of diversified crop rotations yet the regional trend continues to shift away from crop/livestock integration with more focus on feeding animals in confinement operations (MacDonald et al., 2013; Stuart and Gillon, 2013). Our qualitative analysis suggests that financial incentives that encourage alternative cropping systems, such as markets for biomass or small grains, might enable farmers to incorporate more diverse rotations on their farms; however, given the high costs of production, particularly high cash rents, and the need for yearly profitability, these incentives will need to be competitive with commodity and cropland rental markets. The recent downturn in prices for corn and soybean in global markets may affect the feasibility of alternative crops, which might provide farmers with an opportunity to experience the financial and environmental benefits of a more diversified cropping system over time (Davis et al. 2012).

Based on both qualitative and quantitative analyses, some farmers acknowledge the benefits of diversifying their crop rotation as a way to mitigate weather related risks. For farmers who already use diverse crop rotations, they may be more likely to use extended crop rotations as a strategy for responding to future climate changes. Whether farmers who are currently not using extended crop rotations plan on adopting more diverse crop rotations in response to increased weather variability is unclear. The results of the qualitative data suggest that weather events are not a major driver for greater crop diversity, perhaps because farmers are locked into a path dependent system, which affects the financial viability of alternative crops. Overall our findings provide evidence that the use of more diverse crop rotations are not likely to be encouraged by climatic factors alone, much like Bradshaw et al. (2004) found in their study of diversified rotations in the Canadian Prairie.

Despite the rich data that we had available for this study, it continues to be a challenge to get the “right” data, measured at multiple scales that can capture complex social, political, economic, and environmental dynamics occurring across different spatial and human-institutional scales. Further research should parse out the drivers at more macro-levels, particularly if they can identify economic and policy-level drivers that facilitate diversification, particularly in the context of increasingly variable weather. Comparative efforts could also look at larger regions, comparing watersheds in the United States to examine trends across different cropping systems.

Those calling for greater cropping system diversity suggest that greater diversity will help to build greater agroecosystem resilience (Lin, 2011; Davis et al., 2012) and can also help to reduce the “leakiness” of the Corn Belt by reducing negative environmental impacts to water quality (Broussard and Turner, 2009; Porter et al., 2015). Additionally, greater diversity in the crop rotation can reduce risks associated with uncertain future environmental conditions (Jackson et al., 2010) and may also have a positive impact on farm communities and rural infrastructure (Brown and Schulte, 2011). These diversified systems may provide a pathway for integrating more livestock into the agroecosystem (Davis et al., 2012), which is likely to build resilience in the face of a more extreme climate regime (Hatfield et al. 2014). However, our findings suggest that integrating greater crop diversity in the region will be very difficult due to challenges with reversing the trend towards specialization and subsequent field- and landscape-scale homogeneity, particularly with the concomitant loss of crop and livestock integration and the loss of land designated as cropland pasture. Therefore, if facilitating more diversified cropping systems and preventing further landscape-scale cropping systems homogeneity is an important goal then social, political, and economic structures will need to be adjusted to encourage greater crop diversity at the farm-level.

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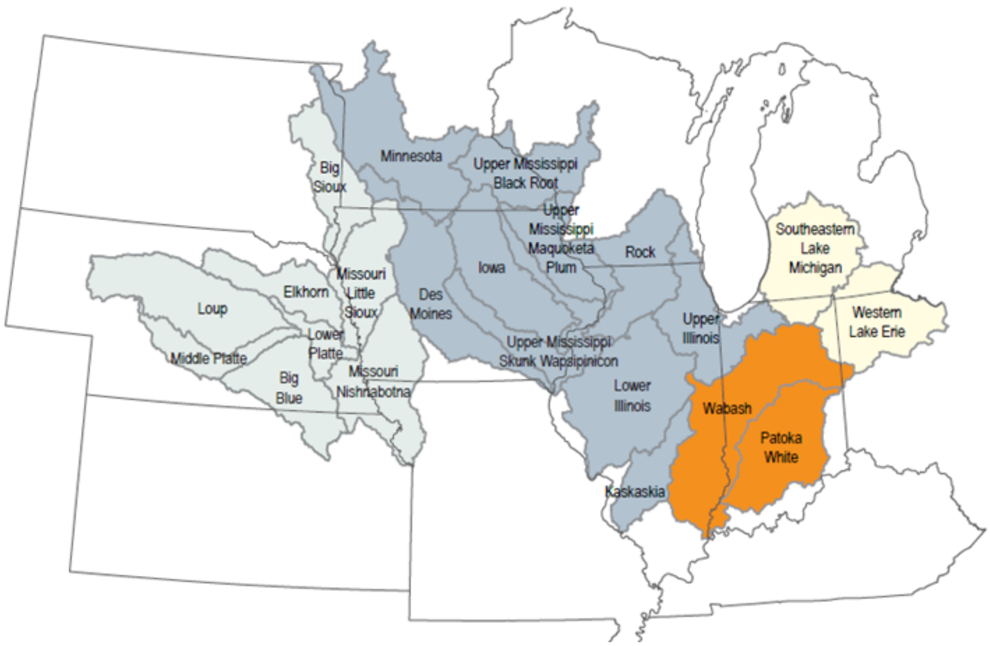
Appendix A

Map of 22 HUC6 watersheds examined in study



Watersheds were sampled from four Water Resource Regions (WRR) and HUC6 five-digit code:

Great Lakes WRR	Southeastern Lake Michigan (40500); Western Lake Erie (41000)
Ohio WRR	Wabash (51202); Patoka-White (51202)
Upper Mississippi WRR	Minnesota (70200); UM Black Root (70400); UM Maquoketa (70600); UM Skunk (70801); Iowa (70802); Rock (70900); Des Moines (71000); Upper Illinois (71200); Lower Illinois (71300); Kaskaskia (71402)
Missouri WRR	Big Sioux (101702); Middle Platte (102001); Lower Platte (102002); Loup (102100); Elkhorn (102200); MO Little Sioux (102300); MO Nishnabotna (102400); Big Blue (102702)

Appendix B

A confirmatory factor analysis was conducted to develop productivist and stewardship identity constructs. The survey question was measured on a 5 point Likert scale (1=Strongly Disagree, 5=Strongly Agree). The survey question and the standardized factor loadings are provided. A partial information estimator was used to develop the factor scores due to the ordinal nature of the response variables.

Factors	**Question/Statement**	**Standardized Factor (Lamda) Loading**
Productivist Identity	A good farmer is one who has the highest yields per hectare	0.58
	A good farmer is one who gets their crops planted first	0.56
	A good farmer is one who has the highest profit per hectare	0.60
	A good farmer is one who has the most up-to-date equipment	0.68
	A good farmer is one who uses the latest seed and chemical technology	0.68
	A good farmer is one who maximizes government payments	0.54
Stewardship Identity	A good farmer is one who considers the health of streams that run through or along their land to be their responsibility	0.70
	A good farmer is one who minimizes erosion	0.74
	A good farmer is one who minimizes nutrient runoff into waterways	0.76
	A good farmer is one who thinks beyond their own farm to the social and ecological health of their watershed	0.77
	A good farmer is one who maintains or increases soil organic matter	0.76
	A good farmer is one who minimizes the use of pesticides	0.58
	A good farmer is one who manages for both profitability and minimization of environmental impact	0.76
	A good farmer is one who scouts before spraying for insects/weeds/disease	0.66
	A good farmer is one who puts long-term conservation of farm resources before short-term profits	0.67
***Fit statistics for confirmatory factor model with two latent constructs (Productivist Identity and Conservationist Identity): Chi-square fit index (0.380, d.f. 89, p-value >0.995); RMSR value 0.0523; AGFI value 0.963). All indicate good fit, including no standardized residuals over 1.96.**		

Appendix C

The outcome from the null model is simply a partitioning of variation to between and within-level components. For the null model (see Model A in Table C.1) the intra-class correlation (ICC) value of 0.09 indicated that about 9% of the variation in on-farm diversification is between watersheds, with the remaining ~ 90% explained by factors at the individual farmer-level. While this value is not very large, there is a statistically significant amount of variability ($z= 3.125$, $p<.05$) suggesting that whether or not a farmer uses diversified rotations on his/her farm does vary across watersheds. A second model, Model B, was run using only level-one variables with a random intercept and no level-two variables. For this model, we assess an ICC of 0.11, which is also significant ($z=2.96$, $p<.05$) with slightly more unexplained variability between watersheds with the inclusion of the 11 independent variables. After conducting a likelihood ratio test, we find that Model B is a much better fitting model as compared to Model A (X^2 of 3,435.99, d.f. 11, $p <.001$). Finally, a third model was developed by including level-2 variables (measured at the watershed-level) that best explain the variability between watersheds. This model, Model C, has an ICC of 0.04, which is still significant ($z=2.42$, $p<.05$). This significance suggests that there may be some, albeit minimal, between-watershed variation in the estimated parameters after controlling for watershed-level variables. Comparing Model C with Model B, we have improvements in model fit (X^2 of 58.48, d.f. 4, p.<.001). We assess that the final model, Model C, explains a total of 9% of the variation at the watershed level with a total of 88% of unexplained variance still unaccounted for at the individual farmer level, which accounts for almost all of the unexplained variance at the watershed level (values approximate a Pseudo R2 based on the method developed by Snjiders and Boskers, 2012).

Table C.1 Multi-level model comparisons are made by providing error variance, the intraclass correlation coefficient (ICC) and the -2Log Likelihood

Multi-level model comparison			
Model fit parameters	**Model A** **Null Model- random intercept only**	**Model B Level-1 variables only w/ random intercept**	**Model C Level-1 and Level-2 variables**
Error Variance			
Level-2 Intercept	0.33	0.40	0.13
ICC	0.09*	0.11*	0.04*
Model Fit			
-2Log Likelihood	6267.06	2831.07**	2772.59**
*p<0.05 ** X^2 likelihood ratio test significant at p<0.05			

CHAPTER 5.

CONCLUSIONS

A farmer from Iowa, when discussing his beliefs about climate change and how this might alter his practices said,

> I think there's considerable reasons to believe the scientists that have studied it [climate change] that we are in for some greater variability in our weather than, perhaps, we've experienced over the last 50-100 years or whatever. While we don't know exactly what's going to happen, that some of these extreme events give us a signal that we need to plan our rotations and our practices to build that resiliency into the soil.

This farmer highlights that many farmers in the U.S. Corn Belt are already experiencing more extreme and variable weather, through bigger storm events and longer periods of drought (Melillo et al., 2014). For some of these farmers, these events provide a signal to re-orient their production towards greater conservation, starting with preserving and enhancing soil resources through adoption or increased use of reduced tillage and no-till systems, cover crops, and extended rotations (Chapter 3).

This research effort examined farmer adaptive decision making in the context of more extreme and variable weather (Chapter 2, 3, and 4) while also exploring how farmers intend to respond to climate change (Chapter 2 and 4). Important questions remain as to whether farmer adaptive strategies might reduce vulnerability and build resilience in the Corn Belt agroecosystem if implemented by more farmers across a larger percentage of the cropping area (Chapter 2 and 3). I found that farmers' current use of conservation and production practices will have a strong influence on what they intend to do in response to a changing climate (Chapter 2 and Chapter 4). However, further use and adoption of adaptive strategies may be less likely to occur particularly if the broader social, political, and economic context does not incentivize their use (Chapter 4; Smit and

Skinner, 2002). My findings thus illustrate that mitigating weather related risks is only one aspect of farmers' motivations for shifting their production practices (Chapter 2, 3, and 4).

Generally, farmers are fairly confident in their ability to respond to and mitigate weather related risks (Chapter 2 and 3); yet their adaptive response may not lead to the kinds of transformation that might be necessary to build more resilient agroecosystems in the Corn Belt (Chapter 3 and 4). I found that farmers are constrained by path dependency on a corn-based cropping system, often driven by the logic of the treadmill of production (Cochrane 1958; Gould et al. 2004), which greatly limits their options for diversifying their cropping systems (Chapter 4) or shifting their production systems to better balance profitability with conservation goals (Chapter 3). However, preserving and enhancing the soil, via greater soil stewardship, suggests that soil may act as a social-ecological feedback that enables farmers to take adaptive action to mitigate weather related risks while helping them to resolve tradeoffs between short-term profitability and longer-term resilience (Chapter 3).

The findings from this dissertation research point towards some policy and outreach recommendations which might serve to improve climate change adaptation approaches in the Corn Belt, in addition to encouraging greater use and adoption of adaptive strategies that have key soil and water conservation benefits. Key recommendations from this study include:

- Farmers plan to respond and are already reacting to more extreme and variable weather on their farm. Therefore, it is recommended that outreach efforts that emphasize adaptive strategies should highlight the ways in which different conservation and production practices (e.g., no-till, cover crops, extended rotations) can help farmers to reduce weather related risks on their farm. This will be particularly helpful in communicating about climate change adaptation in a way that more effectively communicates risks and vulnerabilities associated with climatic changes by emphasizing weather related risks rather than climate change per se. This compliments other research that suggests that outreach and education with farmers should de-emphasize the discussion of anthropogenic climate change due to the fact that many farmers do not believe that climate change is human caused (Morton et al. 2016).

- Farmers indicate that they are fairly confident in their ability to adapt to weather related changes on their farm and many have the capacity to adopt practices that will encourage greater on-farm resilience. This provides evidence that outreach efforts focused on farmer adaptation should build on farmer confidence and capacity to adapt.
- A greater soil stewardship ethic, via farmers' evolving relationship to their soil resources through the use and adoption of soil and water conservation practices, provides an avenue for communicating to farmers about how they might build greater agroecosystem resilience on their farm. However, efforts to meet both production and conservation goals can be difficult given the increasing costs associated with row-crop production in the U.S. Corn Belt; therefore, policy efforts to incentivize a soil stewardship ethic, and associated soil conservation practices, should encourage new markets for soil ecosystem services or other

financial incentives that encourage greater soil stewardship to provide long-term benefits to farmers and to society more broadly.

- Farmers have expressed an interest in and a willingness to diversify their crop rotations yet there are real systemic barriers that make it difficult for farmers to integrate more cropping systems diversity on highly specialized farms in the U.S. Corn Belt. Further policy efforts aimed at incentivizing markets, infrastructure, and/or crop and livestock integration may be an effective way to encourage more farmers to extend their rotation.

Despite the contributions of this dissertation, further research is needed to better understand farmer decision making in the context of a changing climate and the complex interplay between climatic and non-climatic forces and conditions (Smit et al. 2000). Specifically, some important areas for further inquiry emerged as part of this research effort:

- Further research should examine the relative influence of climatic and non-climatic factors that confound adaptive decision-making, such as improving our understanding of how farmers manage the challenge of “inter-periodic variability,” or the difference between weather and climate (Bradshaw et al. 2004) and how this may interfere with purposeful and planned adaptation efforts.
- Further development of a conceptual framework is needed to test whether farmers’ changing relationship to the soil, as a social-ecological feedback, might resolve tensions between economic goals and the goal of preserving as well as enhancing soil resources.

- Multi-scale research should further examine what factors will incentivize more diverse cropping systems in highly specialized conventional agricultural systems, particularly if cropping systems diversity is a priority for climate change adaptation. Further, we need to build better models that connect individual-level drivers at the farm-scale with more macro-level policy and economic influences at broader landscape and human-institutional scales to better understand factors and conditions that influence farmer adaptive decision making.
- Future research should build on interdisciplinary efforts that seek to couple social and biophysical research with farmers that will enable evaluation of potential impacts associated with adaptive actions taken at the farm-scale while making predictions about how these might scale up at the landscape level (e.g., watershed-level) and over time.

Climate change may drive greater transformation of the agricultural system but whether these changes "succeed in moderating harm or exploiting beneficial opportunities" must be evaluated over time (Moser and Ekstrom 2010:22026). A transformation of the Corn Belt agroecosystem will likely require a shift towards a more multifunctional agriculture, one that provides for a more diverse array of ecosystem services (Robertson and Swinton 2005) that have benefits at the farm and landscape scale. Climate change along with other environmental, social, political, and economic factors will likely drive changes in agricultural practices. According to a farmer we interviewed in Indiana, these changes will require a fundamental shift in agricultural production in the future, which prioritizes greater stewardship of on farm soil resources.

> If we were to farm this land that we've been given, that's been given to us for the next 100 years, as it has been farmed and cultivated for the previous 100 years, then we are

> going to diminish this natural resource that we've been blessed with such fertile soil in this part of the world, to a level of depletion and, not only drain the farm itself of nutrients and the production level that it has but we are also complicating our rivers and hypoxia in the Gulf of Mexico and all these things that I think that, as stewards of the soil, we should prioritize on making that [greater soil stewardship] a very important thing.

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"To cherish what remains of the Earth and to foster its renewal is our only legitimate hope of survival." –Wendell Berry

Cherishing the earth and working to assure the preservation of ecological systems and the human communities that work and live within them is what propels my work. John Bellamy Foster, in his work on the Ecological Rift, argues that the "planet is now dominated by a technologically potent but alienated humanity ―alienated from both nature and itself." This alienation is arguably the cause of much ecological destruction and conflict in human society. My deep desire to better understand coupled social and ecological systems, particularly in intensively managed agroecosystems, compelled me to pursue a degree in Sociology and Sustainable Agriculture at Iowa State University. However, I never would have made it here if it hadn't been for Dr. John C. Tyndall and Dr. J. Gordon Arbuckle's encouragement and ongoing mentoring. Mentoring, as I have learned and reflected on over the course of the last four years, is a complex and difficult task, one that most academic faculty never receive formal training in. John and J. however, have risen to the challenge of mentoring me, which at times, could not have been easy! In particular, they were able to integrate constructive criticism with humor, creativity, and compassion, while always pushing me forward. They encouraged me to take on leadership efforts while always reminding me to stay focused on my research. My dissertation research and subsequent career will forever be influenced by their mentoring.

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I understand that this is just the beginning and I look forward to contributing my life's work in pursuit of increasing the resilience of social and ecological systems in an era of anthropogenic climate change and taking the road, as Rachel Carson noted, less traveled.

"We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road — the one less traveled by — offers our last, our only chance to reach a destination that assures the preservation of the earth" –Rachel Carson

APPENDIX 1.

FARMER SURVEY

Agriculture and Weather Variability in the Corn Belt

Photos courtesy of L. Abendroth and J. McGuire

Thank you for filling out our survey. The information gained through this survey will help Extension, university researchers, crop consultants, agribusiness, and others to develop tools and strategies that better serve farmers across the Corn Belt.

We are interested in learning about management of both owned and rented farmland, so many of the following questions ask you to consider both types of land. If you do not rent (or own) land, just skip the parts of questions that do not apply. *Please answer all the questions that apply to your operation.*

Your participation is very important. We appreciate your willingness to share your experiences and opinions. Thank you!

Sincerely,

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Considering the farmland that you <u>own</u> and <u>rent</u>, please answer the following questions. ***(Please select one answer each for owned and rented land, if applicable.)***

	Owned Land		Rented Land	
	Yes	**No**	**Yes**	**No**
1. Over the past five years, have you experienced significant drought on the land you farm?	1	2	1	2
2. Over the past five years, have you had problems with saturated soils or ponding on any of the land you farm?	1	2	1	2
3. Do any creeks, streams, or rivers run through or along any of the land you farm?	1	2	1	2
4. Over the past five years, have you experienced significant flooding (stream/river) on any of the land you farm?	1	2	1	2

5. **The following are problems that some Corn Belt farmers have experienced over the past few years. How concerned are you about the following potential problems for <u>your farm operation</u>?** ***(Please circle one number on each line.)***

	Not Concerned	Slightly Concerned	Concerned	Very Concerned
a. Increased flooding	1	2	3	4
b. Longer dry periods and drought	1	2	3	4
c. Increased weed pressure	1	2	3	4
d. Increased insect pressure	1	2	3	4
e. Higher incidence of crop disease	1	2	3	4
f. More frequent extreme rains	1	2	3	4
g. Increases in saturated soils and ponded water	1	2	3	4
h. Increased heat stress on crops	1	2	3	4
i. Increased loss of nutrients into waterways	1	2	3	4
j. Increased soil erosion	1	2	3	4

6. In 2011, approximately what percentage of the land (owned and/or rented) you farmed was…
(Please write an approximate percentage. If none, please write "0".)

	Owned Land	Rented Land
a. artificially drained through tile or other methods	%	%
b. irrigated	%	%
c. highly erodible land (HEL) that was planted to crops	%	%
d. reduced tillage (e.g., strip, ridge tillage)	%	%
e. no-till	%	%
f. planted to cover crops	%	%

7. Considering the farmland that you *own* and *rent*, are the following practices and strategies currently used? If not, please indicate whether or not you are familiar with the practice.
(Please check all that apply.)

	Used on Owned Land	Used on Rented Land	Familiar with, not used	Not familiar with
a. Grassed waterways	❒	❒	❒	❒
b. Contour grass buffer strips	❒	❒	❒	❒
c. Filter strips of grass/trees next to waterways	❒	❒	❒	❒
d. Field borders of grass/trees	❒	❒	❒	❒
e. Windbreaks and shelterbelts	❒	❒	❒	❒
f. Terraces	❒	❒	❒	❒
g. Restored or constructed wetlands	❒	❒	❒	❒
h. Whole/portions of crop fields converted to grass or trees	❒	❒	❒	❒

i. Cover crops	❒	❒	❒	❒
j. Reduced tillage (e.g., strip, ridge tillage)	❒	❒	❒	❒
k. No-till	❒	❒	❒	❒
l. Diversified rotations that include small grains, forages, or other crops	❒	❒	❒	❒
m. Nutrient management (e.g., testing soil, manure, and/or plant tissue to determine fertilizer rates)	❒	❒	❒	❒
n. Integrated pest management (e.g., managed use of resistant varieties, scouting and considering pest thresholds before spraying)	❒	❒	❒	❒
o. Irrigation efficiency best management practices (BMPs)	❒	❒	❒	❒
p. Use of control structures to drain and store water depending on crop needs and soil conditions (“drainage water management,” not just tile drainage)	❒	❒	❒	❒
q. Precision agriculture using technology such as GPS, GIS, and variable-rate technology	❒	❒	❒	❒
r. Canopy sensors for nitrogen deficiency	❒	❒	❒	❒

8. In order to provide more timely weather information to corn producers, we are interested in when you typically carry out farming practices.

Please check <u>all of the months</u> in which you typically carry out the following practices related to <u>corn production</u>. If you do not typically carry out a practice, check “not applicable.”

I typically…	**…in *(please check all months that apply)***												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	**Not <u>Applicable</u>**
a. apply anhydrous	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
b. apply liquid fertilizer	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
c. apply dry fertilizer	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
d. apply manure	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
e. irrigate corn	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
f. apply fungicides	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
g. apply insecticides	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒

h. apply herbicides	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
i. till fields	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒
j. plant cover crops	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒	❒

9. For each <u>decision</u> related to <u>corn production</u> listed below, please circle the <u>one primary month</u> in which you typically make that decision. If an activity is not part of your operation, circle "not applicable." ***(Please circle one number on each line.)***

I typically make decisions about the following in…	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	**Not Applicable**
a. crop rotations and field assignments	1	2	3	4	5	6	7	8	9	10	11	12	13
b. seed purchases	1	2	3	4	5	6	7	8	9	10	11	12	13
c. seeding rate selection	1	2	3	4	5	6	7	8	9	10	11	12	13
d. fertilizer purchases	1	2	3	4	5	6	7	8	9	10	11	12	13
e. pesticide purchases	1	2	3	4	5	6	7	8	9	10	11	12	13
f. propane purchases	1	2	3	4	5	6	7	8	9	10	11	12	13
g. purchasing crop insurance	1	2	3	4	5	6	7	8	9	10	11	12	13
h. whether or not to till in fall	1	2	3	4	5	6	7	8	9	10	11	12	13
i. fuel purchases for irrigation	1	2	3	4	5	6	7	8	9	10	11	12	13
j. use of cover crops	1	2	3	4	5	6	7	8	9	10	11	12	13

10. In general, how much do the following types of weather information influence your farm decisions? ***(Please circle one number on each line.)***

	No Influence	**Low Influence**	**Moderate Influence**	**Strong Influence**
a. Historical weather trends	1	2	3	4
b. Weather data for the past 12 months	1	2	3	4
c. Current weather conditions	1	2	3	4
d. 1-7 day forecasts	1	2	3	4
e. 8-14 day outlooks	1	2	3	4
f. Monthly or seasonal outlooks	1	2	3	4
g. Annual or longer term outlooks	1	2	3	4

11. Do you use any of the following weather-related decision support resources? Note that these resources may be accessible via newsletters, websites, meetings, radio and other sources and they may not have the exact same name listed here. ***(Please circle one number on each line.)***

	Use	Don't use	Not familiar with
a. Crop disease forecast	1	2	3
b. Insect forecast	1	2	3
c. Evapotranspiration (ET) index	1	2	3
d. Growing degree day tools	1	2	3
e. Forage dry down index	1	2	3
f. Drought monitor/outlook	1	2	3
g. Satellite data/indices of water or soil nitrogen status	1	2	3
h. Farmers' Almanac	1	2	3

12. Do you pay for any weather information (beyond basic internet, satellite, or cable service fees)? ***(Please circle one number)***

Yes................................ 1   No.................................. 2

13. How far apart are your two most distant fields? ____________miles (approximate)

14. For which of the following markets do you produce corn? ***(Check all that apply.)***

- ❐ a. Commodity (sweetener, export, feed)
- ❐ b. Ethanol
- ❐ c. Livestock – silage
- ❐ d. Specialty or value-added incl. organic
- ❐ e. Seed
- ❐ f. Other

15. Listed below are activities you might do in your farm operation to manage for weather or climate related risks. Please check the boxes that best describe your plans to undertake these activities. ***(Please check all that apply.)***

	Not doing and don't plan to	Not doing but considering	Doing as part of short-term risk management	Doing as part of long-term risk management
a. Purchase additional/adjust crop insurance	❒	❒	❒	❒
b. Intensify or expand current enterprises.........	❒	❒	❒	❒
c. Diversify into other forms of production/ different crops	❒	❒	❒	❒
d. Add new technologies..................................	❒	❒	❒	❒
e. Implement in-field conservation practices	❒	❒	❒	❒
f. Implement edge-of-field conservation practices	❒	❒	❒	❒
g. Sell or rent part of property...........................	❒	❒	❒	❒
h. Get an off-farm job to supplement farm income (you and/or your spouse)..................	❒	❒	❒	❒
i. Restructure cash flow and debt	❒	❒	❒	❒
j. Scale back operations (e.g., take land out of production, de-stocking)	❒	❒	❒	❒
k. Exit the industry/quit farming.......................	❒	❒	❒	❒

Suppose the following scenario were to happen in the near future:

- **Violent storms/extreme rain events will become more frequent, particularly in the spring.**
- **More extreme rain events will increase the likelihood of flooding and saturated soils.**
- **Periods between rains will become longer, increasing likelihood of drought.**
- **Changes in weather patterns will increase crop insect, weed, and disease problems.**

16. If you knew with certainty that the above conditions would occur, would use of the following practices and strategies on the cropland you *own* and *rent* decrease, increase, or stay the same? ***(Please select one answer each for owned and rented land, if applicable.)***

	Owned Land				Rented Land			
Use of the following would….	**Decrease**	**Stay same**	**Increase**	**Don't know**	**Decrease**	**Stay same**	**Increase**	**Don't know**
a. In-field structural conservation practices (e.g., grassed waterways, contour buffer strips, and terraces)	1	2	3	4	1	2	3	4
b. Cover crops	1	2	3	4	1	2	3	4
c. Reduced tillage (e.g., strip, ridge tillage)	1	2	3	4	1	2	3	4
d. No-till	1	2	3	4	1	2	3	4
e. Diversified rotations that include small grains, forages or other crops	1	2	3	4	1	2	3	4
f. Edge-of-field conservation practices (e.g., filter and buffer strips of grass and trees)	1	2	3	4	1	2	3	4
g. Nutrient management (e.g., determine fertilizer rates by testing soil, manure, and/or plant tissue)	1	2	3	4	1	2	3	4
h. Integrated pest management (e.g., managed use of resistant varieties, scouting and considering pest thresholds before spraying)	1	2	3	4	1	2	3	4
i. Subsurface "tile" or other drainage	1	2	3	4	1	2	3	4
j. Use of control structures to drain	1	2	3	4	1	2	3	4

	and store water depending on crop needs and soil conditions ("drainage water management," not just tile).....................................								
l.	Irrigation..	1	2	3	4	1	2	3	4
m.	Irrigation efficiency best management practices (BMPs).......	1	2	3	4	1	2	3	4
n.	Canopy sensors for nitrogen deficiency	1	2	3	4	1	2	3	4

17. If the scenario described at the top of the previous page were to occur, how confident are you that the practices and strategies *<u>currently used</u>* on the cropland you farm would maintain the long-term success of your farm operation? *(Please circle one number on each line, if applicable)*

	Not at all Confident	Somewhat Confident	Confident	Very Confident
a. Owned land.................	1	2	3	4
b. Rented land.................	1	2	3	4

18. There is increasing discussion about climate change and its potential impacts. Please select the statement that best reflects your beliefs about climate change. *(Please circle one number.)*

a.	Climate change is occurring, and it is caused <u>mostly</u> by natural changes in the environment..	1
b.	Climate change is occurring, and it is caused <u>mostly</u> by human activities...............................	2
c.	Climate change is occurring, and it is caused more or less <u>equally</u> by natural changes in the environment and human activities..	3
d.	Climate change is not occurring..	4
e.	There is not sufficient evidence to know with certainty whether climate change is occurring or not	5

19. Given what <u>you believe to be true</u> about the potential impacts of climate change on agriculture in the Corn Belt, please provide your opinions on the following statements. *(Please circle one number on each line.)*

		Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
a.	I have the knowledge and technical skill to deal with any weather-related threats to the viability of my farm operation...	1	2	3	4	5
b.	I have the financial capacity to deal with any weather-related threats to the viability of my farm operation	1	2	3	4	5
c.	My farm operation will likely benefit from climate	1	2	3	4	5

change					
d. There's too much uncertainty about the impacts of climate change to justify changing my agricultural practices and strategies............	1	2	3	4	5
e. Climate change is not a big issue because human ingenuity will enable us to adapt to changes............	1	2	3	4	5
f. Crop insurance and other programs will protect the viability of my farm operation regardless of weather.......	1	2	3	4	5
g. My farm operation will likely be harmed by climate change	1	2	3	4	5
h. I am concerned that available best management practice technologies are <u>not effective enough</u> to protect the land I farm from the impacts of climate change............	1	2	3	4	5

20. Organizations, agencies, and individuals can do a number of things to prepare for or address potential changes in climate. Please provide your opinions on the following statements. ***(Please circle one number on each line.)***

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
a. Farmers should take additional steps to protect farmland from increased weather variability	1	2	3	4	5
b. I should take additional steps to protect the land I farm from increased weather variability	1	2	3	4	5
c. Seed companies should develop crop varieties adapted to increased weather variability	1	2	3	4	5
d. University Extension should help farmers to prepare for increased weather variability	1	2	3	4	5
e. State and federal agencies should help farmers to prepare for increased weather variability	1	2	3	4	5
f. Farm organizations (e.g., Farm Bureau, Corn Growers) should help farmers to prepare for increased weather variability..........	1	2	3	4	5
g. Profitable markets for biomass should be developed to encourage planting of perennial crops (grasses, trees) on vulnerable land	1	2	3	4	5
h. Profitable markets for carbon credits should be developed to encourage use of conservation tillage, cover crops, and other practices............	1	2	3	4	5
i. Profitable markets for small grains and other alternative crops should be developed to encourage diversified crop rotations	1	2	3	4	5

j. Government should do more to reduce greenhouse gas emissions and other potential sources of climate change	1	2	3	4	5
k. I should reduce greenhouse gas emissions from my farm operation	1	2	3	4	5
l. It is important for farmers to adapt to climate change to ensure the long-term success of U.S. agriculture	1	2	3	4	5
m. Changing my practices to cope with increasing climate variability is important for the long-term success of my farm	1	2	3	4	5
n. Farmers should invest more in agricultural drainage systems to prepare for increased precipitation	1	2	3	4	5
o. Farmers should invest more in irrigation systems to prepare for more frequent drought	1	2	3	4	5

21. Please indicate your level of agreement with each of the following statements. ***(Please circle one number on each line.)***

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
a. In the past 5 years, I have noticed more variable/unusual weather on my farm	1	2	3	4	5
b. In the past 5 years, I have noticed more variable/unusual weather across the Corn Belt	1	2	3	4	5
c. At least some of land I farm has experienced significant soil erosion over the last five years	1	2	3	4	5
d. The increased intensity of droughts, storms, and floods is a result of climate change	1	2	3	4	5
e. I am willing to use seasonal climate forecasts to help me make decisions about agricultural practices	1	2	3	4	5
f. Changes in weather patterns are hurting my farm operation	1	2	3	4	5
g. Weather forecasts and information are not available when I need them to make crop related decisions	1	2	3	4	5
h. I am confident in my ability to apply weather forecasts and information in my crop related decisions	1	2	3	4	5
i. In the past, inaccurate weather information has negatively affected my farm operation	1	2	3	4	5
j. Extreme weather events in recent years have affected my long-term management goals	1	2	3	4	5
k. I am concerned about emissions of greenhouse gases (nitrous oxides, methane, carbon dioxide) from	1	2	3	4	5

	agricultural activities					
l.	Nutrients and sediment from agriculture have negative impacts on water quality in my state	1	2	3	4	5

22. Please indicate your level of agreement with each of the following statements. ***(Please circle one number on each line.)***

		Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
a.	It is important for me to visit other farms to look at their practices and strategies	1	2	3	4	5
b.	Other farmers tend to look to me for advice....................	1	2	3	4	5
c.	I consider myself to be a role model for other farmers	1	2	3	4	5
d.	Extension staff, crop advisers, and others involved in agriculture tend to look to me for advice.........................	1	2	3	4	5
e.	It is important for me to talk to other farmers about new farming practices and strategies	1	2	3	4	5
f.	Landlords tend to invest less in conservation practices than owner-operators..	1	2	3	4	5
g.	It is difficult for tenants to influence conservation investments on rented land	1	2	3	4	5

23. People have different opinions about what makes a "good farmer." Please rate the importance of the following items. ***(Please circle one number on each line.)***

	A good farmer is one who…	Not Important at All	Slightly Important	Somewhat Important	Important	Very Important
a.	has the highest yields per acre	1	2	3	4	5
b.	is willing to try new practices and approaches...	1	2	3	4	5
c.	gets their crops planted first	1	2	3	4	5
d.	considers the health of streams that run through or along their land to be their responsibility	1	2	3	4	5
e.	minimizes soil erosion................................	1	2	3	4	5
f.	has the highest profit per acre....................	1	2	3	4	5
g.	has the most up-to-date equipment............	1	2	3	4	5
h.	minimizes nutrient runoff into waterways..	1	2	3	4	5

i.	uses the latest seed and chemical technology	1	2	3	4	5
j.	maximizes government payments	1	2	3	4	5
k.	thinks beyond their own farm to the social and ecological health of their watershed	1	2	3	4	5
l.	maintains or increases soil organic matter	1	2	3	4	5
m.	minimizes the use of pesticides	1	2	3	4	5
n.	manages for both profitability and minimization of environmental impact	1	2	3	4	5
o.	scouts before spraying for insects/weeds/disease	1	2	3	4	5
p.	manages their farm operation to reduce income volatility	1	2	3	4	5
q.	puts long-term conservation of farm resources before short-term profits	1	2	3	4	5

24. Are you currently in a paid position offering agricultural advice or information to farmers (e.g. Extension agent, crop consultant)? ***(Please circle one number.)***

Yes................................ 1 No.................................. 2

25. Please indicate how influential the following groups and individuals are when you make decisions about agricultural practices and strategies. ***(Please circle one number on each line.)***

		No contact/ I don't talk to	I talk to, and they have…			
			No Influence	Slight Influence	Moderate Influence	Strong Influence
a.	Family	0	1	2	3	4
b.	Other farmers	0	1	2	3	4
c.	Non-farming friends or neighbors	0	1	2	3	4
d.	Landlord/farm management firm	0	1	2	3	4
e.	Crop/livestock consultant/adviser (independent or with an agribusiness)	0	1	2	3	4
f.	Custom operator	0	1	2	3	4
g.	Seed dealer	0	1	2	3	4
h.	Farm chemical dealer (e.g., fertilizer, pesticides)	0	1	2	3	4
i.	Banker, insurance agent, or lawyer	0	1	2	3	4

j. Farm organizations (e.g., Farm Bureau, Corn Growers, etc.)	0	1	2	3	4
k. NRCS or county Soil and Water Conservation District staff	0	1	2	3	4
l. FSA office staff	0	1	2	3	4
m. State Climatologist	0	1	2	3	4
n. University Extension (e.g., local staff, campus staff and faculty, on-line info.)	0	1	2	3	4
o. Conservation NGO staff (e.g., Pheasants Forever, etc.)	0	1	2	3	4
p. State Department of Agriculture	0	1	2	3	4

26. What is your highest level of education? ***(Please circle one number.)***

Some formal education, Less than high-school.. 1
High school graduate/GED 2
Some college 3
2-year college/technical degree 4
4-year college degree 5
Graduate degree (MS, MD, PhD, etc.) 6

27. Do you plan to retire from farming in the next 5 years? ***(Please circle one number.)***

Yes... 1 No 2

28. When you retire from farming, how likely is it that one of your children or another family member (in-law, nephew, niece) will take over? ***(Please circle one number.)***

Very likely........................... 1
Likely 2
Uncertain 3
Unlikely.............................. 4
Very unlikely....................... 5

APPENDIX 2.

INTERVIEW PROTOCOL

I. Objectives

1. Understand barriers and facilitators of farmer adoption of major conservation practices that the CS CAP project is researching: nutrient management techniques; no/reduced-till; cover crops; extended rotations; and controlled drainage water management.

2. Understand beliefs about climate change and how those beliefs shape attitudes towards adaptation and mitigation.
    a. Understand farmers' perceptions of weather-related risks.
    b. Understand perspectives on what farmers and the companies, advisors, and agencies who work with them should do to ensure long-term productivity.
    c. Better understand who farmers trust for information regarding climate change and who they look to for assistance with conservation

3. Understand farmer perspectives on stewardship in the context of increasingly common extreme weather events.

II. Step-by-Step Procedure

1. Recruit farmers based on sampling protocol (80+ acres, try to recruit some women and a spectrum of highly conventional to organic producers) but stick to your quota.
2. Ask farmers to take the *Farmer Survey*, which they mail-in (follow-up to make sure they do).
3. Take the ***Interview 1: Farm-Level Data Collection*** *worksheet* with you to meet with farmer and conduct an interview about their farm. (See *Interview 1: Farm-Level Data Collection* section and Data Collection worksheet).
4. Identify two fields, one good and one marginal and get location information so that you can print a Google Earth map of the fields for the second interview.
5. Upload data onto the online data sheet that is found at the sustainablecorn.org website. Other management worksheets/Enterprise budget information will be designed at a later date.
6. Set up second interview time with farmer. This interview will take about one hour.
7. Conduct a semi-structured interview with each farmer (make sure you record the interview **AND** take notes). See ***Interview 2: Farmer-Level Interview Protocol section***.
8. Consult your *Checklist* to ensure that you have completed all components necessary for each farmer.
9. Repeat until you have completed your interview goal (5 or 10 farmers per person)
10. If the farmer is interested, develop a management plan/scenario for the farmer that includes adding one or more conservation methods that are targeted to their landscape and operation.

11. Conduct individual/group discussions about farm scenarios to discuss facilitators and barriers to adoption of practices.

III. *Farm-Level Data Collection*

[**Sample Script**] As a farmer in the [region X], you have been selected to participate in a study we are conducting. I want to begin by telling you that your participation in this study is voluntary, and if we come to any question that you do not wish to answer you can just tell me to go on to the next question . You may opt out of the study at any time. Your individual responses will remain confidential and any information reported as a result of this research will maintain your anonymity. This study consists of two in-person interviews. Today I would like to gather some information on the management of two fields; I expect this process to take about an hour. Then, whenever it is convenient but as soon as possible, I would like to meet with you again for a longer interview, which should take between 1-1.5 hours. We recognize that your time is valuable, and therefore, we are offering a $100 honorarium for participants that complete both interviews.

Our study is part of a larger multi-state project that is interested in ensuring that corn production is economically and ecologically sustainable into the future.

First, I would like to collect some [basic] information on your farm practices for [two] fields [choose total of two fields, one good field and one marginal]. I will take this information here today and use it to model some agronomic and environmental outputs associated with this field—by this I mean things like crop yield, nutrient budgets, and soil loss.

- *Fill out Data Collection Sheet*

Alternate scripting:
I would like to meet with you again whenever it is convenient but as soon as possible to have a broader conversation about your farm management and other issues that relate to your agricultural enterprise. We can arrange a time now, or I can contact you in a week or so to schedule a time.

Some other things that we would like to look at with your interest and voluntary participation:

- ❖ Development of field-level scenarios that will help us to characterize some of the environmental outputs from your current operation along with some information that might include variations to your current management that might include additional conservation tools.

- This information will be presented down the road in a setting that works for you.
- We would also be interested in working with a group of farmers in the area to discuss watershed scenarios that would help us explore the impacts of a variety of practices.

Again, I want to thank you for your willingness to participate in this research project. Your voice will influence researchers and policymakers who are very interested in understanding farmers' perspectives throughout the Corn Belt.

IV. *Farmer-Level Interview Protocol*

Prior to arriving for an interview, do the following:

a. Make list of the conservation practices this farmer uses on his/her fields for which data were gathered or bring their Data Collection worksheet with you.
b. Print Google Earth map of their fields to aid in the discussion about management practices.

Part I: Icebreakers

1. Can you tell me a little bit about the history of your farm and your farming operation?

Part II: Conservation Practices

Revisit discussion from the end of the data collection interview… "Last time we talked about your overall conservation practices and some of your future goals with regards to specific fields. I would like to start with a discussion about the specific practices that you use on the fields that we talked about last time, how you first got started with them and how your use of these practices may have changed over time."

1. **Nutrient management** refers to ways in which the amount, form, placement, and timing of the application of nutrients to crop plants is controlled.
   a. Could you describe your nutrient management system in detail for each of the fields we discussed last time?
   b. What are your main motivations for managing nutrients the way you do?

Prompts: 1) What kinds of fertilizers are used? 2) When are fertilizers typically applied? 3) How are application rates determined? 4) What is done to minimize nutrient loss?

2. **Tillage:**

   I would like to ask a few questions about your tillage methods used on these two fields.

   a. When did you start using [whatever the tillage practice is] on these field(s), and what were your main motivations for starting?
   b. What are the primary benefits of your tillage approach? [financial, soil health, off-farm environmental?]

   c. Are there challenges associated with using this tillage approach?
   d. Where do you get information about tillage methods?

Prompts:
1. What factors have determined their choice of tillage methods? (i.e., economic, soil health, erosion).

3. **Cover crops**

   IF they use cover crops on either of the fields:

   a. When did you start using cover crops, and what were your main motivations for starting?
   b. What are the main species you utilize as cover crops?
   c. What are the primary benefits of your cover crops approach? [financial, soil health, off-farm environmental?]
   d. Are there any challenges associated with using cover crops on these fields?
   e. Where do you get information on cover crops?

   IF they do not use cover crops on either of the fields:

   f. Have you ever used cover crops? [If not, ask why they have not tried them. If yes, ask what their experience was, and why they no longer use them.]
   g. Would you consider using cover crops in the future? If so, under what conditions would you be willing to? [Cost-share, custom planting, government support etc.?]

   Prompts:
   1. What do they think about the potential uses of specific cover crops and how this might enhance/detract from their operation? (e.g. do they see other market or forage benefits of a specific crop)

4. **Other practices _________________ (Pick *one or two* major/unique methods used on their fields or on their entire farm)**
    a. When did you start using X practice, and what were your main motivations for starting?
    b. What are the primary benefits of using X practice? [financial, soil health, off-farm environmental?]
    c. Are there challenges associated with using this method?
5. **Other Conservation Methods:**
    a. Have you ever heard of drainage water management? If so, what do you think about it?
    b. Have you ever heard of nitrogen sensors? If so, what do you think about them?
    c. What, if any, practices do you implement differently on land you own as opposed to land you rent?

Part III: Weather Variability

1. Over the past five years or so, have you experienced any extreme weather that has adversely affected your farm operation? [*If yes*, ask follow-on questions about impacts of each]
2. Have these weather events changed your management practices at all? If so, how?
3. There have been a lot of discussions lately about global climate change and its potential impacts on agriculture. What are *your* opinions about climate change and its potential impacts on your farm operation?
4. **IF FARMER thinks that climate change is occurring ask**: What do you think are the causes of climate change and who do you think is responsible for addressing the challenges associated with it?
    a. What sources of information about climate and weather variability do you trust the most? [**Ask** whether they talk to other farmers and others about climate change]

5. **IF Farmer doesn't think that human or naturally caused climate change is happening AT ALL then ask**: What types of information, conversations, or other resources have shaped your current thoughts on climate change?

Part IV: Trusted Sources of Information

1. Who do you look to for information on conservation management practices? [**Explore** specifically for whom they trust when it comes to these issues]?
    a. Can you give me a sense of what these particular organizations/agencies do specifically that make you more willing to take their advice or technical expertise?

2. What can extension, government, or the private sector do to assist further development of conservation practices on your farm? [**Explore** each entity]
3. What types of programs or policies do you think might assist you participating in more conservation programs or implementing new/different management practices?

Part V: Resiliency

1. Can you describe what long-term, on-farm sustainability means to you?
2. Let's think about your marginal field right now, or other marginal areas on your whole farm, and consider other uses that might be of value or interest to you.
    a. Would you ever consider changing your current cropping system on this field and if so, what are the types of things you have considered doing with this land?
    b. Would you ever consider growing other row crops, fruits/vegetables, or converting marginal cropland to pasture for livestock?
    c. What about adding woodlots, incorporating agroforestry or other land uses, including wetlands or prairie restoration?
3. As you think about *your* business and the lifestyle of farming, what is it that you most want researchers and perhaps government agencies to understand about the long-term goals you have for your farming operation?

Final Follow-Up (Keep Recorder Going)

1. As we wrap up do you have any questions for me?
2. Going forward with this project over the next few years, do you have any specific requests for additional resources, with regards to climate/weather variability or conservation management practices, that you would like more resources on for coming meetings/workshops?

APPENDIX 3.

INSTITUTIONAL REVIEW BOARD APPROVAL

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Resear
Vice President for Research
1138 Pearson Hall
Ames, Iowa 50011-2207
515 294-4566
FAX 515 294-4267

Date: 11/14/2011

To: Dr. J Gordon Arbuckle Jr.
303C East Hall

CC: Dr. John Tyndall
238 Science II

From: Office for Responsible Research

Title: Climate Change, Mitigation, and Adaptation in Corn-Based Cropping Systems (CSCAP)

IRB ID: 10-599

Study Review Date: 11/14/2011

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

- (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified directly or through identifiers linked to the subjects.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**

- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
1138 Pearson Hall
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515 294-4566
FAX 515 294-4267

Date: 9/27/2012

To: Dr. John Tyndall
238 Science II

From: Office for Responsible Research

Title: Sustainable Corn Production: Farm-Level Scenario Analysis and Economic Assessment

IRB ID: 12-473

Study Review Date: 9/27/2012

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**