CLIMATE AND MANAGING CORN-SOYBEAN AGROECOSYSTEMS I

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Findings, Implications and Recommendations

Technical Report Series:
Findings and Recommendations of the
USDA-NIFA funded Climate and Corn-based
Cropping Systems Coordinated Agricultural Project

Volume 1 of 5

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HIGHLIGHTS OF FINDINGS AND RECOMMENDATIONS

Corn is the major cereal crop of the United States, with two-thirds of national corn and soybean acreage concentrated in the Upper Midwest. Farmers in the region have highly specialized knowledge and experience with these crops and considerable capital and infrastructure investments. It is critical, given an increasingly variable climate and occurrence of extreme weather events, to develop and test management approaches that increase the adaptive capacity of corn-based agriculture, and equip farmers and land managers to be functionally resilient.

The corn-soybean system has been the focus of research since 2011 by 140 scientists, extension and outreach educators, and cooperating farmers of the USDA-NIFA funded Climate and Corn-based Cropping Systems Coordinated Agricultural Project (CAP), commonly known as the Sustainable Corn CAP. The project team and 35 experimental research sites across nine states in the upper Midwest including Iowa, Illinois, Indiana, Michigan, Minnesota, Missouri, Ohio, South Dakota, and Wisconsin and involve 10 land grant universities and USDA-Agricultural Research Service (ARS).

This technical report, *Climate and Managing Corn-Soybean Agroecosystems* (Volume 1) is a synthesis and integration of sciences spanning 19 disciplines and local knowledge of Upper Midwest farmers. The findings, implications and recommendations in this report represent research conducted by the team over the last five years (2011-2016) and is focused on improving understanding of the complex interactions among weather-climate, water cycles, nitrogen, soil carbon, and human-social systems of corn-based systems. This work reflects experimentation and assessments of in-field management practices, such as drainage, tillage, cover crops, extended rotations, and nitrogen sensing to determine how farmers can better utilize these practices to meet crop productivity and environmental goals under increasingly variable weather.

CLIMATE

Mean precipitation is predicted to increase slightly, mostly in winter and spring. This is because the air is projected to warm, which can then hold more moisture.

Heavy rainfall events have increased significantly more than the annual or the seasonal totals have increased. This trend is predicted to continue and to strengthen over the next 30 years.

Over the past 60 years the Midwest has seen a slight warming, mostly in the cooler half of the year, which has allowed the hardiness zones to move northward.

WATER

Controlled drainage infrastructure can retain water in the soil profile and be beneficial in years when moisture stress occurs. Careful site selection and design are necessary to limit seepage from the system to improve the likelihood of increasing growing-season soil moisture.

Less benefit is achieved from controlled drainage infrastructure in areas where a substantial portion of total annual drain flow occurs in spring resulting in the need for drainage in order to complete field work.

In years with high daily temperatures and limited moisture, no-till systems will have a yield advantage relative to tilled systems.

NITROGEN

Controlled drainage can reduce offsite nitrate loss to surface water from drained cropland. The drainage systems do not reduce the nitrate concentration in tile drains; rather a reduction in nitrate loss is a result of reduced drain flow from the land.

Cover crops are effective for reducing nitrate and sediment losses from a variety of cropland landscapes. Models of extensive adoption of cover crops across the Corn Belt region confirm that wider cover crop adoption by producers in the study region would be of value.

GREENHOUSE GAS

To reduce nitrous oxide (a greenhouse gas) emissions in a corn-soybean system, replacement of corn with another crop, such as soybean or wheat, can achieve a greater reduction than what can be achieved solely through improved crop management practices.

Our cover crop and drainage experiments showed no consistent effect on nitrous oxide emissions from the soil surface. More research is needed.

CARBON

Losses and gains in soil organic carbon, soil nitrate, and soil water holding capacity are site specific. These changes reflect soil characteristics, position on the landscape, and tillage practices. For example, soil organic carbon in the root zone (0-20 cm) is eroded over time on slopes and summits, causing crop yields to decrease in those locations.

When used as part of a long-term (3+ years) soil conservation strategy, no-till can be implemented without yield penalty compared to more aggressive tillage systems in a corn-soybean rotation, under most Corn Belt environments.

Cover crops can be added to increase organic matter inputs and aid in protection of soil organic carbon.

STAKEHOLDERS

Farmers' beliefs, attitudes, and concerns about climate change, as well as confidence in their capacity to cope and willingness to take adaptive and mitigative action, vary a great deal across the Corn Belt. Strategies in support of adaptive management are likely to be most successful when they align with local context and conditions and take differences among farmer perspectives into account.

Farmers are generally confident in their capacity to adapt to adverse weather. Highly confident farmers are less likely to have experienced negative impacts of extreme weather.

Farmers are pragmatic problem solvers. Our extension educators found farmers to be more receptive to exploring risk management solutions when discussions focused on the challenges associated with "increased weather variability and extremes" versus the topic of "climate change."

Farmers need more timely and accurate local weather and climate information as well as tools to make management decisions that effectively protect their economic, soil and water resources.

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CLIMATE AND MANAGING CORN-SOYBEAN AGROECOSYSTEMS

Findings, Implications and Recommendations

SECTION 1. INTRODUCTION

1.1 VARIABLE CLIMATE AND MANAGING CORN-SOYBEAN AGROECOSYSTEMS

Agriculture in the United States (U.S.) is a complex and dynamic social-agroecological system. The temporal and spatial distribution of soil, water, climate, economic and social conditions affect the mix of crops farmers select and the practices and technologies they apply on their farms (Walthall et al. 2012). Corn-soybean agroecosystems, the dominant cropping system in the upper Midwest, influences and are regulated by these conditions with impacts on productivity and ecological well-being at field, farm, watershed, and regional levels. These systems have been the focus of research since 2011 by scientists, extension and outreach educators, and cooperating farmers of the USDA-NIFA funded Climate and Corn-based Cropping Systems Coordinated Agricultural Project (CAP), commonly known as the Sustainable Corn CAP. The project team and research sites span nine states in the upper Midwest including Iowa, Illinois, Indiana, Michigan, Minnesota, Missouri, Ohio, South Dakota, and Wisconsin. This technical report is a synthesis of key biophysical and social findings from the Sustainable Corn CAP research conducted over the last five years (2011-2016).

Managing complex interconnected systems of carbon (C), water, nitrogen (N) and human action takes science, experiential knowledge, and a capacity to adjust crops and farming practices to integrate past and new information. A central goal of this project is to increase what is known about a suite of practices that can help farmers create management systems that, in turn, sustain a competitive agriculture and ensure the ecological integrity of the landscape under increasingly variable climate and extreme weather events. Climate change is one of the primary challenges facing the production of commodity crops and stewardship of land and water resources for future generations. Assessment of current systems and adaptation experiments are first steps in formulating effective individual and policy responses to risks, benefits, and pressures.

Corn is the major cereal crop in the U.S., which along with rice, soybean and wheat provides a total of 75 percent of the world caloric intake. Two-thirds of national corn and soybean acreage is concentrated in the U.S. upper Midwest. These agricultural commodities are economic engines for the region and the nation with the production of corn, soybean, and wheat amounting to $357 billion during the 2011-2015 project period (see Appendix B). Farmers in the region have highly specialized knowledge and experience with these crops and considerable capital and infrastructure investments. It is critical, given an increasingly variable climate and occurrence of extreme weather events, to develop and test management approaches that increase the adaptive capacity of corn-based agriculture, and equip farmers and land managers to be functionally resilient. The Sustainable Corn CAP institutions and scientists are well suited geographically to identify the capacity and evaluate strategies that can improve the resilience of corn-based systems.

Successful adaptation strategies employed in this nine-state region can be expected to be applicable outside the area. The region has a diversity of soils, weather and climate, social, and economic conditions. There is a significant difference in range of crop acreage and production among the states are shown in 2011 to 2015 production values. Across these nine states, corn yields ranged from 75 to 200 bu/acre (4707 to 12554 kg/ha), soybean from 30 to 56 bu/acre (2017 to 3766 kg/ha), and wheat from 37 to 81 bu/acre (2488 to 5447 kg/ha) (Figures 1, 2, 3; Appendix B). The variation across this region in production, soils, and climate has enabled the team to evaluate a suite of management practices under differing scenarios.

Report Overview

Section 1 begins by framing the U.S. and upper Midwest corn, soybean, and wheat production systems to understand the current crops grown in the region. Next, project goals regarding synthesis and integration of sciences and stakeholder views relative to production, pest management, water, nitrogen (N), and carbon (C) are discussed. Section 1 ends with details of the project research sites and biophysical and social science methodologies used to conduct the research components of the project.

Section 2 outlines team findings, implications and key recommendations based on analyses, integration, and modeling of research data to address complex components within these agroecosystems and a scaling-up to identify landscape-wide effects. The section begins with a discussion of changing climate patterns in the upper Midwest, followed by productivity of corn-based systems, and the water cycle, nitrogen and soil organic carbon (SOC) stocks. Each subsection presents both biophysical and social science findings, implications, and recommendations based on integration of the sciences.

Section 3 highlights the connecting threads among the data, findings and recommendations, and suggests policy implications and future research.

Section 4, "Supporting Scientific Publications," and Section 5, "Project Principal Investigators," serve as references to Sections 1, 2, and 3.

1.2 CORN-BASED SYSTEMS

Corn, the most widely produced grain in the U.S., provides the main energy ingredient for livestock feed, is processed into a wide range of food and industrial products, and approximately 20% is exported (USDA ERS, 2014). Two-thirds of the U.S. corn crop is grown in a nine-state region of the upper Midwest, where the Sustainable Corn CAP project took place.

Currently, and for the past several decades, the dominant cropping system in this region has been an annual rotation of corn and soybean. Other cropping systems include two years of corn followed by soybean, corn grown continuously, and the addition of a third crop such as wheat. For the past five years, farmers have on average planted 60 million acres (24 million hectares) of corn in this region, followed by 50 million acres (20 million hectares) of soybean and 7.5 million acres (3 million hectares) of wheat. These values represent approximately 67% of the corn and soybean U.S. acreage and 15% of wheat acreage. See Appendix B for acreage, production, and yield data per state and year (USDA NASS, 2016a; USDA NASS, 2016b).

Corn-based systems are well suited to a wide variety of geographies. Corn is particularly productive in the upper Midwest due to favorable climate and soils, although stresses can occur such as temperature, moisture excess or shortage, weed pressure, soil characteristics, fertility, and other factors. Yields for corn, soybean, and wheat continue to trend upward (see Figures 1, 2, 3) as a result of substantial efforts to improve crop genetic and farmer management practices. Yet research has shown yield gains for this region would have been greater if climate conditions had been more stable (Mourtzinis et al., 2015; Melillo et al., 2014; Romero-Lankao et al., 2014). Unintended environmental consequences of intensified corn-based cropping systems present challenges that farmers, crop advisors and policymakers must address. The impact of variable climate on U.S. farmers is predicted to continue into the future based on model simulations of two primary climate components — temperature and precipitation.

These three major crops (corn, soybean, wheat) differ in plant physiology, progression of vegetative and reproductive development, and recommended management practices. Because of these differences, the impacts of climate change are crop and landscape position specific. Corn-based cropping systems are vulnerable to these stresses from a changing climate:

- Longer growing season (shifted frost dates)
- Warmer winters
- Warmer nights
- More frequent severe precipitation events
- Greater annual stream flows

Corn, which is predominately grown in yearly rotation with soybean, is a crop that is highly productive, intensively managed, and cultivated to positively respond to historical precipitation and regional temperature patterns. Corn and soybean production often represents a low diversity of land use and, even without climate change, has a history of unintended consequences on soil conditions, water quality, and water supplies (Morton 2014). In the last 100 years, changes in the precipitation patterns in the upper Midwest have compromised productivity in some locales, increased soil erosion, affected N leaching into water, increased nitrous oxide (N_2O) atmospheric levels, and altered timing of intraseasonal water availability.

1.3 SYNTHESIS AND INTEGRATION OF SCIENCES

The Sustainable Corn CAP team has integrated knowledge from research spanning 19 disciplines,

(continued on page 7)

FIGURE 1 | **CORN**

Corn acres planted and harvested, grain yield, and grain production value for years 2011 to 2015 in states within the Sustainable Corn project region (USDA NASS 2016a, USDA NASS, 2016b). USDA NASS data set available in Appendix B.

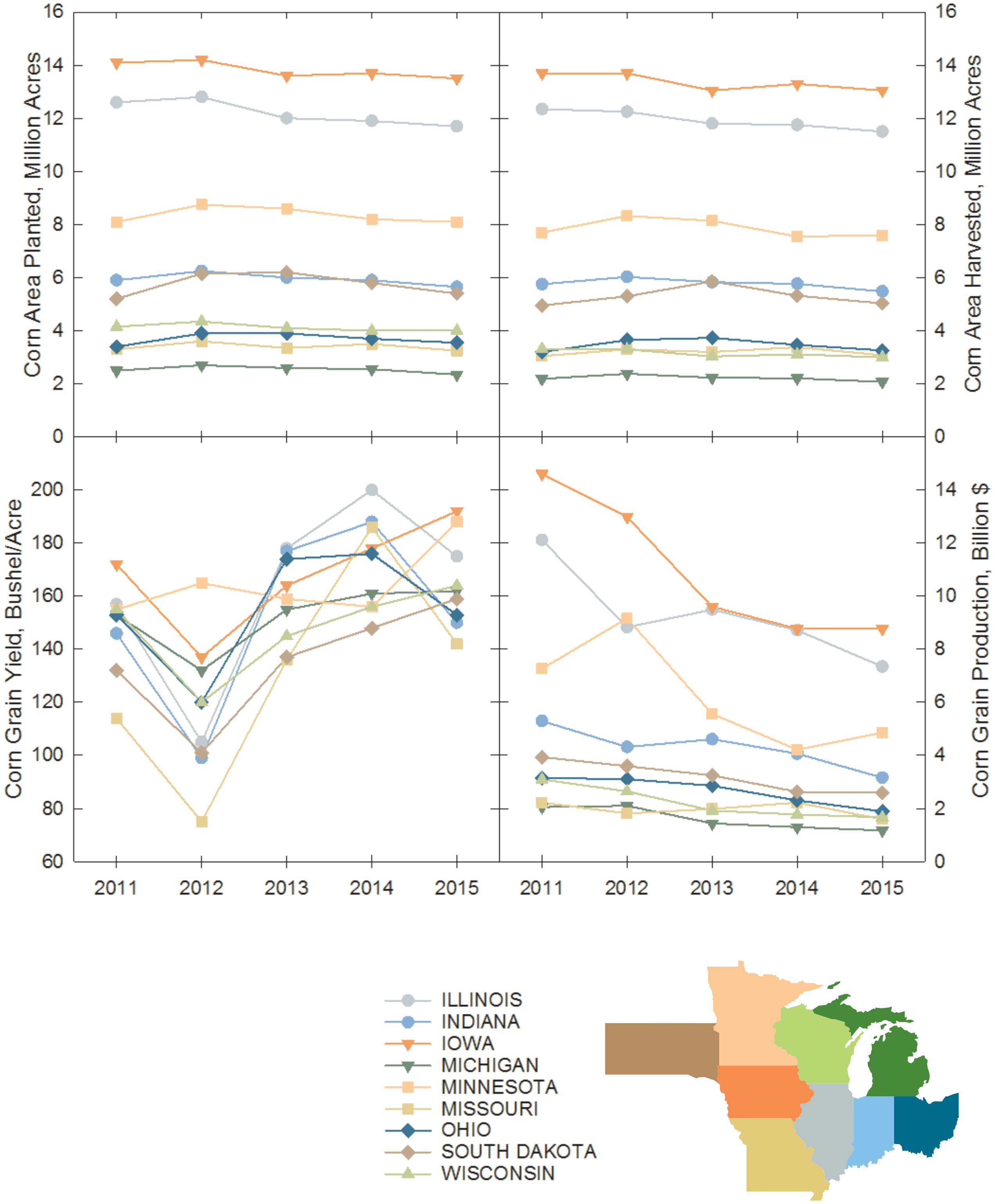


FIGURE 2 | SOYBEAN

Soybean acres planted and harvested, grain yield, and grain production value for years 2011 to 2015 in states within the Sustainable Corn project region (USDA NASS 2016a, USDA NASS, 2016b). USDA NASS data set available in Appendix B.

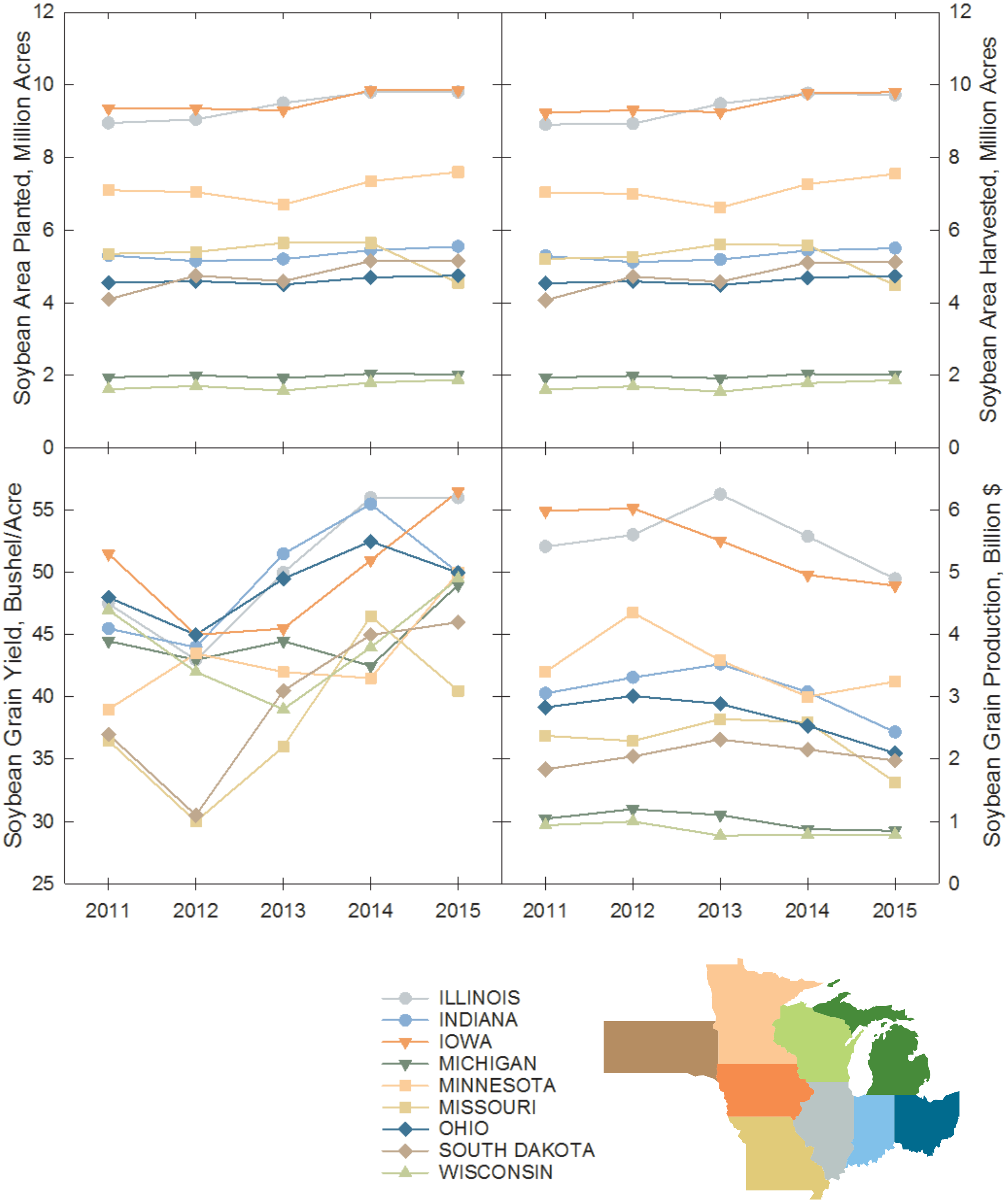
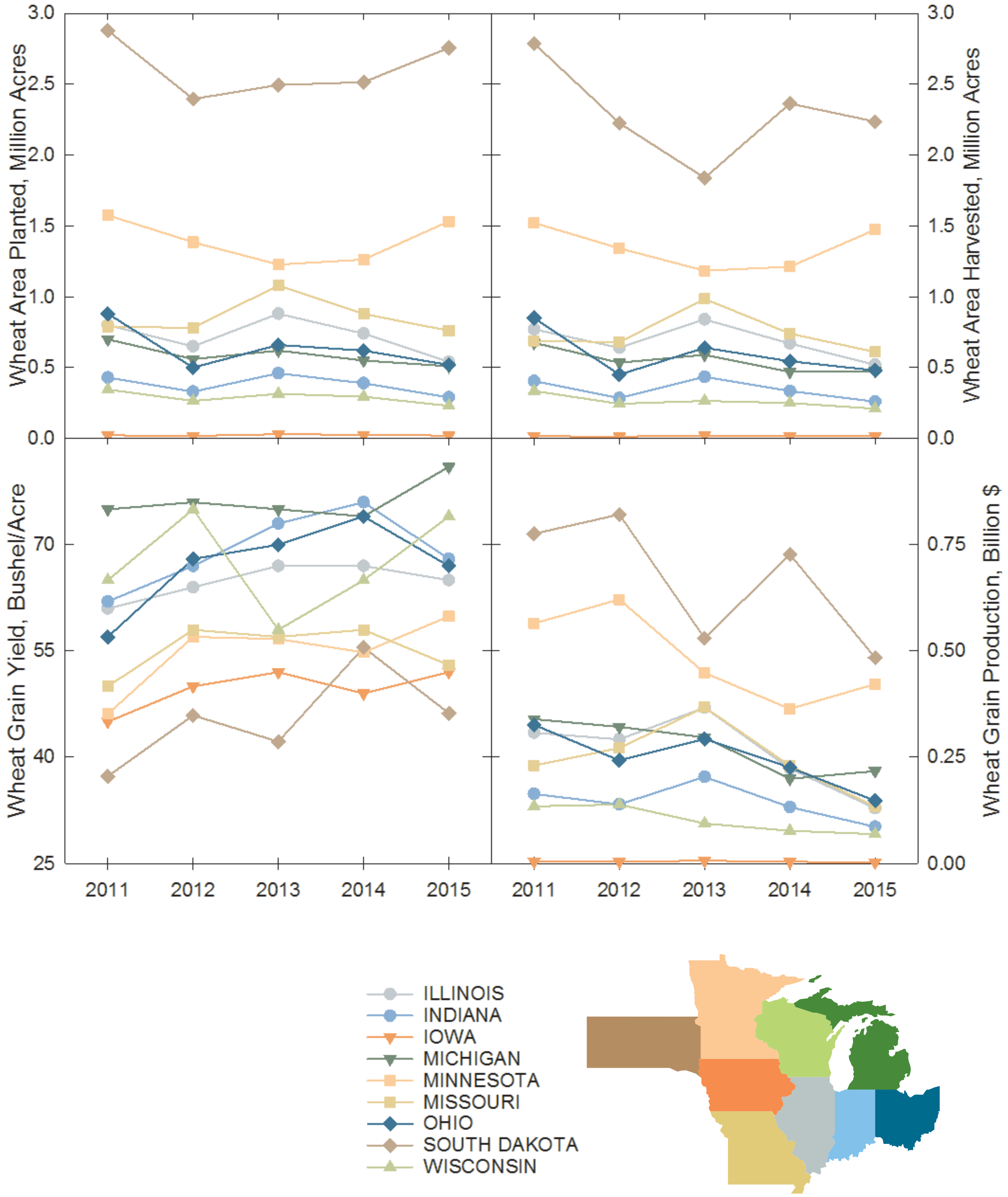


FIGURE 3 | WHEAT

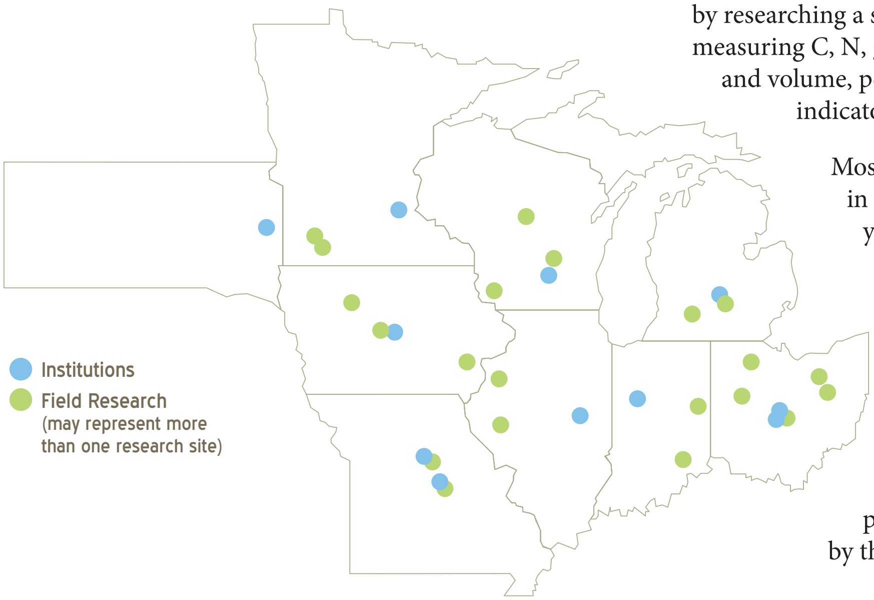
Wheat acres planted and harvested, grain yield, and grain production value for years 2011 to 2015 in states within the Sustainable Corn project region (USDA NASS 2016a, USDA NASS, 2016b). USDA NASS data set available in Appendix B.



plus local knowledge of upper Midwest farmers, to improve understanding of the complex interactions among climate, water cycles, nitrogen, carbon, and human-social systems in corn-based systems. The result is a synthesis of research findings, implications and recommendations developed from analyses and modeling based on field and survey data, climate data, and secondary data. This technical report (Volume 1) and following volumes capture the comprehensive work of the project, and connect multiple sciences and stakeholder perspectives to evaluate a suite of management practices with these goals:

- Increase soil carbon for improved soil quality and sustainability
- Limit loss of nitrogen from the system
- Stabilize soil and nutrients during periods of saturated and flooded conditions while improving water availability and efficiency for crop use during moisture stress conditions
- Build system resilience by integrating productivity and environmental goals through field, farm, watershed and landscape level management in the face of changing climate
- Transfer knowledge and findings through science-driven, experiential learning opportunities to equip and educate farmers and teachers

FIGURE 4 | Location of Sustainable Corn CAP participating institutions and field research sites.



In the first two reports, Volume 1 and 2, *Climate and Managing Corn-Soybean Agroecosystems: Findings, Implications, and Recommendations*, site specific and system-scale project data are synthesized and integrated to address the challenge of climate change adaptation for upper Midwest agricultural systems. The research encompassed includes not only the biophysical findings pertaining to grain yield, C, N, and water cycles, but also the social science findings on the views and practices of farmers who are managing the landscape and seeking ways to adapt to changing conditions while assuring productivity and protecting the agroecosystem.

Volume 3, *Climate Change and Agricultural Extension*, and Volume 4, *Preparing the Next Generation Scientists and Teachers*, use synthesis and integration to link the suite of experimental practices at many scales (field, farm, watershed, landscape) and under different climate conditions to extension and education. Volume 5, *Project and Research Management of Data and Systems*, presents recommendations on creating and managing large multi-institutional collaborative data, and the structural challenges of monitoring and facilitating large multi-disciplinary, multi-institutional collaborative science. Volumes 1 to 5 will be published in 2016 and 2017.

1.4 BIOPHYSICAL AND SOCIAL-ECONOMIC RESEARCH DATA COLLECTED

An expansive field research network of 35 sites made up the biophysical research network and included previously existing as well as newly established sites; sites were in all project states except South Dakota (Figure 4 and Appendix C). Across the sites, team members were able to assess crop and environmental responses by researching a suite of management practices and measuring C, N, greenhouse gas (GHG), water quality and volume, pest populations, and agronomic indicators (Appendices D and E).

Most research sites began collecting data in 2011 and measured parameters for five years through the 2015 growing season. In 2012, some additional treatments were initiated, plots added, and monitoring sensors installed. Project scientists collected and analyzed biophysical data, using standardized protocols developed by the team prior to the first field season (Kladivko et al. 2014). Standardized protocols exist for all data collected by the team, which includes soil organic carbon (SOC), total N, soil physical properties, soil moisture, water quality and volume, greenhouse gas, crop biomass, C and N in biomass and grain, insect and disease pressure, and grain yield (Appendix E).

The discussions and group decision-making were central to developing team standardized methodologies (Kladivko et al. 2014). The challenges of standardizing and ensuring methods are as similar as possible were worthwhile to achieve team goals related to temporal and spatial data analysis. But this endeavor required not only effort upfront in establishing these, but continual communication, time-intensive management and quality review by the data team, and high-level adherence checks and correction by researcher leads and data team (Herzmann et al. 2014). Research data were uploaded to the team's central database by team members with review and quality control performed by database managers to ensure data integrity and adherence to standardization (Herzmann et al. 2014).

These field data were integrated with climate science data to evaluate a suite of management practices. There were many practices that could have been studied. The team selected management practices that were widely used by farmers as well as counterparts to those that were relatively novel or not yet widely implemented. Different management allowed a baseline of current practices to be established and determination of the potential improvement possible. Management practices investigated include: corn-soybean rotation, cover crops (cereal rye in particular) within a corn-soybean rotation, extended and diverse crop rotations, organic cropping system, drainage water management, canopy N sensing, tillage management (no-till and conventional), and landscape position (Appendix D).

Every site included a corn-soybean rotation or continuous corn as a comparative baseline to measure change over time from different practices and climate conditions. Specific sites varied in the combination of treatments studied, due to varying site capacities and when it was established. Integration and recommendations were developed and are presented here at a systems level, when possible.

The social and economic primary data were collected using a mixed methods approach: a major random sample survey, conducted in partnership with the USDA-NIFA funded Useful to Usable project, of 4,778 farmers across 11 Upper Midwest Corn Belt states (Figure 5) and in-depth interviews and pre-post surveys with a select group of farmer cooperators. The 2012 random sample survey, which was stratified by 22 HUC 6 (Hydrological

FIGURE 5 | Social economic research at the HUC 6 watershed level map.

Unit Code) watersheds, drew its sample from the USDA National Agricultural Statistics Service (NASS) Census of Agriculture master list of farmers. Two criteria were used to select the sample from the overall population of corn farmers: at least 80 acres (32.3 hectares) of corn and USD$100,000 in the 2007 Census of Agriculture. These minimum production criteria were set because larger-scale operations farm a disproportionately large amount of acreage relative to their numbers: across the 11 states in Figure 5, farm operations with 2007 gross sales of at least USD$100,000 gross farm revenue represented 27% of farms with cropland, but cultivated 78% of all cropland acres (USDA-NASS 2009).

The farmer survey's main objective was to develop a research-based understanding of Corn Belt farmers' perspectives on climate change and potential adaptation and mitigation strategies. The survey collected data on beliefs about climate change, concerns about predicted impacts of climate change, recent experiences with extreme weather, use of decision support tools, current management practices, and attitudes toward potential individual-level and societal adaptation and mitigation actions. To date, this survey remains the largest scientifically rigorous survey focused on farmers and climate change.

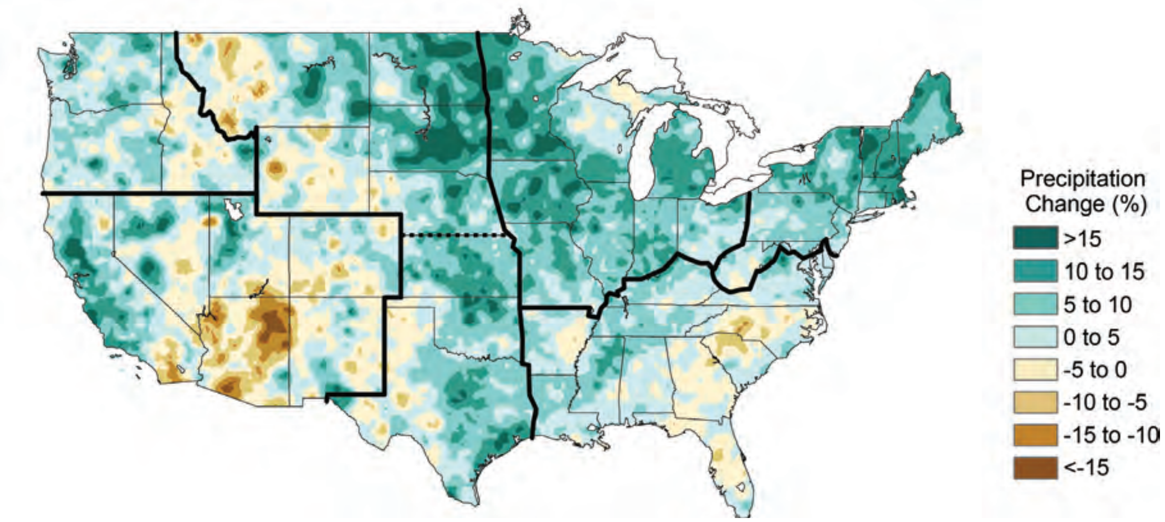
The second major social science research component consisted of in-depth interviews with 159 cooperating farmer-cooperators who were recruited from the Sustainable Corn CAP extension educators' networks. The interview process consisted of two parts: a longitudinal survey (baseline 2012 and follow-up 2015) and in-depth interviews in 2003 with the 159 cooperating farmers. The combination of in-depth interviews and surveys offered deeper insights into how farmers are viewing the national and local climate change conversation, their interpretation and responses to perceived risks, concerns for the sustainability of their operation and capacities to adapt (or not) to system changes. Quotes from in-depth interviews with these participating project farmers, while not representative of all farmers in the region, are used throughout this report to illustrate and elaborate survey findings.

SECTION 2. DATA, IMPLICATIONS, RECOMMENDATIONS

2.1 CLIMATE CHANGE AND THE UPPER MIDWEST

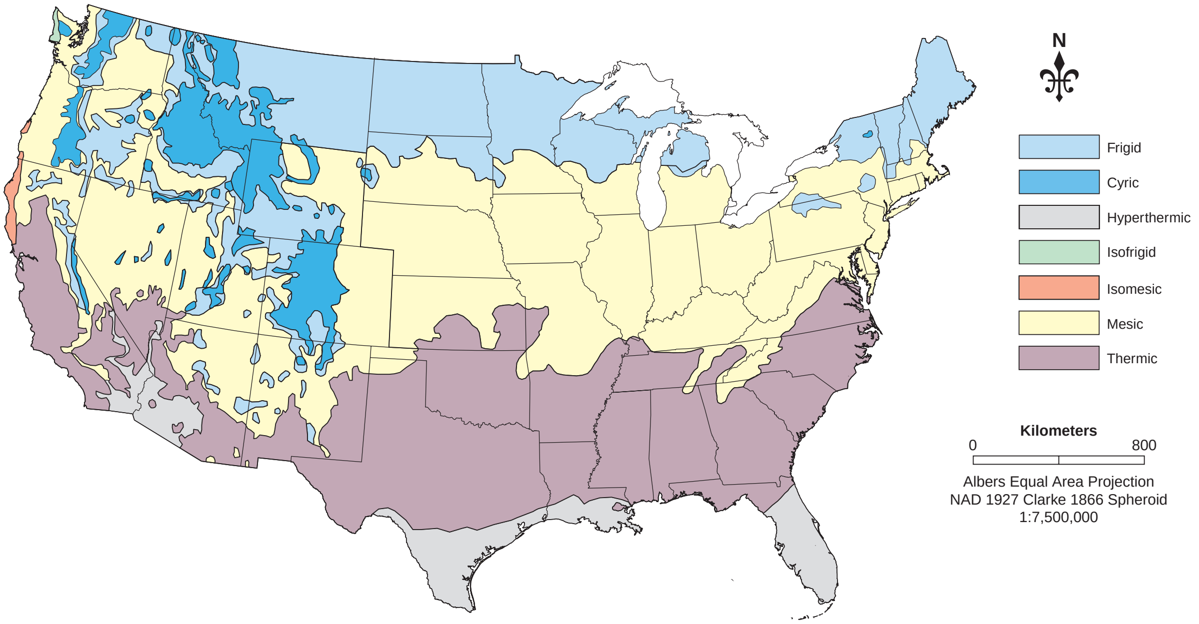
Weather variability and extremes are factors farmers respond to daily by adjusting decisions and

FIGURE 6 | Observed U.S. annual total precipitation changes for 1991-2012 compared to 1901-1960 average.



Original graphic from Melillo, J.M., T.C. Richmond, and G.W. Yohe, eds. 2014. Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program. Washington, DC: US Government Printing Office.

FIGURE 7 | U.S. soil temperature regimes.



Morton, LW. 2014. The science of variable climate and agroecosystem management. JSWC 69(6):207A-212A, doi:10.2489/jswc.69.6.207A. Image used with permission from the Journal of Soil and Water Conservation.

management practices. Although changing conditions are accepted as part of farming, the uncertainties associated with increasing weather variability due to climate change makes managing even more complex.

2.1.1 U.S. Climate. The Third National Climate Assessment documents increased climate disruptions to agriculture in the U.S. over the past 40 years and projects accelerated impacts in the next 25 years (Melillo et al., 2014). Loss and degradation of soil and water resources due to increasing extremes in precipitation (Figure 6) are identified as key concerns to both rain-fed and irrigated agriculture. The 2014 North America Regional Aspects Report by the Fifth Intergovernmental Panel on Climate Change (IPCC) cites rising temperatures and carbon dioxide (CO_2) concentrations, high vulnerability to climate extremes, regional drought, pest infestations, land use changes, and pollution as stressing North American ecosystems (Romero-Lankao et al., 2014). This report also finds that effects of temperature and climate variability on yields of major crops have been observed; and further notes water resources are already stressed by non-climate change anthropogenic factors. The authors conclude the uncertainty and risks associated with increased rainfall intensities and highly variable climate influence agricultural productivity and present huge challenges to managing water and soil resources.

Increasing future climate variability is predicted to result in heightened temperature effects and uneven distribution of excess water and water deficits; these will make crops vulnerable in known and unknown ways (Morton 2014). As agriculture adapts to these spatial and temporal changes, land cover and use shifts also will occur. Crop production may decline in some areas and expand in others. Changes in temperature patterns can alter accumulation of growing degree units (GDU), growing season length, and precipitation amount, intensity, and distribution (Johnson et al., 2010). For example, soil temperature patterns (Figure 7) influence where row crop production may expand to meet demands for corn and soybean. Recent expansion of corn, wheat and forage production have been observed in the frigid temperature zone of North Dakota and South Dakota with increases in temperature and precipitation (Laws et al. 2014). Without careful management, a changing climate along the expected trajectory will: 1) exacerbate soil erosion, transport and sediment deposition in streams, lakes and rivers, 2) increase off-field and off-farm nutrient losses which pollute water, and 3) threaten limited water supplies (Morton 2014).

2.1.2 Upper Midwest climate. Average annual global and U.S. temperature and precipitation data mask geographic variations in weather and climates across continents and within regions in the U.S. The Upper Midwestern U.S. has experienced quite different annual and intraseasonal temperature and precipitation patterns compared to the rest of the country (Laws et al. 2014; Arritt 2016). In the past 60 years, the Upper Midwest has seen a slight warming most notably in the cooler half of the year, allowing the hardiness zones to extend northward. A 5 to 10% increase in average yearly precipitation also has occurred, which for most states in the Upper Midwest equals 1 to 3 inches (2.5 to 7.5 cm). The greatest current and projected challenge to farmers is the increase in heavy rainfall in the region. There is evidence wetter spring and fall conditions in the eastern part of the region present substantial field management challenges and affect planting and harvest conditions. Heavy rainfall (>4 inch per day (>10 cm/day)) has increased significantly more than the annual or the seasonal totals. These extremes in precipitation have been observed by many farmers across the region.

A Wisconsin farmer compared past and current extreme rain events in his own local area:

> “*…it seems our rains are less frequent, they're heavier, they're more intense than they were, than I ever remember …not to say that we didn't have wet falls back then [the first few years I farmed]. I remember very wet falls. I remember very wet springs. I remember dry springs, dry falls. But it just seems like, when we get rain now, it's a couple inches at a time or it's just a trace.*”

Sustainable Corn CAP analyses of historical precipitation records reveal that from the 1950s through the present, there have been strong increases in the occurrence of heavy rainfall across the region, despite only a modest increase in total rainfall. Increases are greatest for the heaviest amounts (more than 4 inches per day (10 cm/day)). Specific findings include:

- **Finding:** Over the past 60 years the Upper Midwest has seen a slight warming, mostly in the cooler half of the year, which has allowed the hardiness zones to move northward.
- **Finding:** Mean precipitation is predicted to increase slightly, mostly in winter and spring. This is in part because the air is projected to warm, allowing it to hold more moisture.
- **Finding:** Heavy rainfall events have increased significantly more than the annual or the seasonal totals have increased. This trend is predicted to continue and to strengthen over the next 30 years.
- **Finding:** The length of intraseasonal dry spells (i.e., days between rainfall events) is predicted to increase.
- **Implication for landscape level and individual farmer decisions**: The recent trend of more frequent heavy rainfall in the Upper Midwest is expected to continue and intensify in future decades. Increased frequency of heavy rainfall in past decades is not a natural fluctuation, but is the “new normal” and is expected to intensify. This is a robust result that is found under all climate modeling approaches. Predicted interaction of climate change with farm management depends on the climate model that is used, mainly because of different changes in water availability predicted by different climate models.

These climatic trends set the context for evaluating and interpreting current management practices to understand how well fields, farms, and the regional landscape can absorb the shocks associated with increasing variability in weather and climate shifts. Increased knowledge about threats to and opportunities for productivity and environmental impacts on C, N, water, and farmers under future climate scenario models can guide farm practices and policy towards more effective adaptive management.

- **Recommendation:** Farmers need to be prepared for shortened windows of time for field operations and for the impacts of more frequent heavy rainfall with longer intraseasonal dry periods.
- **Recommendation:** Long-term adaptation measures will need to accommodate changes in precipitation and can include practices that help compensate such as no-till and residue management, drainage water management or cover crops to reduce erosion.

2.1.3 Farmers' experiences and views on climate change. A wide variety of adjustments and adaptations must occur if we are to successfully address short and long-range challenges to the resilience of cropping systems and the broader agricultural landscape. A major question underlying the work of the Sustainable Corn CAP is how we can help farmers deal with production and environmental impacts and associated uncertainties caused by weather variability, taking into consideration regional and local soil and environmental variations. In order to answer this question, there was a need to better understand farmers who are managing corn-based systems. This meant seeking answers to questions such as: What are farmers thinking about climate change? What are their experiences with variability in weather and extreme rain and drought

events? What are their concerns and perceptions of risk associated with variability in weather and long term weather shifts? What are their current practices and to what extent are they adapting to changing conditions?

Social scientists on the team explored these questions by assessing farmer beliefs, risk perceptions, attitudes toward adaptation and mitigation actions, and perceived capacities to respond to climate change. Beliefs are people's perceptions about the world and how it works. They are statements about what is regarded as true and not true. Beliefs originate from a variety of sources, ranging from scientific fact, systematic or unsystematic observations, learned behaviors, and unverified assumptions (Arbuckle et al. 2013; Church et al. 2015; Loy et al. 2013). Perceptions of risk are subjective assessments people use to understand and cope with danger and uncertainties in their lives. Risk assessments, rational and intuitive, vary based on perceptions of whether there is a problem, the parameters of the problem, exposure and sensitivities to the risk, probabilities of loss, and resources available to address the risk (Slovic 2009; Morton et al. In Review). Farmers continually assess and manage risk in their agricultural operations. These risks include production risks (yield loss), price/market volatility, institutional change (regulations), weather (short-term field management) and climate (longer-term investments), and social norm expectations. Farmer capacities to respond to changing conditions are based on their current situation, access to data, information and technology, and their confidence, ability and skills to turn data into useable information about how to best respond (Arbuckle et al. 2014).

Beliefs

An Indiana farmer elaborated what he is thinking about climate change:

“*Now, I'm not sure how much things are actually changing. When they talk about the world temperature changing 2/10 of a degree in a year relative to... to what it has been, you know, historically. I don't know. I wish I had a dinosaur around to ask him…what kind of changes I should be looking at? I'm just not too torn up about the weather and changes right there. But, as far as the drought that happened [2012], you know, it didn't rain so I don't know how any practice I could have made last year that would have changed my outcome other than the level or the type of crop insurance I would have bought. Other than that... I tried my best. It went in better than I've ever seen a crop go in and [I was] just tickled pink until it didn't rain. So that's just the way life is when you farm. It doesn't rain, you don't make money.*”

Finding: Two-thirds of surveyed farmers believed climate change is occurring. However, they differed in their beliefs about causality. Eight percent attributed climate change primarily to human actions; 33% to both human and natural causes, and 25% to mostly natural causes. One-third of farmers thought there was not enough evidence to know with certainty whether climate change is occurring (31%) or did not believe that it is (3.5%).

Finding: Despite differences in beliefs about the causes of climate change, a majority of farmers agreed or strongly agreed they had noticed more variable or unusual weather on their farms over the last five years.

Implication to farmer risk assessments: Beliefs about climate were associated with perceptions of risk, and willingness to take action to mitigate and adapt to weather/climate conditions. Those who believed climate change was primarily caused by human activities were those most concerned and willing to adjust their practices (Arbuckle et al. 2015).

Implication to farmers moving out of current status quo: Farmers' uncertainty about projected climate change impacts on their production systems were associated with beliefs about the causality of climate change, experiences with drought, concern about heat stress on crops and their agricultural information network. These factors were information sources that reduced (or increased) perceptions of too much uncertainty (Morton et al. In review).

Experience with weather

Finding: Many farmers seem to use their experiences with past weather as a baseline to make sense of current weather and projected weather in order to make good management decisions. Project models examining factors that influence decisions to implement no-till (NT), cover crops, and to plant more crops on highly erodible land (HEL) find that actual past climate and precipitation can have a significant effect on the type of management put in place. Further responses are local, since seasonal precipitation varies greatly across the upper Midwest and has a differential impact on the type of management used (Morton et al. 2015).

Finding: There is significant variability among farmers in their beliefs about climate change causality, experiences with drought and flooding, concern about impacts of extreme events on the farm enterprise, and assessments of risks and opportunities that change may bring. (Arbuckle et al. 2014)

Implication for those working with farmers: Weather experiences and perceptions of risk may increase willingness to adapt to climate change regardless of climate beliefs (Arbuckle et al. 2015).

Risk perceptions and uncertainty

Uncertainty about local weather conditions present challenges to farmers making real time decisions about planting, nitrogen fertilizer applications, herbicide and pest management, and harvest. These risks and uncertainties associated with variable climate and extreme weather events are direct and underlying factors that affect daily and longer-term farm management decisions.

One Wisconsin project farmer voiced his concern about the unpredictability of weather:

> “*Well, my real concern about climate change is… the wind patterns and what that affects, rainfall, either getting too much, too little, whatever. The fact that the Midwest, what we would consider the Corn Belt or the bread basket of the United States, is that way because we have predictable rainfall and predictable weather and my concern is unpredictability… which doesn't lend itself well to producing a crop or to planting for anything.*”

A Michigan farmer acknowledged that uncertainty in weather was expected:

> “*The only thing I trust is it's going to change. It's not going to be the same. Next year will not be ... like any year previous, right? This summer won't be like any of the other summers I've experienced. It'll be different. And that's what makes it glorious to farm. Cause you don't get bored. You've just got to be ready.*”

Finding: Beliefs, perceived risks, confidence, attitudes and current practices varied widely across the upper Midwest. In Iowa, trust in environmental or agricultural interest groups as sources of climate information influenced the perceived climate risks to agriculture, and support for adaptation and/or mitigation responses (Arbuckle et al. 2015).

Implication: Variations in trust and beliefs about climate change can have direct effects on perceived risks to the farm operation and potential changes in practices.

Finding: The majority of farmers in the upper Midwest perceive there is too much uncertainty about the impacts of climate change to justify changing their agricultural practices (Morton et al. In review).

Implication: Farmer uncertainty points to using a “wait and see” approach as a rational adaptation strategy until better, more locally accurate climate information and future consequences are available to guide decisions.

Attitudes toward adaptation and mitigation actions

The survey measured farmer attitudes regarding potential individual-level and societal responses to increased weather variability. The survey provided respondents with a number of statements about actions that might be taken by individual farmers, farmers as a group, private sector firms, extension, government agencies, and other actors. In general, farmers expressed favorable attitudes toward adaptation actions, but few farmers supported reduction of GHG emissions (Arbuckle et al. 2013; Loy et al. 2013).

Finding: Most respondents believed farmers in general (65%) and they themselves (58%) should take additional steps to protect their farmland from increased weather variability.

Finding: Majorities of surveyed farmers agreed Extension (62%) and farm organizations (52%) should help farmers prepare for increased weather variability. Just 43% agreed state and federal agencies should do the same.

Finding: Less than one-fourth of respondents agreed they should reduce GHG emissions from their farms (23%) or that government should do more to reduce GHG emissions (23%).

Finding: Farmers who believed climate change was occurring were more likely to support adaptive action, but even farmers who were uncertain about or did not believe in climate change supported action to adapt to increased weather variability.

Implication: Extension and outreach should be framed in terms of helping farmers adapt to increased weather variability and extreme weather (refer to Volume 3).

Capacity to adapt

Finding: The biophysical situation (flooding, drought, saturated soils, and/or having a river run through the farm) and farmer's identities (conservationist and productivist) significantly influence field and farm management strategies to adapt (or not) to changing conditions.

Implications: There is evidence that farmers are paying attention to the biophysical situation as well as are being guided by their own understandings of themselves as good farmers in making decisions about their farm operation.

Recommendations: This work suggests that educators and policymakers should focus on interventions, incentives and policies that appeal the farmer's conservationist identity to increase adaptations that protect the agroecosystem in the longer term. More research is needed to better understand what activates identities, core values and beliefs and how some values are privileged over others in adaptive decisions.

Finding: Many farmers are confident that they have the knowledge, technical skills and financial capacity available to adapt to future changes in climate. A great majority of them are supportive of individual, private sector and government action in support of adaptation.

Implication: Farmers have a great deal of experience with variability in weather and have successfully addressed issues associated with these changing conditions. This confidence seems to reduce stress and concerns about the impacts of changes in climate. Outreach that appeals to farmers' skills and capacity to adapt to weather extremes may resonate with them.

Project findings about current and projected upper Midwest climate patterns and an understanding of farmers' beliefs about climate change, experiences with climate hazards, perceptions of risk, and capacities to adapt suggest the following recommendations:

Recommendation: To reduce farmers' uncertainty, increase their access to and capacity to understand and interpret local historical and current weather and climate records.

Recommendation: Give farmers opportunities to learn how to use decision support tools that simulate the effects of different climate scenarios, use of different production practices and their impacts on productivity, SOC and N stocks.

Recommendation: Convey scientific probabilities using confidence levels based on scientific evidence to help farmers more accurately interpret how to incorporate scientific uncertainty into their production decision making.

Recommendation: Focus on adaptation measures that are consistent with farmers' concerns with current experience of climate variability, such as measures that are effective in managing heavier but less frequent precipitation. Because most farmers do not attribute climate change to human activity, farmer engagement strategies that focus on increasing capacity to deal with extreme or variable-weather may be more effective than strategies focused on "climate change" or "global warming."

Project social scientists found Midwest farmers have highly heterogeneous perspectives about climate change and associated risks (Arbuckle et al. 2014). Six distinct classes of farmers were identified based on the variations of beliefs about climate change, the degree to which they had experienced extreme weather, risk perceptions and attitudes toward public and private adaption, and mitigation action. These categories were labeled the concerned (14%), the uneasy (25%), the uncertain (25%), the unconcerned (13%), the confident (18%), and the detached (5%). The farmers comprising the concerned and the uneasy groups were relatively engaged in thinking about climate change, worried about the potential impacts, and were supportive of public and private, individual, and collective action to address the risks and causes of climate change. These farmers also tended to have experienced negative impacts of extreme weather in recent years. The uncertain class appeared to be less concerned, but tended to believe that climate

Nsalambi Nikongolo, Lincoln Univ., inspects an insect sticky trap

change is occurring, and were supportive of adaptation and mitigation at levels similar to those of the concerned and uneasy. Farmers who made up the unconcerned, the confident, and the detached tended to not believe climate change is occurring, expressed much less concern about potential risks, were more confident in their capacity to adapt, and were not as likely to support action. Except for the confident, these subpopulations reported very little experience with adverse weather-related impacts on their farm operations over the previous five years. The significance of personal experience in many analyses of the data suggests that as increased climate variability and extreme weather events become more visible, farmers may become less uncertain and more pro-actively seek management strategies to reduce perceived risks.

2.2 CORN AND SOYBEAN PRODUCTION AND MANAGEMENT

Although corn biomass has economic value for feed and bedding, and recently cellulosic energy, grain production per area is the primary measurement of productivity. The amount of grain harvested each year is a function of the environment and farm management impact on the genetic potential of the hybrid or variety. Corn, soybean, and wheat are each well suited for production in the Upper Midwest, but differ in overall crop development, type of stressors, length of time required for grain fill, and other production factors. Therefore, the impact of climate change will vary within and across years due to the crops grown, weather conditions experienced, management practices employed, and inherent site characteristics.

The impact on grain development and overall yield is a function of understanding how changing climate patterns impact the sensitivity and vulnerability of the crops. For corn, the silking period is the most sensitive period and historically has received much attention by plant breeders to ensure successful pollination and fertilization occurs. Stressors such as heightened temperatures, drought, or disease can be long-term in nature and can hasten grain fill, resulting in less starch accumulated and thus, lower yields. Soybean has an overlap in its development with the growth of leaves, flowers, and pods occurring simultaneously much of the season. This growth pattern inherently lessens the impact of a one-time stress or event experienced by the crop because of its compensatory behavior. Flower abortion, however, occurs more frequently at higher temperatures. A stressful environment, especially related to moisture availability and temperatures (both air and soil), will reduce grain yields in all crops.

Farmer specialization, knowledge and experience with corn, soybean, and wheat production practices in the

Upper Midwest are key reasons these crops are produced here efficiently. This knowledge is a valuable building block as the region strives for greater sustainability and resilience. Use of these monoculture systems has several strong qualities primarily because the field can be custom-managed to suit these crops as optimally as possible each growing season. However, the downtime between crops, most typically six months, is a long period for the landscape to be exposed to weather events that can lead to soil erosion, nutrient leaching, and fallow periods that may impact overall system performance when taking into consideration environmental indicators. Management strategies are needed that reduce the period when no living crops are on the landscape. Any new management practice involves a learning curve, different risks and challenges for the farmer. Our recommendations are derived from research findings and are aimed at facilitating successful adoption of practices with which an individual farmer may not be familiar.

2.2.1. Analyses of plot and field experiment data by project scientists reveal a number of patterns that inform yield and management under differing conditions.

Yield and Management

- **Finding:** Corn yields were sometimes reduced following a cereal rye cover crop. Greater rye biomass tended to be associated with greater corn yield reductions when there was less time between termination and corn planting, colder temperatures, and greater precipitation.

- **Implications for farmers:** To manage a cereal rye cover crop before corn, terminate the rye when small and a minimum of 2 weeks before planting corn. This recommendation is congruent with the Midwest Cover Crops Council (MCCC) targeting a rye height of 6 to 8 inches (15 to 20 cm) at termination. This can help reduce risks from allelopathy, insects, and N immobilization.

- **Recommendation for farmers:** Use planting and production practices that enhance early season corn growth to help eliminate potential corn grain yield penalty from a cereal rye cover crop. Corn planters should have attachments and proper setup. Some states recommend starter N for corn when planting into cereal rye cover crop or no-till.

- **Finding:** Soybean grain yield was not increased or decreased when planted following a winter cereal rye cover crop, no matter the amount of rye growth or the number of days planted after rye termination.

- **Implication for farmers:** Soybean crops can be planted the same day as cereal rye termination or any time after termination without detrimental effects on grain yield.

- **Finding:** Cereal rye cover crop growth varied widely across the region and across years. This was due to climate variation across the region, weather in a given year, timing of rye seeding and termination, and specific management practices utilized.

- **Recommendation for agricultural researchers and funders:** There is a need for more research and experimentation to improve the practicality and reliability of rye cereal cover crop seeding and establishment due to the regional and within year variability.

- **Recommendation for farmers and land managers:** Additional site specific on-farm experimentation is needed to discover effective management strategies to establish and grow cereal rye cover crops within the time windows (fall and spring) available between management of grain crops.

- **Finding:** Averaged across all seven sites, annual corn yields were similar between tillage systems during all years except 2012. In 2012, yields in conventional tillage were 9 and 8% less than yields in no-till for the continuous corn and corn-soybean rotations, respectively. This was due to low precipitation and high air temperatures during the 2012 growing season.

- **Implication for farmers:** In years with stressful growing conditions, particularly high daily temperatures and limited moisture, no-till systems with residue mulch may have a yield advantage relative to tilled systems due to inherent changes in the soil and plant microclimate.

- **Finding:** Five-year average corn yields of the corn-soybean rotation did not differ between conventional tillage and no-till for five of the seven research sites evaluated.

- **Implication for farmers:** When used as part of a long-term (3+ yrs.) soil conservation strategy, no-till often can be implemented without yield penalty compared to more aggressive tillage systems in a corn-soybean rotation under many upper Midwest environments.

- **Finding:** Five-year average soybean yields of the corn-soybean rotation did not differ between conventional tillage and no-till for four of six research sites (one of the seven sites was not included in the analysis). The two research sites with differences had greater yields in no-till compared to conventional tillage.

Recommendation to extension and crop advisors: Encourage use of no-till to improve soil structure, increase long-term infiltration and reduce runoff and erosion based on soil, slope, other field characteristics and crop.

Project findings associated with corn and soybean production systems reveal important nuances in emerging research on cover crop use and reaffirm prior research on tillage. Use of no-till can reduce vulnerability to varying amounts and intensities of precipitation and improve soil moisture retention. For production capabilities, additional cover crop research is needed to move towards established best management practices for regions that effectively improve the management, timing of seeding, and springtime termination, as well as variations in climatic and geographic responses. The soil health benefits of no-till and cover cropping may not always be translated into direct yield benefits because the latter is strongly influenced by conditions during the growing season. Yet the ecological and ecosystem benefits of these best management practices must be considered in an overall production strategy.

2.2.2 Management practices of Upper Midwest farmers reflect attempts to address the sometimes competing goals of sustaining or improving productivity, environmental, economic, and social indicators. Accomplishing these goals present difficult trade-offs for farmers as they seek to manage under increasingly variable weather and changing climate.

In order to understand receptivity to new practices and capacity to adapt the corn-based system, the project focused on medium and large-scale farmers whose operations represent a large portion of the region. Social scientists studied farmers with a minimum of 80 acres (32 hectares) of corn production and U.S. $100,000 gross sales whose farming operations were in the 22 watersheds with the highest acres of corn harvested in 2007 in the Upper Midwest (see Section 1.4 for full description of methods). Farmers surveyed, on average, owned and rented a total of 1025 acres (415 hectares), with a little more than 59% of those acres rented. Farmers reported producing corn for diverse markets: commodity, sweetener, export, feed (81.3%); ethanol (64.5%); livestock-silage (39.4%); specialty or value-added including organic (4.5%); seed (5.5%); and other (3.6%). Over half of the farmers produced corn for at least two different markets. Ninety-eight percent of the farmers graduated from high school (GED equivalent) and one-quarter had a 4-year or higher college degree. Twenty-six percent planned to retire in the next five years. Almost 55% of all farmers anticipated a family member would take over the farm operation whenever they decided to retire.

A little more than one-fourth of the random sampled farmers reported using cover crops in 2011, with most of those planting cover crops on 40% or less of their land (Table 1). Soil types and slope vary considerably across the region. Some landscapes have steep slopes that are highly erodible land (HEL), and many farmers were planting these hillsides to a cultivated crop and used management practices such as limited tillage or no-till to reduce water runoff and soil erosion. Nearly 60% of farmers reported planting at least some HEL to crops in 2011 (Morton et al. 2015). Just over 60% of farmers reported using no-till on at least some of their land, with 18% reporting using it on 100% of their land. Forty-one percent of the farmers used diversified rotations that included small grains, forages, or other crops on their own land. Most farmers reported using nutrient management strategies such as testing of soil, manure

TABLE 1 | Summary statistics for farmer response variables.

Practice	Mean	Standard Deviation	0%	1-40%	41-59%	60-99%	100%
Artificially drained through tile or other methods	49.3	40.0	22.9	22.7	9.0	22.8	22.6
No-till	37.5	38.8	38.3	18.5	15.3	9.9	18.0
Planted to cover crops	6.4	16.5	73.3	21.8	2.6	1.1	1.2
Highly erodible land that was planted to crops	24.5	33.1	41.0	34.0	6.5	10.9	7.6

Reprinted by Permission, ASA, CSSA, SSSA. Table originally published in Morton, L.W., J. Hobbs, J.G. Arbuckle and A. Loy. 2015. Upper Midwest climate variations: Farmer responses to excess water risks. 44:810-822. http://dx.doi.org/10.2134/jeq2014.08.0352 and plant tissue to determine fertilizer rates on their own (81%) and rented (71%) land. A similar percentage of farmers used integrated pest management techniques.

A Minnesota project farmer explained his use of soil tests to guide nitrogen management:

> “*And so to get a handle on nitrogen and rates, for the most part, but then also looking at P & K,… (we're) looking... for cost effectiveness and where we want to be. So we... soil test and it's fairly complicated. The more we know, the less we know on certain places.*”

Almost one-quarter to one-third reported to not be familiar with three technologies that could help them manage inputs (irrigation efficiency best management practices, 24%; water control structures, 23%; and nitrogen canopy sensors, 34%).

2.3 INTEGRATED PEST MANAGEMENT

Increased carbon dioxide (CO_2) and subsequent change in temperature are predicted to affect plant-eating insects (Bale et al. 2002) and possibly crop pests (Cannon et al. 1998). Although day-length is the greatest stimulus for triggering the start or end of overwintering, insect development and migration can be predicted in temperate regions because insects are cold blooded. Increases in temperature are likely to speed their development and improve overwintering success in temperate regions (Bale and Hayward 2010). However, long periods of high temperatures may lower survival, especially if temperatures exceed upper lethal limits. If the maximum daily temperatures decrease, as predicted for the Midwest (see Section 2.1), a changing climate still may negatively affect insects. For example, if the average temperature remains consistently higher during key points in an insect's development, this may interfere with development. Finally, the changes in temperature and resulting impact on insect herbivores (i.e. crop pests) is complicated, as many suffer significant mortality from predation and parasitism from other insects, which in turn may respond to a changing climate.

Beyond existing pests, invasive species continue to negatively affect agriculture (Liebhold and Tobin 2008) especially within the U.S. Elevated temperatures can expand or shift the range available for invasive insects. For example, soybean aphids are sensitive to changes in temperature (McCornack et al. 2004) and combined with its natural enemies, this becomes a model system for exploring the possible impact of climate change on an insect pest. Elevated CO_2 increases soybean aphid population (Dermody et al. 2008), not because of CO_2 directly, but rather from an increase in temperature at the leaf surface (O'Neill et al. 2011), and affected plant physiology (O'Neill et al. 2010a). Anticipating the impact of increasing temperature on aphids and their natural enemies is challenging. Several efforts to model the relationship between aphid and natural enemies have suggested biological control may be strengthened (Abbott et al. 2014) or destabilized (Meisner et al. 2014) depending upon the life history traits of the prey and natural enemies. To improve future modeling efforts, empirical data are needed, especially in the context of farming practices that may be adopted due to climate change, if pest managers are to be proactive in preventing future insect outbreaks.

2.3.1 Farmer response to climate change also may affect pest pressure.

Specifically, farmers may use cover crops and extended rotations to improve soil quality and prevent erosion. However, cover crops may produce a ‘green-bridge’ during the spring for migrating pests to better inhabit spring-seeded crops.

Finding: An increased risk from true armyworm (*Mthimna unipuncta*) occurred in Iowa due to the use of cover crops in corn (Dunbar et al. 2016). Unfortunately a compensatory increase in predatory insects did not occur with the presence of a cover crop in corn or soybean (Dunbar et al. in review A). This increased pest pressure risk occurred even when farmers were following recommendations to remove the cover crop to prevent a green-bridge from forming.

Implication for integrated pest management funding: This pest can be managed, but will come at a cost for a practice that requires governmental support to ensure adoption. It is not clear to what extent other mitigation practices will increase the likelihood of previously uncommon pests causing outbreaks.

Extending rotations beyond continuous corn to include more frequent inclusion of other crops can have multiple benefits, especially in light of a changing climate. Crop rotation is recommended for the most important insect pest of corn, the western corn rootworm (WCR, *Diabrotica virgifera virgifera*). Areas within the Upper Midwest have a higher percentage of continuous corn acreage due to a host of reasons including soil type, high market demand, and adoption of WCR resistant corn. Although most farmers in the upper Midwest use Bt-corn with specific proteins that target this pest, the overuse of this tactic has led to resistance to multiple Bt-toxins (Gassmann et al. 2011). A hopeful outcome from this situation is that farmers will return to rotation, which could reduce both the impact of the WCR and the occurrence of Bt-resistant populations. Unfortunately, although the former is true, we did not see evidence that crop rotation reduced the occurrence of resistant populations (Dunbar et al. in press). Furthermore, extending rotations within a corn production system did not affect beneficial insect communities within either corn or soybeans (Dunbar et al. in review B).

2.3.2 Weed pressure. Almost 50% of upper Midwest farmers surveyed by the project in 2011 were concerned or very concerned about increased weed pressure. Similar concerns were expressed about increased insect pressure (50%) and higher incidence of crop disease (50%) (Loy et al. 2013).

2.4 WATER CYCLE

The continuous movement of water throughout the earth is the hydrological cycle as it moves from one storage location to another by processes of precipitation, infiltration, runoff, and evaporation. Its storage location depends greatly on climatic factors, especially temperature changes. The water balance refers to a change in internal moisture storage as balanced by moisture fluxes into and out of a particular location (Bowling 2012; Laws et al. 2014). Over multi-year periods with little to no change in the hydrologic system, the field-scale water balance describes how precipitation causes runoff, drain flow, ground water recharge and evapotranspiration. Increasing precipitation intensity can generate more surface runoff and lessen the amount in the soil profile. Storage of snow and soil ice decreases during warmer winter periods and thereby, increases winter surface runoff, drain flow, and groundwater recharge. Changes in the winter months can change the historic soil moisture and temperatures at the start of a growing season. Surface runoff, especially on sloped topographies, is erosive and can lead to soil movement down slope, off-field and off-farm causing sedimentation of nearby creeks, rivers, and lakes.

Management of the water balance in corn-soybean production is designed to remove excess water at the field and watershed scales as well as retain soil moisture in preparation for the growing season. In rainfed climates, like the Upper Midwest, surface ditching and subsurface tile drainage are used to improve soil aeration in the root zone of growing plants and crop yields on poorly-drained soils. Potential benefits of drainage on naturally poorly drained soils are reduced erosion, earlier planting date, improved seed germination and establishment and more rigorous plant growth and health. (Laws et al. 2014; Strock 2016).

Controlled drainage refers to the practice of limiting the outflow from a subsurface drainage system through the use of a control structure at the system outlet. It is one mechanism that researchers are studying to discover under what conditions farmers can use it to adapt to increased variability in precipitation. It may allow farmers to “save” subsurface water for later use by the crop when needed.

There are a number of concerns associated with drainage that need to be carefully addressed. Tile drainage during periods of extreme precipitation and lack of vegetation has had an unintended consequence of off-field and off-farm N, phosphorous (P), and sediment losses. Nitrate loads from tile-drained fields have been shown to contribute to hypoxic conditions in the Gulf of Mexico (Alexander et al. 2008; Frankenberger 2012; Laws et al. 2014). Attention to practices that reduce nitrate loss while maintaining drainage functions during the cropping season are of high importance at the individual farm and watershed levels.

2.4.1 Project findings based on plot and field experiments reveal a number of implications and recommendations for farmers who have or will install drain tile in their fields. This pertains to the use of controlled drainage to retain water and decrease nitrate loss during the non-growing season.

- **Finding:** The seasonal timing of drain flow differs between the northwest portion of the region (Minnesota and Iowa), where most flow occurs in April-June, and the eastern portion (Ohio and Indiana) where flow can occur throughout the winter. The timing is correlated with the quantity of winter precipitation and the amount of annual soil freezing, with more soil frost leading to later drain flow, but greater winter precipitation resulting in earlier drain flow. Regionally, the drain flow was most correlated with (1) winter precipitation, and (2) annual precipitation minus evapotranspiration, as influenced by soil type. The volume of drainage and subsequent nitrate load from subsurface drainage is strongly influenced by these two climate variables allowing for USDA and land managers to target regions for controlled drainage.

- **Implication to drainage contractors and farmers:** Addition of controlled drainage infrastructure should be targeted to locations where it is most effective based on drain flow timing and landscape characteristics. Less benefit is achieved from controlled drainage infrastructure in areas where a substantial portion of total annual drain flow occurs in spring, when stored drainage water must be released to completed field work.

- **Finding:** Controlled drainage reduced annual drain flow by 3-68% in Iowa, 7-49% in Indiana, 12-68% in

Ohio, and 25-100% in Minnesota. Controlled drainage did not result in substantial soil moisture increases.

a) Controlled drainage raised the water table on average, but differences in the number of hours during the growing season in which the water table was within 12 inches (30 cm) of the surface (which might be detrimental) and between 12 and 24 inches (30 and 60 cm) of the surface (which might be beneficial) were not statistically significant in Iowa or Ohio, and only significant in one of two sites in Indiana.

b) Controlled drainage increased volumetric soil water content in the profile during July and Aug by an average of 0.3 inches (0.8 cm) in Ohio and 0.4 to 2.2 inches (1.1 to 5.7 cm) in Indiana, and reduced total hours of soil moisture deficit over the entire year. However, growing season metrics of soil moisture deficit that included the magnitude of the deficit did not show significantly different levels of soil moisture stress.

- **Implications to drainage contractors and farmers:** Controlled drainage infrastructure can retain water in the soil profile and may be beneficial in years when moisture stress occurs. Careful site selection and design are necessary to limit seepage from the system to improve the likelihood of increasing growing season soil moisture.

Although drainage water management adoption is limited, it is being encouraged through training in the design and installation of drainage management systems, education of landowners, and financial incentives provided by state and federal conservation programs. Individual landowners and farmers' decisions have landscape-scale impacts on soil and water resources. A number of recommendations for future research, education and policy development are:

- **Recommendation to extension and crop advisors:** Increase engagement and education of landowners and farmers to help them assess their drainage challenges and explore solutions that address their individual field and farm concerns and watershed scale impacts associated with nutrient loss and water quality.

- **Recommendation to extension and crop advisors:** Given the uncertainty in future climate and local weather variability, farmers should implement methods that are appropriate to localized conditions that affect water availability.

- **Recommendation to policymakers:** Develop policies that encourage drainage water management;

Jeff Strock, Univ. of Minnesota, sets up water quality sampling equipment

Ray Arritt (left), Iowa State Univ., and Dennis Todey, South Dakota State Univ.

especially targeting cropping regions with greatest potential to benefit from improved management and highlighting importance of the timing of drainage for improving water quality.

2.4.2 Upper Midwest farmer responses to managing water. Variability in climate and extreme weather events means farmers need strategies to manage their crops so they have enough water to produce healthy plants, but not too much. Forty-seven percent of farmers agreed that increased investments in agricultural drainage systems were needed to prepare for increased precipitation (Loy et al. 2013); with almost 68% of farmers within the Western Lake Erie HUC 6 (Hydrologic Unit Code) watershed calling for more drainage. Seventeen percent of farmers across the region thought more investments in irrigation systems were needed to prepare for more frequent drought with the percentage of agreement in the Middle Platte HUC 6 (47%) and Southeastern Lake Michigan HUC 6 (36%).

Finding: More than 75% of farmers have creeks, streams, or rivers running through or along the land they farm. Nearly three-fourths reported experience with saturated soils and 37% reported significant flooding from a stream or river on some of the land they farmed at some point during the five years prior to the survey (2007-2011). Slightly less than 30% had experienced significant drought on the land they farmed in the past five years.

Finding: Farmer concern about excess water varied across the region. In the Western Lake Erie watershed (OH, MI, IN), 72% of farmers were concerned or very concerned about more frequent, extreme rains and 64% were concerned or very concerned about increases in saturated soils, compared to 31% and 14%, respectively, in the Big Blue watershed (NE, KS).

A Wisconsin farmer-cooperator reflects on the variability of weather from year to year:

> “*[The weather is] all over the board from last year's drought and heat to years of wet and cold. I mean,… you'll never have an average year; it's always one extreme or the other and it's just how do you try to work around it.*”

A Michigan farmer-cooperator responds to extreme variations in precipitation in his locale:

> “*We seem to be having these extremes from one year to the next. Like this year, it's 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… You need to do the best you can so that you're not locked into a corner. 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...you're going to conserve more moisture than if it's wide open and getting baked by the sun.*”

Implications of variability in precipitation: The timing, amount and intensity of precipitation during the growing season will have significant effects on whether the crop germinates, becomes established, and develops to maximize its yield potential.

Finding: Almost 75% of farmers in the region reported at least some cropland they farmed was artificially drained and 23% reported 100% of their land was drained (see Table 1, Morton et al. 2015). Farmers in the western portion of the region studied (Nebraska) and Southeastern Lake Michigan were the most likely to irrigate portions of their farmland. Middle Platte, Loup, and Big Blue farmers reported irrigating on average 78%, 56%, and 57% respectively of their owned lands. Southeastern Lake Michigan farmers reported irrigating on average 17% of owned land.

Finding: Growing season precipitation varied across the six subregions of the Upper Midwest (2007-2011) and was significantly associated with variations in management practices (cover crops, tillage, drainage, and planting to HEL) (Morton et al. 2015).

Implications for farmers: Regional climate conditions may not well represent individual farmers' actual and perceived experiences with changing climate conditions.

Implications to climate science: Accurate climate information downscaled to localized conditions has potential to influence specific adaptation strategies.

Finding: Increased wetness in the last five years relative to the past 40 years was associated with water management, NT, cover crops and planting crops on HEL. Further, the differential responses in practices were associated with geographic locations, personal experiences with saturated soils and flooding, marginality of soils and diversification of corn markets (Morton et al. 2015).

Implications at field, farm, and watershed scales: Extensive drainage of crop land is practiced across much of the Upper Midwest and is one strategy farmers seem to be using to deal with heavy rain events so they can get into their fields for planting, early season application of nitrogen, and harvest. Excess water not only can affect crop growth and productivity but also influences off-field, off-farm soil erosion and N losses with unintended consequences to water quality and future soil productivity.

Recommendations to farmers: Experiment with a suite of practices to better manage your cropping system with close attention to technologies that mitigate excess water, soil erosion, and nutrient losses during the growing season.

2.4.3. Landscape-wide modeling offers a region-wide view of how conservation practices could affect downstream water quality.

Recommendations to policymakers: Government cost share and other conservation practice support programs should focus on identification of the most cost-effective locations for installing/adopting conservation practices for a given watershed or region.

2.5 NITROGEN SYSTEM

Nitrogen (N) is an essential nutrient for plant growth and often is the limiting nutrient in corn-based systems (Sawyer 2012). Although abundant in nature, most N is not in a form that plants can take up and must be converted to plant available ammonium or nitrate. This may be accomplished by either atmospheric N_2 fixation by plant/microbe symbiosis or by industrial fertilizer manufacture. Ammonium (NH_4) can be biologically converted to nitrite (NO_2) and then rapidly to nitrate (NO_3). Nitrate is highly mobile in the soil and easily leaches through the hydrologic system during times of the year when growing plants are not on the landscape. Denitrification occurs when soils are saturated and nitrogen is lost from the soil into the atmosphere. This is a biological process that converts nitrate (NO_3) into dinitrogen (N_2), nitric oxide (NO) or nitrous oxide (N_2O) gases. Dinitrogen gas is inert in the air (a main component of air), but nitrous oxide is a greenhouse gas.

The complex pathways and reactions of nitrogen as it passes between soil, air, microbes, plants, and humans is called the N cycle (Sawyer 2012). In soils, microbes create many of these reactions; many processes can occur simultaneously, and the resulting forms of nitrogen may behave very differently than the previous forms of N. The management of N fertilizer in corn production impacts timing and availability of N for plant growth and whether it is lost through water flows or to the atmosphere. During wet springs in fields with bare soils, nitrogen applied through fertilizer applications or from natural soil processes can be lost from the system. This may result in lower crop yields, economic loss, and increased levels of local and downstream N in water systems (Laws et al. 2014).

A range of approaches are available to maintain good N supply to crops while reducing N losses to water and air. Some involve management of nitrogen fertilizer (N timing, N rate, N source) while others involve practices such as cover crops and controlled drainage as discussed in this report. For example, cover crops grow during seasons of the year when the cash crop has been harvested and the field is fallow. The use of a cover crop provides vegetation that can actively take up nutrients such as N, thereby reducing N loss.

2.5.1 Soil nitrate. Analyses of project data based on plot and field experiments reveal a number of findings that help the project research team better understand the soil N cycle and the influence of climate. These findings have implications for some of the management options available to farmers.

Finding: Total N uptake by the cereal rye cover crop increased as the cover crop growth increased. The cereal rye cover crop reduced soil nitrate-N concentrations in the spring, with the amount of reduction weakly correlated to the amount of rye biomass and rye N content. Cereal rye also reduced soil nitrate-N concentrations in the fall at some sites where measured, in spite of relatively little fall growth.

Implications: Total nitrogen uptake by the cereal rye cover crop increased as growth of the cover crop increased. With a crop on the landscape during periods without a cash crop, the soil nitrate-N concentration was reduced in spring and fall when compared to soil nitrate-N with no rye cover crop.

Recommendations to extension and crop advisors: Promote greater cover crop use to reduce NO_3^- leaching; engage the industry to accelerate effective technologies that integrate row crop and cover crop combinations.

Implications to farmers: The rye cover crop system should be managed to maximize fall cover crop growth and have proper management in the spring before establishment of the cash crop. However, maximizing cover crop growth could be a tradeoff as that could increase risk of reduced corn yield.

Finding: Modeling results indicate climate change will bring about precipitation changes in future spring seasons. Approximately 22% of future springs (April to June) will have a >20% increase in precipitation compared to the historical mean. This could cause a shift toward more NO_3^- loss in spring that may not be alleviated entirely by split N applications.

Finding: Model results indicate NO_3^- leaching is expected to increase with climate change. This is because of increased soil organic matter decomposition occurring from increased temperatures. The increase in nitrate leaching and decrease in soil organic matter are reduced when cover crops or extended rotations are implemented.

Finding: Modeling hypothetical adoption of cover crops across 95% of the cropland in the Upper Mississippi River Basin (UMRB) and Ohio-Tennessee River Basin (OTRB) resulted in total mean annual reductions (1981 to 2000) across the two regions of total N of about 18% to 21%, total P of about 15% to 21% and large reductions in the Northern Gulf of Mexico (NGM) hypoxic zone.

Recommendation: Cover crops have been shown to be effective in field studies for mitigating NO_3^- and sediment losses for a variety of cropland landscapes. Our simulation results of extensive adoption of cover crops across the Upper Midwest region confirm this, and point to the need for wider cover crop adoption by producers in the region.

2.5.2 Nitrate movement to water. The value obtained in using a water control structure is its potential influence on the total nitrogen exiting the system. A farmer can manage the drainage outlet during parts of the year when a higher water table will not harm the crop, and may benefit the crop, and thereby, reduce the nitrate load to ditches and streams. This nitrate load reduction is due primarily to the reduced drain flow volume and potentially higher denitrification from anaerobic soil conditions.

Finding: Controlled drainage reduced NO_3^- load (which is the quantity of most interest for nutrient reduction, calculated as NO_3^- concentration x drain flow). Ranges: 11-72% in Iowa; 30% in Indiana; 12-70% in Ohio; 30-100% in Minnesota. Controlled drainage, unlike some other practices such as cover crops, should not be expected to reduce nitrate concentration in tile drains but rather reduce loads through decreasing the flow.

Implications: Controlled drainage can reduce offsite NO_3^- loss to surface water from drained cropland. The systems do not reduce the NO_3^- concentration in tile drains; rather a reduction in nitrate loss is a result of reduced drain flow from the land.

Recommendations to farmers and crop advisors: Tile-drained areas are vulnerable to nitrate loss. Farms can implement conservation approaches appropriate to their climate, landscape, and cropping patterns.

The nitrogen, water, and carbon cycles are interrelated, along with crop productivity, so alterations in one will impact others.

Finding: Model results indicate by targeting cropland conservation investments to the most cost-effective location and extent of coverage in the Mississippi-Atchafalaya River basin, northern Gulf of Mexico (NGM) hypoxic zone goals can be reached at less than half the cost of non-targeted conservation practices. It is important to note, however, that limitations in site suitability exist because of low slope requirements.

Recommendations to policymakers: Conservation agency policies need to encourage implementation of practices such as controlled drainage, which may not have an economic benefit, possibly through incentive/cost share programs that continue beyond three years and pay more than a portion of costs.

2.5.3. Greenhouse gases (GHG) include an array of naturally occurring and human-synthesized chemical compounds (Castellano 2012). Agriculture directly accounts for 10-12% of total global anthropogenic GHG emissions and indirectly 17-30% is associated with land use changes (US EPA 2015). Nitrous oxide (N_2O) production from agricultural soil management accounts for 35-50% of all U.S. agricultural GHG emissions and has been a focus within the Sustainable Corn project. The project gathered and analyzed data on N_2O emissions from corn and soybean systems at 18 sites to discern influence from various management practices.

Finding. Drainage had no consistent effect on N_2O emissions (mass N_2O/area/time) over 10+ site years of data. Patterns of N_2O loss from year-to-year could not be consistently correlated to differences in surface soil moisture.

Implication: Due to year-to-year variation in weather, drainage did not have a consistent effect on N_2O emissions.

Finding. A cereal rye cover crop, as managed in this project (herbicide termination, no incorporation, no tillage) had no consistent effect on direct N_2O emissions in the corn or soybean phases of the corn-soybean rotation. However, indirect N_2O emissions resulting from NO_3^- leaching were not considered.

Implication: On average, cover crops increased direct N_2O emissions from the soil surface by approximately 10% relative to no cover crops, but indirect N_2O emissions resulting from leaching of NO_3^- were not considered. Moreover, more measurements in the late fall and early spring when cover crops are actively growing may reveal the positive effect is a spurious result due to lack of more comprehensive measurements.

Finding. Cereal rye cover crop and drainage experiments had no consistent effect on N_2O direct emissions from the soil surface. A reduction in GHG emissions, specifically N_2O, from systems that incorporate cover crops cannot be assumed. More research is needed.

Finding. N_2O emissions from corn were greater than those from soybean or wheat. Wheat and soybean emitted 30-70% less N_2O than corn (massN_2O/area/time).


Joe Lauer, University of Wisconsin, works with two next generation scientists

Implication for policymakers: To reduce N_2O emissions in corn-based cropping systems, replacement of corn with another crop, such as soybean, wheat, or perennial crops will typically achieve greater reduction than what can be achieved solely through improved crop management practices of the corn phase, such as N fertilizer optimization.

Recommendation: A change in crop rotations to include greater cash crop diversity, such as soybean or wheat, will reduce N_2O emissions compared to corn.

Finding. The application of N fertilizer increased N_2O emissions from the soil up to 2.5 months after application, especially when soils were warm and wet. Sensor-based variable-rate sidedress N reduced N_2O emissions compared to standard uniform preplant N field-level rates based on initial results and site modeling.

Implication to farmers: Applying N fertilizer in-season with sensor-based variable rate technology, rather than using whole field uniform rate recommendations, may reduce N_2O emissions early in the season resulting in lower total annual emissions.

2.5.4. Upper Midwest farmers' perceptions and selection of practices to manage N

vary across the region. Farmer surveys and interviews offer insights into what farmers are thinking about the relationships among agricultural fertilizer use, N in water, and their management practices.

Finding: Just one-third of random sample surveyed farmers agreed or strongly agreed with the statement, "nutrients and sediments from agriculture have negative impacts on water quality in their state." A similarly low proportion of farmers were concerned or very concerned about the increased loss of nutrients into waterways.

Implications: Despite the fact that nutrient loss from agriculture is negatively impacting surface water quality in all surveyed watersheds, nearly two-thirds of farmers in the region were not aware of those negative impacts on water quality.

A South Dakota project farmer elaborates his view on the problem of N in the water:

> "*... nitrates in Minnesota and the Dakotas [were] here long before commercial fertilizers were even used. And so we got to keep in mind that's a part of the nitrogen cycle and that these nutrients cycle over time and... nitrates happen to be soluble and... move with the water. And in a year like last year [2012] where there's less water, they get concentrated. And that is probably more the problem, the amount of water that we had last year rather than just the tile structure... So we've got to keep that balance in mind and... make sure that we're not harming the environment but, at the same time,... we need to be able to produce agricultural products.*"

An Iowa project farmer says he does not have much control over where nitrogen goes:

> "*So everybody gets up in arms… and they don't understand Mother Nature's process… Whether it be my process to why I apply nitrogen or anybody else's [process], they do the best they can but, if it doesn't get utilized by the plant, you can't control that because Mother Nature always holds the trump card. And we can only do the best we can and if she decides she wants to do something different, we're [out of luck].*"

A number of literatures find that farmers who manage for both profitability and minimization of environmental impacts, and put long-term conservation in place because of concern for the ecological health of their watershed, also are likely to be concerned about N runoff from their fields and farm (McGuire et al. 2013, 2015). Project scientists' analysis of farmer survey data found similar evidence.

Finding: Farmers who have stronger conservationist identities are more likely to put in place adaptive management strategies for long term protection against soil erosion and excess N losses from high precipitation events and runoff.

Implications: Use of a suite of conservation management practices can help prevent soil erosion and reduce loss of excess N. Farmers who value soil and water resources, are concerned about the long-

Daren Mueller (left), Iowa State Univ., and Bryan Overstreet, Purdue Univ., measure the plant population in a soybean field term implications of their farming practices, and consider these values as central to their farmer identity, are implementing a variety of conservation practices.

Cover crops are conservation practices known to scavenge N and improve water quality. Adoption of cover crops in 2011, when social scientists surveyed farmers across the Upper Midwest, was at about 27% of farmers (see Table 1) and they had planted cover crops on 40% or less of their cropland. Although project field experiments were focused on the use of cereal rye as a cover crop, farmers are trying many types and combinations of cover crops with differing experiences. Subsequent in-person interviews with farmers in the region identified personal and structural barriers to incorporating cover crops into corn-soybean rotations. In some interviews, farmers using cover crops expressed disillusionment with cover crops and their capacity to be scaled up across the region (Roesch-McNally et al. in press).

Finding: Many farmers believe cover crop use entails risks from establishment and termination to timely field work and to yield. Farmers who report higher levels of perceived risks are less likely to report cover crop use; however, farmers who report greater understanding of cover crops report lower levels of perceived risk (Arbuckle and Roesch-McNally, 2015).

Interviewed project farmers offer their perspectives on cover crops:

“Yeah, I have [considered cover crops]. I think the concept is intriguing and interesting and I’m just not sure how would I... implement a cover crop.”

South Dakota farmer

“No [haven’t used cover crops] considering it though.... we’re looking at seeing the positives and negatives of it. We have several around us here that are using cover crops.... I just need to talk to some more producers. We’re probably going to,… within a year or two of taking a look at it… Of course, it does improve the soil tilth… but we’d like to see a cover crop that, maybe, can add some nitrogen at a... more reasonable expense than what the cost of anhydrous ammonia is. You know, if we can do that, I’d be really interested in that.”

Illinois farmer

“… Cover crops definitely, I think, hold a lot of promise but I think there’s going to be a learning curve there, definitely, that you’re going to look to your neighbor or whoever to say, hey, he’s out killing off his oats or whatever, maybe I’d better get after it and get that done too.”

Another Illinois farmer

“And I’m not saying I wouldn’t do it again, it’s just that it’s... hard getting it established [be] cause, a lot of times, we don’t like to work our bean ground in the fall…. But it seems like you would have to get it established so I’m not sure how much I’m going to gain if I open up that ground in the fall of the year and try to get this thing established or, leave the ground undisturbed and not establish anything... It’s something... I’ve argued it in my mind but I haven’t come up with a good answer yet.”

Wisconsin farmer

Recommendation to researchers: Increase research to quantify potential risks with cover crops and develop risk management practices.

Recommendation to extension and crop advisors: Focus more outreach on helping farmers to better understand risks and how to manage them. A better understanding of risks and the effectiveness of risk management strategies would help farmers to more effectively weigh costs and benefits of cover crops.

2.5.5. Nitrogen management is a production efficiency concern with huge implications for water quality and farm profitability. Current management practices are inadequate to address the unacceptable N, sediment, and phosphorus losses into near-by streams and lakes (Alexander et al. 2008; Ribaudo 2011). These high sediment and phosphorus loads are exacerbated by an increasingly variable climate and more frequent and extreme (4-inch or 10-cm) rain events in short periods of time.

Recommendations to farmers: Improve management of N to increase plant productivity, economic efficiencies, and reduce N loss that contributes to hypoxia conditions in the Gulf of Mexico.

Recommendations to extension and crop advisors: Provide farmers and landowners with nutrient reduction strategies (in field, edge of field, farm, and watershed scale practices) that can reduce off-farm N loss and watershed level accumulations that increase nitrate levels in downstream waters. Engage in an active dialogue about water quality issues associated with changes in the water cycle influenced by climate variability.

2.6 CARBON SYSTEM

Soil carbon, comprising ~1-6% of the total soil mass, plays a key role in the global carbon cycle. Most of the soil carbon resides within soil organic matter (SOM) and is stored in the upper 3 feet (1 m) of the soil profile

(Kravchenko 2012). SOM, an essential component of healthy fertile soil, is made up of previously living plant and animal residues that are in different stages of decomposition (Lal 2014). It is a reservoir for nutrients necessary for plant growth and development such as N, P, sulfur (S) and micronutrients. Microorganisms feed on SOC and decompose SOM at different rates ranging from fast (several years), slow (decades to centuries), and passive (thousands of years) (Kravchenko 2012). Water, air, and temperature conditions influence the rate of microbe decomposition of SOM.

SOM is one of the major binding agents of soil aggregation (Lal 2015a). It holds particles together and creates soil pores within and between aggregates to provide air and moisture to the roots and drain excess water. Carbon within the upper soil profile is more affected by changes in management practices than deeper in the root zone. While tillage has been a staple in many agricultural systems, scientists know soil aggregate formation is disrupted when carbon is released from tillage operations (Lal 2015b). Soil disturbance increases the availability of carbon to microorganisms and speeds the rate of decomposition and release of carbon into the atmosphere as CO_2 under aerobic conditions and CH_4 under anaerobic environments. Tillage also increases the propensity for erosion and other types of soil degradation.


Phillip Owens, Purdue Univ., examines soil samples

The elimination of tillage results in the seed placed directly into an undisturbed soil with a goal of 100% soil cover, although this is difficult and not possible for all soil and crop systems (Dick 2012; Lal 2015b). No-till can preserve complexity and heterogeneity of soil structure, reduce loss of SOC, improve water infiltration and storage in the soil, limit soil erosion and enhance soil health (Lal 2014). Use of cover crops has the potential within certain environments to increase soil aggregation, retain SOC, reduce soil erosion, and improve water infiltration and soil biological activity (Kladivko 2012).

For researchers to detect a change in SOC varies by soil type and experimental design (Necpalova et al. 2013) due to site variability and the slow, small changes in SOC. Scientists within this project measured SOC at three periods capturing baseline, midpoint, and at the end; these results will be included in Volume 2. The design of our sampling protocol and experiments were focused towards constructing a long-term footprint that requires more than 5 years of funding. Implementation of these management practices on the landscape and their ability to sequester SOC take an uncertain length of time to see an appreciable increase.

2.6.1 Regional variation in soil organic carbon. Losses and gains in SOC, soil NO_3, and soil water holding capacity are site specific. These changes reflect soil characteristics, position on the landscape, and tillage practices. For example, SOC in the root zone (0-8 inches or 0-20 cm) is eroded over time on slopes and summits, causing crop yields to decrease in those locations. The Sustainable Corn CAP research experiments have significantly different amounts of SOC as seen in Figure 8; this needs to be considered when understanding the rate of change and sequestration capacity of soils in the Upper Midwest.

Based on preliminary analysis of the data and in congruence with existing literature, project recommendations to protect and increase SOC and limit carbon loss from climate change include:

- **Finding:** Some soil types and experiments could require more than 20 years to show a measurable change (Necpalova et al. 2013), which is important in funding programs and policies focused on improvement of SOC.
- **Finding:** Cover crops can be added to increase organic matter inputs and aid in protection of SOC.

- **Recommendation to farmers:** Grow cover crops with a management goal of obtaining higher biomass, thereby increasing SOC, when and where possible.

- **Recommendations to extension and crop advisors:** Continue to document and raise awareness of benefits of cover crops and NT, and how to manage them for different benefits.

- **Recommendations to farmers and crop advisors:** Learn about conservation management strategies that can increase soil organic matter and control erosion, especially in sensitive fields with highly erodible land. In general, best management practices that create a positive carbon budget (input > losses) will enhance SOC.

Additional project data and analyses of SOC and tillage are reported in Volume 2, published in 2017.

2.6.2 Upper Midwest farmers' views on the value of soil and carbon. The project's 2012 random sample survey of farmers found that, on average, 38% of farmers believed profitable markets for carbon credits should be developed to encourage use of conservation tillage, cover crops and other practices (Loy et al. 2013). This is a solid one-third of farmers with a very narrow range of variability in the region; from 30% in the Des Moines HUC 6 to 44% in Black Root HUC 6. Over 60% of farmers were using no-till on some portion of their cultivated system with 43% implementing it on over 41% of their land (Morton et al. 2015). However it is observed that the use of no-till is not continuous from one year to another and is mostly a rotational no-till, which is not as effective from an ecological standpoint. Many farmers realize that conservation practices must be in place for many years for an increase in SOC to occur.

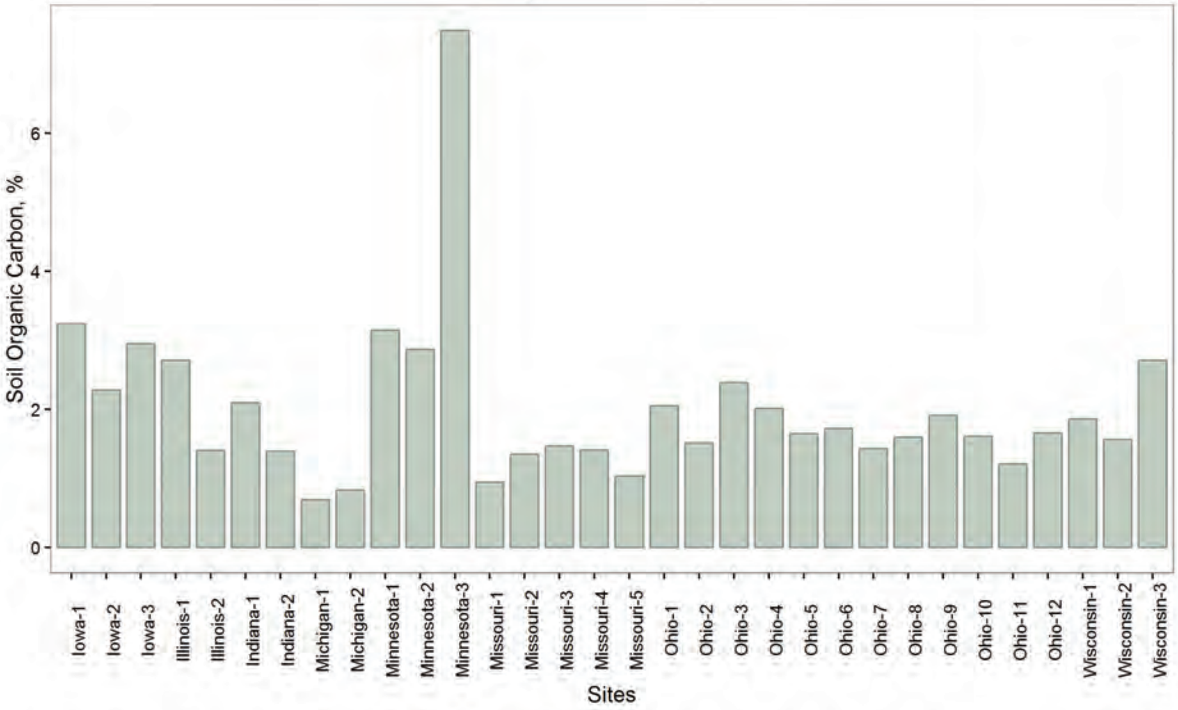
An Iowa farmer observes:

> *"When you're working with the soil, it's not like a light switch. You can't just change things and see immediate results. The soil needs time to transition. The conversion time of three or more years (to no-till) can pose difficult tradeoffs for farmers."*

- **Finding:** More than one-quarter of farmers reported experiencing significant soil erosion on at least some of their land over the five years prior to the survey (2007-2011). Almost 38% expressed concern about increased soil erosion on their farm.

- **Finding:** Farmers who reported higher proportions of their farmland as being HEL and planted to crops also tended to have higher proportions of land in no-till and cover crops (Morton et al. 2015).

FIGURE 8 | Soil organic carbon in the root zone (0-8 inches or 0-20 cm) across research sites in the region.



- **Finding:** 19 of 22 HUC 6 watersheds experience more extreme precipitation events (exceeding the 99th percentile) between 2007-2011 than would be expected by chance compared to the historical record.
- **Implications for farmers:** Planting crops on HEL under increasing extreme precipitation events of 4 inches (10 cm) or higher rainfall may increase the vulnerability of the soil resource and the likelihood of high levels of erosion and gully formation.
- **Recommendation to policymakers:** Put policies in place that incentivizes not planting crops on HEL. Planting crops on HEL, under increasing number of extreme rain events, is an increasingly risky practice that is likely to escalate erosion and reduce SOC.
- **Finding:** Many farmers believe cover crops have numerous agronomic (e.g., soil health) and environmental (e.g., water quality) benefits. Farmers who rate benefits more highly are more likely to report cover crop use.
- **Finding:** Farmers believe structural barriers such as lack of market infrastructure (e.g., seed, equipment, and technical assistance), compatible regulatory/ policy frameworks (e.g. crop insurance), and conventional thinking among landlords and crop advisors are impediments to cover crop adoption.
- **Implications:** Farmers' perceptions about cover crop implementation and the balance of risks and benefits are influencing their decisions to try them.
- **Recommendations for policymakers:** Continue to work toward improved facilitating infrastructure. Outreach to agricultural advisors (e.g., agricultural retailers, custom operators) will help them become more comfortable with cover crops, or to view them as a business opportunity.
- **Recommendations for policymakers:** Develop outreach strategies for non-operator landowners; for example, educational materials that target them with messages about the potential short and long-term benefits of cover crops.

Jane Frankenberger, Purdue Univ., leads a field demonstration during the project's 2013 annual meeting, in Indiana

SECTION 3. CONCLUSION

Management practices employed in corn-based cropping systems and utilized to build adaptive capacity to climate change allow significant gains in production, resilience, and sustainability overall. Analyses and modeling of project field experimental data offer new findings and add detail to prior literatures related to managing water, nitrogen, and carbon in Upper Midwest corn-based cropping systems under increasingly variable climate and extreme precipitation events. This team has substantially advanced agro-climate science and increased understanding of the barriers to action from the field to the watershed level. This information can be used to develop regional policies that more effectively influence adoption of diverse conservation practices and equip farmers for climate change.

Project biophysical scientists have identified basic processes that enhance soil health, conserve nutrients and sustain productivity. Strategies are directed towards retention of SOC to improve soil health, reduce the loss of soil N and other nutrients to enhance use efficiency of resources, improve system resilience to sustain productivity, and strengthen communication with land managers to develop an effective action plan. These strategies can be mutually obtained by adopting a suite of practices proven to be successful across much of the Upper Midwest, followed by local adoption by the farmer based on farm-level agronomic and ecological goals.

The interconnectedness among carbon, nitrogen, water, and crop productivity necessitates a system mindset with the benefit of ripple effects occurring across many facets of the agroecosystem when improvements are made. Findings, implications, and recommendations highlighted in this report include cover crops to build SOC, no-till to conserve soil and water and enhance SOC, and controlled drainage to conserve nutrients and leverage water resources.

Widespread adoption of these strategies by transfer of knowledge through science-driven learning opportunities and educational programs is necessary to lessen the impact from climate change on agricultural systems in the Upper Midwest. This transdisciplinary team has determined that improving the system as a whole, with a focus on the soil, is critical to developing climate-resilient corn-based systems.

Project social scientists found that Midwest farmers have highly heterogeneous perspectives about climate change


Laura Bowling, Purdue Univ., leads a field demonstration in Indiana

and associated risks (Arbuckle et al. 2014). Many farmers seem to use their experiences with past weather as a baseline to make sense of current weather and projected weather in order to make good management decisions. Project models examining factors that influence decisions to implement no-till, cover crops, and to plant more crops on highly erodible land find that actual past climate and precipitation can have a significant effect on the type of management put in place. Further, responses are local, since seasonal precipitation varies greatly across the Upper Midwest and has a differential impact on the type of management used (Morton et al. 2015). Uncertainty, perceptions of vulnerability, and access to resources such as crop insurance and other programs can affect capacities (and willingness) to respond to perceived risks and hazards (Loy et al. 2013; Morton et al. In review). Farmer adaptations are responses to perceptions and interpretations of information and experiences; these do not always reflect best management practices scientists have found to be most effective.

The effectiveness of adaptive responses to a changing climate in corn-based systems depends on the degree to which the region's farmers are willing and able to link known science with their own local knowledge-based experiences. Farmers, crop advisors, climatologists and technical specialists are the stakeholders who are the ultimate integrators of agricultural science within and across the agroecosystem (Prokopy et al. 2013; Wilke and Morton 2015a, 2015b). These stakeholders combine and weigh science with their own knowledge and experiences to make land use and management decisions that influence production and environmental outcomes at field, farm, and watershed levels. Prior literatures and findings from this project suggest that underlying beliefs and values, attitudes, social norms and relationships are situationally activated in farmers' assessments of risks and opportunities (Slovic 2009; Prokopy et al. 2015a; Prokopy et al. 2015b; Arbuckle et al. 2015; Morton et al. 2015). Social scientists are just beginning to understand how these factors are incorporated into a farmer's decision to adapt (or not), and how they affect willingness and capacities to respond to increased variability in weather and climate.

The Sustainable Corn team has developed an extensive cross-disciplinary network of colleagues and research to better understand current and future capacity of Upper Midwest corn-based agroecosystems for resilience to climate change. This complex challenge spans biophysical, social, and economic aspects necessitating integrated research questions that drive solutions that can be implemented on a local and regional basis. Scientists and stakeholders now have a greater set of resources grounded in scientific research to evaluate management systems and the dynamic potential to reduce uncertainty and risk under an increasingly variable climate.

The findings and recommendations in this report represent project research intended to increase understanding of the distribution and timing of precipitation and temperature, management practices, and human perceptions of risk and vulnerability of corn-based agroecosystems. This science is critical if agriculture is to continue to innovate, adapt and thrive under changing conditions. **The research findings and work with stakeholders reinforce one overarching conclusion: local adaptation of corn-based cropping systems to climate extreme will require farmers to experiment with practices, and customize a suite of practices that work for their landscape and local climate.**

The Sustainable Corn CAP team acknowledges that people learn and change behaviors in different ways and at different rates. Human adaptations to a changing climate will not be linear nor always seem rational. A variety of strategies are needed to increase continuous access to science and its changing parameters, and to ensure interpretations that are meaningful and of value to farmers, agricultural policymakers, and society at large. The transfer of scientific knowledge and the reconstruction of new knowledge when scientific and stakeholder knowledge are integrated is a dynamic and ever-changing process. Findings in this report have implications for Extension and outreach efforts as well as education of science teachers and next generation scientists. Volume 3 of this Technical Report series, *Climate Change and Agricultural Extension*, co-produced in partnership with the USDA-NIFA Useful to Usable (U2U) project, addresses the challenges and provides guidance for communicating climate science and applying it to managing agricultural systems. Volume 4, *Agri-Climate Education; Preparing the Next Generation*, documents hands-on learning field days and modules that help teachers communicate these principles in the classroom.

The Sustainable Corn CAP has expanded knowledge about C, N, water, and human-social systems that underpin corn-soybean systems and their interactive responses to variability and extreme weather events. While funding for this project has ended, the work continues. Many of the Sustainable Corn CAP scientists continue this work in a variety of ways. Project next generation scientists, the graduate students and post-doctoral associates who were trained in their discipline as part of this project, will use what we have learned to build new science as they move into their future careers. These next generation scientists worked side-by-side with more experienced scientists within and outside their discipline to bring together disciplinary theories, methodologies, and known science with other disciplinary sciences to create new knowledge that better represents the dynamic and complex nature of the corn-based agroecosystem.

The Sustainable Corn team continues to evaluate system scale research outcomes of in-field management practices to determine how farmers can develop systems that meet crop productivity and environment goals under changing conditions.

Group discussion during the project's 2012 annual meeting.
From left: Reagan Waskom, Colorado Water Institute; Dennis Todey, South Dakota State Univ.; and Robert Anex, Univ. of Wisconsin.

SECTION 4. SUPPORTING SCIENTIFIC PUBLICATIONS

Papers listed here represent the science of the team published from 2011 to early 2016.

Adeuya, R., N. Utt, J. Frankenberger, L. Bowling, E. Kladivko, S. Brouder and B. Carter. 2013. Impacts of drainage water management on subsurface drain flow, nitrate concentration, and nitrate loads in Indiana. Journal of Soil and Water Conservation. 67(6):474-484. http://dx.doi.org/10.2489/jswc.67.6.474

Akinsete, S. J. and N.V. Nkongolo. 2016. Soil carbon and nitrogen fractions of a grassland in central Missouri, USA. Communications in Soil Science and Plant Analysis. 47(9):1128-1136. http://dx.doi.org/10.1080/00103624.2016.1166240

Anderson, C., R. Anex, R. Arritt, B. Gelder, S. Khanal, D. Herzmann and P. Gassman. 2013. Regional climate impacts of a biofuels policy projection. Geophysical Research Letters. 40(6):1217-1222. http://dx.doi.org/10.1002/grl.50179

Arbuckle, J., L.W. Morton and J. Hobbs. 2015. Understanding farmer perspectives on climate change adaptation and mitigation: The roles of trust in sources of climate information, climate change beliefs, and perceived risk. Environment & Behavior. 47:205-234. http://dx.doi.org/10.1177/0013916513503832

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

Arbuckle, J.G., L.S. Prokopy, T. Haigh, J. Hobbs, T. Knoot, C. Knutson, A. Loy, A.S. Mase, J. McGuire, L.W. Morton, J. Tyndall and M. Widhalm. 2013. Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. Climatic Change Letters. 117:943-950. http://dx.doi.org/10.1007/s10584-013-0707-6

Arbuckle, J.G., L.W. Morton and J. Hobbs. 2013. Farmer beliefs and concerns about climate change and attitudes toward adaptation and mitigation: Evidence from Iowa. Climatic Change. 118:551-563. http://dx.doi.org/10.1007/s10584-013-0700-0

Basche, A. T.C. Kaspar, S.V. Archontoulis, D.B. Jaynes, T.J. Sauer, T.B. Parkin and F.E. Miguez. 2016. Soil water improvements with the long-term use of a winter rye cover crop. Agricultural Water Management. 172(1):40-50. http://dx.doi.org/10.1016/j.agwat.2016.04.006

Basche, A., F. Miguez, T. Kasper and M. Castellano. 2014. Do cover crops increase or decrease nitrous oxide emissions in agroecosystems? A meta-analysis. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):471-482. http://dx.doi.org/10.2489/jswc.69.6.471

Basche, A.D., G.E. Roesch-McNally, L.A. Pease, C.D. Eidson, G. Bou Lahdou, M.W. Dunbar, T.J. Frank, L. Frescoln, L. Gu, R. Nagelkirk, J. Pantoja and A.K. Wilke. 2014. Challenges and opportunities in transdisciplinary science: The experience of next generation scientists in an agriculture and climate research collaboration. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):176A-179A. http://dx.doi.org/10.2489/jswc.69.6.176A

Basche, A.D., S.A. Archontoulis, T.K. Kaspar, D.B. Jaynes, T.B. Parkin and F.E. Miguez. 2016. Simulating long-term impacts of cover crops and climate change on crop production and environmental outcomes in the Midwestern United States. Agriculture, Ecosystems and the Environment. 218:95-106. http://dx.doi.org/10.1016/j.agee.2015.11.011

Basso B., B. Hyndman, A. Kendall, P. Grace and G. Robertson. 2015. Can impacts of climate change and agricultural adaptation strategies be accurately quantified if crop models are annually reinitialized? PLOS ONE. 10(6):1-12. http://dx.doi.org/10.1371/journal.pone.0127333

Basso B., B. Hyndman, A. Kendall, P. Grace and G. Robertson. 2016. Tradeoffs between maize yield and nitrate leaching in a Mediterranean nitrate-vulnerable zone under current and projected climate scenarios. PLOS ONE. http://dx.doi.org/10.1371/journal.pone.0146360

Basso, B., B. Dumont, D. Cammarano, A. Pezzuolo, F. Marinello and L. Sartori. 2016. Environmental and economic benefits of variable rate nitrogen fertilization in a nitrate vulnerable zone. Science of the Total Environment. 545-546:227-235. http://dx.doi.org/10.1016/j.scitotenv.2015.12.104

Basso, B., L. Liu and J. Ritchie. 2015. A comprehensive review of the CERES-wheat, maize and rice models performances. Advances in Agronomy. 136:27-132. http://dx.doi.org/10.1016/bs.agron.2015.11.004

Bonta, J.V. 2013. Precipitation data considerations for evaluating subdaily changes in rainless periods due to climate change. Journal of Soil and Water Conservation. 68:238-253. http://dx.doi.org/10.2489/jswc.68.3.238

C. Rosenzweig, J.W. Jones, J.L. Hatfield, A.C. Ruane, K.J. Boote, P. Thorburn, J.M. Antle, G.C. Nelson, C. Porter, S. Janssen, S. Asseng, B. Basso, F. Ewert, D. Wallach, G. Baigorria and J.M. Winter. 2013. The agricultural model intercomparison and improvement project (AgMIP): Protocols and pilot studies. Agricultural and Forestry Meteorology. 170:166-182. http://dx.doi.org/10.1016/j.agrformet.2012.09.011

Campbell, B., L. Chen, C. Dygert and W. Dick. 2014. Tillage and crop rotation impacts on greenhouse gas fluxes from two long-term agronomic experimental sites in Ohio. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):543-552. http://dx.doi.org/10.2489/jswc.69.6.543

Carlton, J.S., A.S. Mase, C.L. Knutson, M.C. Lemos, T. Haigh, D.P. Todey and L.S. Prokopy. 2016. The effects of extreme drought on climate change beliefs, risk perceptions, and adaptation attitudes. Climatic Change. 135(2):1-16. http://dx.doi.org/10.1007/s10584-015-1561-5

Castellano, M.J., K.M. Mueller, D.C. Olk, J. Sawyer and J. Six. 2015. Integrating plant litter quality, soil organic matter stabilization and the carbon saturation concept. Global Change Biology. 21(9):3200-3209. http://dx.doi.org/10.1111/gcb.12982

Cerezo-Mota, R., T. Cavazos, R. Arritt, A. Torres-Alavez, K. Sieck, G. Nikulin, W. Moufouma-Okia and J. A. Salinas-Prieto. 2015. CORDEX-NA: Factors inducing dry/wet years on the North American Monsoon region. International Journal of Climatology. 36(2):824-836. http://dx.doi.org/10.1002/joc.4385

Christianson L., J.C. Tyndall and M. Helmers. 2013. Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage. Water Resources and Economics. 2-3:30-56. http://dx.doi.org/10.1016/j.wre.2013.09.001

Comito, J., J. Wolseth and L.W. Morton. 2012. Tillage practices, the language of blame and responsibility for water quality impacts in cultivated row crop agriculture. Human Ecology Review. 19(2):146. http://connection.ebscohost.com/c/articles/84997117/tillage-practices-language-blame-responsibility-water-quality-impacts-row-crop-agriculture

Comito, J., J. Wolseth and L.W. Morton. 2013. Stewards, businessmen, and heroes? Role conflict and contradiction among row-crop farmers in an age of environmental uncertainty. Human Organization. 72(4):283-292. http://search.proquest.com.proxy.lib.iastate.edu/docview/1467970847/abstract?accountid=10906

Comito, J., J. Wolseth and L.W. Morton. 2013. The state's role in water quality: Soil and water conservation district commissioners and the agricultural status quo. Human Organization. 72(1):44-54. http://dx.doi.org/10.17730/humo.72.1.e5h845348306411h

Daigh, A.L., M.J. Helmers, E. Kladivko, X. Zhou, R. Goeken, J. Cavadini, D. Barker and J. Sawyer. 2014. Soil water during the drought of 2012 as affected by rye cover crop in fields in Iowa and Indiana. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):564-573. http://dx.doi.org/10.2489/jswc.69.6.564

Dunbar, M.W., M.E. O'Neal and A.J. Gassmann. 2016. Increased risk of insect injury to corn following rye cover crop. Journal of Economic Entomology. http://dx.doi.org/10.1093/jee/tow101

Dunbar, M.W., M.E. O'Neal and A.J. Gassmann. 2016. Effects of field history on adult abundance of northern and western corn rootworm (Coleoptera: Chrysomelidae) and root injury. Journal of Economic Entomology. In press.

Dzotsi, K. A., B. Basso and J.W. Jones. 2013. Development, uncertainty and sensitivity analysis of the simple SALUS crop model in DSSAT. Ecological Modelling. 260:62-76. http://dx.doi.org/10.1016/j.ecolmodel.2013.03.017

Dzotsi, K. A., Basso, B. and Jones, J. W. 2015. Parameter and uncertainty estimation for maize, peanut and cotton using the SALUS crop model. Agricultural Systems. 135:31-47. http://dx.doi.org/10.1016/j.agsy.2014.12.003

Eigenbrode S., L.W. Morton and T. Martin. 2014. Big interdisciplinarity to address climate change and agriculture: Lessons from three USDA Coordinated Agricultural Projects (CAPs). Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):170A-175A. http://dx.doi.org/10.2489/jswc.69.6.170A

Frescoln, L. and J. Arbuckle. 2015. Changes in perceptions of transdisciplinary science over time. Futures. 73:136-150. http://dx.doi.org/10.1016/j.futures.2015.08.008

Goeken, R., X. Zhou and M. Helmers. 2015. Comparison of timing and volume of subsurface drainage under perennial forage and row crops in a tile-drained field in Iowa. Transaction of American Society of Agriculture and Biological Engineering. 58(5):1193-1200. http://dx.doi.org/10.13031/trans.58.10054

Gold, A.J., D. Parker, R.M. Waskom, J. Dobrowolski, M. O'Neill, P.M. Groffman, K. Addy, M. Barber, S. Batie, B. Benham, M. Bianchi, T. Blewett, C. Evensen, K. Farrell-Poe, C. Gardner, W. Graham, J. Harrison, T. Harter, J. Kushner, R. Lowrance, J. Lund, R. Mahler, M. McClaran, M. McFarland, D. Osmond, J. Pritchett, L. Prokopy, C. Rock, A. Shober, M. Silitonga, D. Swackhamer, J. Thurston, D. Todey, R. Turco, G. Vellidis and L. Wright Morton. 2013. Advancing water resource management in agricultural, rural, and urbanizing watersheds: Why land-grant universities matter. Journal of Soil and Water Conservation. 68(4):337-348. http://dx.doi.org/10.2489/jswc.68.4.337

Gonzalez-Ramirez, J., C.L. Kling and A. Valcu. 2012. An overview of carbon offsets from agriculture. Annual Review of Resource Economics. 4:145-184. http://dx.doi.org/10.1146/annurev-resource-083110-120016

Haigh, T., L.W. Morton, L. Prokopy, C. Knutson, M. Lemos, Y. Lo and J. Angel. 2015. Agricultural advisors as climate information intermediaries: Exploring differences in capacity to communicate. Weather, Climate, and Society. 7(1):83-93. http://dx.doi.org/10.1175/WCAS-D-12-00036.1

Haruna, S.I. and N.V. Nkongolo. 2015. Effects of tillage, rotation and cover crop on the physical properties of a silt-loam soil. International Agrophysics. 29(2):137-154. http://dx.doi.org/10.1515/intag-2015-0030

Haruna, S.I. and N.V. Nkongolo. 2013. Variability of soil physical properties in a clay-loam soil and its implication on soil management practices. ISRN Soil Science. 2013:1-8. http://dx.doi.org/10.1155/2013/418586

Haruna, S.I. and N.V. Nkongolo. 2014. Spatial and fractal characterization of soil chemical properties and nutrients across depths in a clay-loam soil. Communications in Soil Science and Plant Analysis. 45(17):2305-2318. http://dx.doi.org/10.1080/00103624.2014.932371

Haruna, S.I., S. Anderson and N.V. Nkongolo. 2016. Soil hydraulic properties: Influence of tillage and cover crop. Pedosphere. *In press.*

Herzmann, D.E., L.J. Abendroth and L.D Bunderson. 2014. Data management approach to multidisciplinary agricultural research and syntheses. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):180A-185A. http://dx.doi.org/10.2489/jswc.69.6.180A

Hu, Z. and L.W. Morton. 2011. US Midwestern residents' perceptions of water quality. Water. 3:217-234. http://dx.doi.org/10.3390/w3010217

Hu, Z., L.W. Morton and R. Mahler. 2011. Bottled water: Consumers in the U.S. and their perceptions of water quality. International Journal of Environmental Research and Public Health. 8:565-578. http://dx.doi.org/10.3390/ijerph8020565

Iqbal J., M.J. Castellano and T.B. Parkin. 2013. Evaluation of photoacoustic spectroscopy for simultaneous measurement of N^2O and CO_2 gas concentrations and fluxes at the soil surface. Global Change Biology. 19(1):327-336. http://dx.doi.org/10.1111/gcb.12021

Iqbal, J., D. Mitchell, F. Miguez, J. Sawyer, J. Pantoja, D. Barker and M.J. Castellano. 2015. Does nitrogen fertilizer rate to corn affect N_2O emissions from the rotated soybean crop? Journal of Environmental Quality. 44:711-719. http://dx.doi.org/10.2134/jeq2014.09.0378

Iqbal, J., M.J. Helmers, X.B. Zhou, T.B. Parkin and M. Castellano. 2014. Denitrification and N_2O emissions in annual croplands, perennial grass buffers and restored perennial grasslands. Soil Science Society of America Journal. 79(1):239-250. http://dx.doi.org/10.2136/sssaj2014.05.0221

Iqbal, J., T.B. Parkin and M. Castellano. 2013. Accuracy and precision of no instrument is guaranteed: A reply to Rosenstock et al. Global Change Biology. 20(5):1362-1365. http://dx.doi.org/10.1111/gcb.12446

Jha, M. and P. Gassman. 2013. Changes in hydrology and streamflow as predicted by a modeling experiment forced with climate models. Hydrological Processes. 28:2772-2781. http://dx.doi.org/10.1002/hyp.9836

Jha, M.K., P.W. Gassman and Y. Panagopoulos. 2013. Regional changes in nitrate loadings in the Upper Mississippi River Basin under predicted mid-century climate. Regional Environmental Change. 15:449-460. http://dx.doi.org/10.1007/s10113-013-0539-y

Kavdir, Y., W. Zhang, B. Basso and A.J.M. Smucker. 2014. Development of a new long-term drought resilient soil water technology. Journal of Soil and Water Conservation. 69(5):154A-160A. http://dx.doi.org/10.2489/jswc.69.5.154A

Kladivko, E.J., M.J. Helmers, L.J. Abendroth, D. Herzmann, R. Lal, M. Castellano, D.S. Mueller, J.E. Sawyer, R.P. Anex, R.W. Arritt, B. Basso, J.V. Bonta, L. Bowling, R.M. Cruse, N.R. Fausey, J. Frankenberger, P. Gassman, A.J. Gassmann, C.L. Kling, A. Kravchenko, J.G. Lauer, F.E. Miguez, E.D. Nafziger, N. Nkongolo, M. O'Neal, L.B. Owens, P. Owens, P. Scharf, M.J. Shipitalo, J.S. Strock and M.B. Villamil. 2014. Standardized research protocols enable transdisciplinary research of climate variation impacts in corn production systems. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):532-542. http://dx.doi.org/10.2489/jswc.69.6.532

Kling, C.L. and A. Valcu. 2013. State level efforts to regulate agricultural sources of water quality impairment. Choices. 28(3):1-4. http://www.choicesmagazine.org/magazine/pdf/cmsarticle_326.pdf

Kling, C.L., Y. Panagopoulos, A. Valcu, P.W. Gassman, S. Rabotyagov, T. Campbell, M. White, J.G. Arnold, R. Srinivasan, M.K. Jha, J. Richardson, G. Turner and N. Rabalais. 2014. LUMINATE: linking agricultural land use, local water quality and Gulf of Mexico hypoxia. European Journal of Agricultural Economics. 41(3):431-459. http://dx.doi.org/10.1093/erae/jbu009

Kravchenko, A.N. and G.P. Robertson. 2015. Statistical challenges in analyses of chamber-based soil CO_2 and N_2O emissions data. Soil Science Society of America Journal. 79(1):200-211. http://dx.doi.org/10.2136/sssaj2014.08.0325

Kravchenko, A.N., B. Hildebrandt, T.L. Marsh, W.C. Negassa, A.K. Guber and M.L. Rivers. 2014. Intra-aggregate pore structure influences phylogenetic composition of bacterial community in macroaggregates. Soil Science Society of America Journal. 78:1924-1939. http://dx.doi.org/10.2136/sssaj2014.07.0308

Kravchenko, A.N., W.C. Negassa, A. K. Guber, and M.L. Rivers. 2015. Protection of soil carbon within macro-aggregates depends on intra-aggregate pore characteristics. Scientific Reports. 5:0016261. http://dx.doi.org/10.1038/srep16261

Kravchenko, A.N., W. Negassa, A.K. Guber and S. Schimidt. 2014. New approach to measure soil particulate organic matter in intact samples using X-ray computed micro-tomography. Soil Science Society of America Journal. 78:1177-1185. http://dx.doi.org/10.2136/sssaj2014.01.0039

Kumar S., T. Nakajima, E.G. Mbonimpa, S. Gautam, U.R. Somireddy, A. Kadono, R. Lal, R. Chintala, R. Rafique and N. Fausey. 2014. Long-term tillage and drainage influences on soil organic carbon dynamics, aggregate stability, and corn yield. Soil Science and Plant Nutrition. 60(1):108-118. http://dx.doi.org/10.1080/00380768.2013.878643

Kumar, S., A. Kadono, R. Lal and W. Dick. 2012. Long-term tillage and crop rotations for 47-49 years influences hydrological properties of two soils in Ohio. Soil Science Society of America Journal. 76(6):2195-2207. http://dx.doi.org/10.2136/sssaj2012.0098

Kumar, S., A. Kadono, R. Lal and W. Dick. 2012. Long-term no-till impacts on organic carbon and properties of two contrasting soils and corn yields in Ohio. Soil Science Society of America Journal. 76(5):1798-1809. http://dx.doi.org/10.2136/sssaj2012.0055

Ladoni, M., A. Basir and A.N. Kravchenko. 2015. Which soil carbon characteristic is the best for assessing management differences? View from statistical power perspective. Soil Science Society of America Journal. 79:848-857. http://dx.doi.org/10.2136/sssaj2014.10.0426

Ladoni, M., A.N. Kravchenko and G.P. Robertson. 2015. Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PLOS ONE. http://dx.doi.org/10.1371/journal.pone.0143358

Ladoni, M., A. Basir, G.P. Robertson and A.N. Kravchenko. 2016. Scaling-up: cover crops differentially influence soil carbon in agricultural fields with diverse topography. Agriculture, Ecosystems and Environment. 225:93-103. http://dx.doi.org/10.1016/j.agee.2016.03.021

Li, A., B.D. Duval, R. Anex, P. Scharf, J.M. Ashtekar and P.R. Owens. 2016. A case study of environmental benefits of sensor-based nitrogen application in corn. Journal of Environmental Quality. 45(2):675-683. http://dx.doi.org/10.2134/jeq2015.07.0404

McGuire, J., L.W. Morton and A. Cast. 2013. Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. Agriculture and Human Values. 30:57-69. http://dx.doi.org/10.1007/s10460-012-9381-y

Mitchell D.C., M.J. Castellano, J.E. Sawyer and J.L. Pantoja. 2013. Cover crop effects on nitrous oxide emissions: Role of mineralizable carbon. Soil Science Society of America Journal. 77:1765-1773. http://dx.doi.org/10.2136/sssaj2013.02.0074

Mitchell, D.C., M.J. Helmers, T.B. Parkin, X.B. Zhou and M.J. Castellano. 2014. Comparing nitrate sink strength in perennial filter strips at toeslope of cropland watersheds. Journal of Environmental Quality. 44(1):191-199. http://dx.doi.org/10.2134/jeq2014. 05.0201

Morton, L.W. 2014. The science of variable climate and agro-ecosystem management. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):207A-212A. http://dx.doi.org/10.2489/jswc.69.6.207A

Morton, L.W. 2014. Achieving water security in agriculture the human factor. Agronomy Journal. 106:1-4. http://dx.doi.org/10.2134/agronj14.0039

Morton, L.W. and K.R. Olson. 2013. Birds Point-New Madrid Floodway: Redesign, reconstruction and restoration. Journal of Soil and Water Conservation. 68(2): 35A-40A. http://dx.doi.org/10.2489/jswc.68.2.35A

Morton, L.W., J. Hobbs and J.G. Arbuckle. 2013. Shifts in farmer uncertainty over time about sustainable farming practices and modern farming reliance on commercial fertilizers, insecticides and herbicides. Journal of Soil and Water Conservation. 68(1):1-12. http://dx.doi.org/10.2489/jswc.68.1.1

Morton, L.W., J. Hobbs, J. Arbuckle and A. Loy. 2015. Upper Midwest climate variations: Farmer responses to excess water risks. Journal of Environmental Quality. 44(3):810-822. http://dx.doi.org/10.2134/jeq2014.08.0352

Morton, L.W., S. Eigenbrode and T. Martin. 2015. The architecture of adaptive integration: Coordinated Agricultural Projects. Ecology and Society. 20(4): http://dx.doi.org/10.5751/ES-07788-200405

Mukherjee, A. and R. Lal. 2014. Comparison of soil quality index using three methods. PLOS ONE. 9(8):1-15. http://dx.doi.org/10.1371/journal.pone.0105981

Mukherjee, A. and R. Lal. 2015. Short-term effects of cover cropping on quality of a Typic Argiaquolls in central Ohio. Catena. 131:125-129. http://dx.doi.org/10.1016/j.catena.2015.02.025

Mukherjee, A. and R. Lal. 2015. Tillage effects on quality of organic and mineral soils under on-farm conditions in Ohio. Environmental Earth Science. 74:815-1822. http://dx.doi.org/10.1007/s12665-015-4189-x

Munoz-Robayo, J.D. and A.N. Kravchenko. 2012. Deriving the optimal scale for relating topographical attributes and cover crop plant biomass. Geomorphology. 179:197-207. http://dx.doi.org/10.1016/j.geomorph.2012.08.011

Nakajima, T. and R. Lal. 2014. Tillage and drainage management effect on soil gas diffusivity. Soil and Tillage Research. 135:71-78. http://dx.doi.org/10.1016/j.still.2013.09.003

Nakajima, T. and R. Lal. 2015. Comparison of greenhouse gas emissions monitored with a photoacoustic infrared spectroscopy multi-gas monitor and a gas chromatograph from a Crosby silt loam. Carbon Management. 6(1-2):69-76. http://dx.doi.org/10.1080/17583004.2015.1080473

Nakajima, T., R. Lal and S. Jiang. 2015. Soil quality index of crosby silt loam in central Ohio. Soil and Tillage Research. 146(B):323-328. http://dx.doi.org/10.1016/j.still.2014.10.001

Necpálová, M., R.P. Anex, A.N. Kravchenko, L.J. Abendroth, S.J. Del Grosso, W.A. Dick, M.J. Helmers, D. Herzmann, J.G. Lauer, E.D. Nafziger, J.E. Sawyer, P.C. Scharf, J.S.Strock and M.B. Villamil. 2014. What does it take to detect a change in soil carbon stock? A regional comparison of minimum detectable difference and experiment duration in the North-Central United States. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):517-531. http://dx.doi.org/10.2489/jswc.69.6.517

Necpálová, M., R.P. Anex, M.N. Fienen, S.J. Del Grosso, M.J. Castellano and J.E. Sawyer. 2015. Understanding the DayCent model: calibration, sensitivity, and identifiability through inverse modeling. Environmental Modeling & Software. 66:110-130. http://dx.doi.org/10.1016/j.envsoft.2014.12.011

Negassa, W., A.K. Guber, A.N. Kravchenko, T.L. Marsh, B. Hildebrandt and M.L. Rivers. 2015. Properties of soil pore space regulate pathways of plant residue decomposition and community structure of associated bacteria. PLOS ONE. 10(4):1-22. http://dx.doi.org/10.1371/journal.pone.0123999

Negassa, W., R. Price, A. Basir, S.S. Snap and A.N. Kravchenko. 2015. Cover crop and tillage system effects on soil CO_2 and N_2O fluxes at contrasting topographic positions. Soil and Tillage Research. 154:64-74. http://dx.doi.org/10.1016/j.still.2015.06.015

Obade, V. and R. Lal. 2014. Soil quality evaluation under different land management practices. Environmental Earth Sciences. 72:4531-4549. http://dx.doi.org/10.1007/s12665-014-3353-z

Obade, V. and R. Lal. 2014. Using meta-analyses to assess pedo-variability under different land uses and soil management in central Ohio, USA. Geoderma. 232-234:56-68. http://dx.doi.org/10.1016/j.geoderma.2014.04.030

O’Leary, G.J., B. Christy, J. Nuttall, N. Huth, D. Cammarano, C. Stöckle, B. Basso, I. Shcherbak, G. Fitzgerald, Q. Luo, I. Farre-Codina, J. Palta and S. Asseng. 2015. Response of wheat growth, grain yield and water use to elevated CO_2 under a Free-Air CO_2 Enrichment (FACE) experiment and modelling in a semi-arid environment. Global Change Biology. 21:2670-2686. http://dx.doi.org/10.1111/gcb.12830

Oliveira, L.F. and P.C. Scharf. 2014. Diurnal variability in reflectance measurements from cotton. Crop Science. 54:1769-1781. http://dx.doi.org/10.2135/cropsci2013.04.0217

Olson, K.R. and L.W. Morton. 2013. Impacts of 2011. Len Small levee breach on private and public Illinois lands (July/August). Journal of Soil and Water Conservation. 68(4): 89A-95A. http://dx.doi.org/10.2489/jswc.68.4.89A

Olson, K.R. and L.W. Morton. 2013. Soil and crop damages as a result of levee breaches on Ohio and Mississippi rivers. Journal of Earth Science and Engineering. 3(3):139-158. http://www.davidpublishing.com/davidpublishing/Upfile/7/20/2013./2013.072001676346.pdf

Olson, K.R. and L.W. Morton. 2014. Dredging of the fractured bedrock laden Mississippi river channel at Thebes, Illinois. Journal of Soil and Water Conservation. 69(2):31A-35A. http://dx.doi.org/10.2489/jswc.69.2.31A

Olson, K.R. and L.W. Morton. 2014. The 2011 Ohio River flooding of the Cache River valley in southern Illinois. Journal of Soil and Water Conservation. 69(1):5A-10A. http://dx.doi.org/10.2489/jswc.69.1.5A

Panagopoulos, Y., P.W. Gassman, R. Arritt, D.E. Herzmann, T. Campbell, M.K. Jha, C.L. Kling, R. Srinivasan, M. White and J.G. Arnold. 2014. Surface water quality and cropping systems sustainability under a changing climate in the Upper Mississippi River Basin. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):483-494. http://dx.doi.org/10.2489/jswc.69.6.483

Panagopoulos, Y., P.W. Gassman, R.W. Arritt, D.E. Herzmann, T.D. Campbell, A. Valcu, M.K. Jha, C.L. Kling, R. Srinivasan, M. White and J.G. Arnold. 2015. Impacts of climate change on hydrology, water quality and crop productivity in the Ohio-Tennessee River Basin. International Journal of Agricultural and Biological Engineering. 8(3):36-53. https://ijabe.org/index.php/ijabe/article/view/1497/pdf_1

Panagopoulos, Y., P.W. Gassman, T. Campbell, M.K. Jha, C.L. Kling, R. Srinivasan, M. White and J.G. Arnold. 2015. Towards the development of an integrated modeling system for the Corn Belt: A refined regional modeling approach. Journal of Hydrology. 524:348-366. http://dx.doi.org/10.1016/j.jhydrol.2015.02.039

Panday D. and N.V. Nkongolo. 2016. Comparison of models for predicting pore space indices and their relationships with CO_2 and N_2O fluxes in a corn-soybean field. Canadian Journal of Soil Science. http://dx.doi.org/10.1139/CJSS-2015-0074

Panday, D. and N.V. Nkongolo. 2015. Soil water potential control of the relationship between moisture and greenhouse gases fluxes in corn-soybean field. Climate. 3(3):689-696. http://dx.doi.org/10.3390/cli3030689

Pantoja, J.L. and J.E. Sawyer. 2016. Winter rye cover crop biomass production, degradation, and nitrogen recycling. Agronomy Journal. 108(2):841-853. http://dx.doi.org/10.2134/agronj2015.0336

Pantoja, J.L., K.P. Woli, J.E. Sawyer and D.W. Barker. 2015. Corn nitrogen fertilization requirement and corn soybean productivity with a rye cover crop. Soil Science Society of America Journal. 79(5):1482-1495. http://dx.doi.org/10.2136/sssaj2015.02.0084

Prokopy L., J.G. Arbuckle, A.P. Barnes, V.R. Haden, A. Hogan, M.T. Niles and J.C. Tyndall. 2015. Farmers and climate change: a cross-national comparison of beliefs and risk perceptions in high income countries. Environmental Management. 56:492-504. http://dx.doi.org/10.1007/s00267-015-0504-2

Prokopy, L., L. Morton, J. Arbuckle, A. Mase and A. Wilke. 2014. Agricultural stakeholder views on climate change: Implications for conducting research and outreach. Bulletin of the American Meteorological Society. 96(2):81-90. http://dx.doi.org/10.1175/BAMS-D-13-00172.1

Prokopy, L.S., C.E. Hart, R. Masse, M. Widhalm, J. Klink, J. Andresen, J. Angel, T. Blewett, O.C. Doering, R. Elmore, B.M. Gramig, P. Guinan, B.L. Hall, A. Jain, C.L. Knutson, M.C. Lemos, L.W. Morton, D. Niyogi, R. Power, M.D. Shulski, C.X. Song, E.S. Takle and D. Todey. 2015. Using a team survey to improve team communication for enhanced delivery of agro-climate decision support tools. Agricultural Systems. 138:31-37. http://dx.doi.org/10.1016/j.agsy.2015.05.002

Prokopy, L.S., J.S. Carlton, J.G. Arbuckle, T. Haigh, M.C. Lemos, A.S. Mase, N. Babin, M. Dunn, J. Andresen, J. Angel, C. Hart and R. Power. 2015. Extension's role in disseminating information about climate change to agricultural stakeholders in the United States. Climatic Change. 130:261-272. http://dx.doi.org/10.1007/s10584-015-1339-9

Prokopy, L.S., T. Haigh, A.S. Mase, J. Angel, C. Hart, C. Knutson, M.C. Lemos, Y. Lo, J. McGuire, L.W. Morton,

J. Perron, D. Todey and M. Widhalm. 2013. Agricultural advisors: A receptive audience for weather and climate information? Weather, Climate, and Society. 5:162-167. http://dx.doi.org/10.1175/WCAS-D-12-00036.1

Rabatyagor, S., A. Valcu and C. Kling. 2013. Reversing property rights: practice-based approaches for controlling agricultural nonpoint-source water pollution when emissions aggregate nonlinearly. American Journal of Agricultural Economics. 96(2):397-419. http://dx.doi.org/10.1093/ajae/aat094

Rabotyagov, S., A. Valcu, C.L. Kling, P.W. Gassman, N.N. Rabalais and R.E. Turner. 2014. The economics of dead zones: causes, impacts, policy challenges, and a model of the Gulf of Mexico Hypoxic Zone. Review of Environmental Economics and Policy. 8(1):58-79. http://dx.doi.org/10.1093/reep/ret024

Rabotyagov, S., T. Campbell, M. White, J. Arnold, J. Atwood, L. Norfleet, C. Kling, P. Gassman, A. Valcu, J. Richardson, G. Turner and N. Rabalais. 2014. Cost-effective targeting of conservation investments to reduce the northern Gulf of Mexico hypoxic zone. Proceedings of the National Academy of Sciences. 111(52):18530-18535. http://dx.doi.org/10.1073/pnas.1405837111

Rabotyagov, S.S., A. Valcu, C.L. Kling, T. Campbell, P.W. Gassman and M. Jha. 2014. An improved reverse auction for addressing water quality in agricultural watersheds using coupled simulation-optimization models. Frontiers of Economics in China. 9(1):25-51. http://journal.hep.com.cn/fec/EN/10.3868/s060-003-014-0003-1

Rafique, R., M.N. Fienen, T.B. Parkin and R.P. Anex. 2013. Nitrous oxide emissions from cropland: A procedure for calibrating the DAYCENT biogeochemical model using inverse modeling. Water, Air, & Soil Pollution. 224-1677: 1-15. http://dx.doi.org/10.1007/s11270-013-1677-z

Roley S., J. Tank, J.C. Tyndall and J. Witter. 2016. How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin? Water Resources & Economics. http://dx.doi.org/10.1016/j.wre.2016.06.003

Scharf, P.C., D.K. Shannon, H.L. Palm, K.A. Sudduth, S.T. Drummond, N.R. Kitchen, L.J. Mueller, V.C. Hubbard and L.F. Oliveira. 2011. Sensor-based nitrogen applications out-performed producer-chosen rates for corn in on-farm demonstrations. Agronomy Journal. 103:1683-1691. http://dx.doi.org/10.2134/agronj2011.0164

Schilling, K., P. Gassman, C. Kling, T. Campbell, M. Jha and C. Wolter. 2013. The potential for agricultural land use change to reduce flood risk in a large Midwestern watershed, U.S.A. Hydrological Processes. 28:3314-3325. http://dx.doi.org/10.1002/hyp.9865

Sengupta, A. and W.A. Dick. 2015. Bacterial community diversity in soil under two tillage practices as determined by pyrosequencing. Microbial Ecology. 70(3):853-859. http://dx.doi.org/10.1007/s00248-015-0609-4

Smidt, S.J., E.M.K. Haacker, A.D. Kendall, J.D. Deines, L. Pei, K.A. Cotterman, H. Li, X. Liu, B. Basso and D.W. Hyndman. 2016. Complex water management in modern agriculture: Trends in the water-energy-food nexus over the High Plains Aquifer. Science of the Total Environment. 566-567:988-1001. http://dx.doi.org/10.1016/j.scitotenv.2016.05.127

Tyndall, J., J.G. Arbuckle, T. Haigh, C. Knutson, L.W. Morton, L.S. Prokopy and M. Widhalm. 2015. New atlas features Corn Belt farmers' perspectives on agriculture and climate. Journal of Extension. 53(1):1-4. http://www.joe.org/joe/2015.february/pdf/JOE_v53_1tt9.pdf

Tyndall, J.C. and G. Roesch. 2014. A standardized approach to the financial analysis of structural water quality BMPs. Journal of Extension. 52(3):1-12. http://www.joe.org/joe/2014.june/a10.php

Wilke, A.K. and L.W. Morton. 2015. Climatologists' patterns of conveying climate science to the agricultural community. Agriculture and Human Values. 32:99-110. http://dx.doi.org/10.1007/s10460-014-9531-5

Wilke, A.K. and L.W. Morton. 2015. Communicating climate science: Components for engaging the agricultural audiences. Science Communication. 37(3):371-395. http://dx.doi.org/10.1177/1075547015581927

Zuber, S.M. and M.B. Villamil. 2016. Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities. Soil Biology and Biochemistry. 97:176-187. http://dx.doi.org/10.1016/j.soilbio.2016.03.011

Zuber, S.M., G.D. Behnke, E.D. Nafziger and M.B. Villamil. 2015. Crop rotation and tillage effects on soil physical and chemical properties in Illinois. Agronomy Journal. 107(3): 1-8. http://dx.doi.org/10.2134/agronj14.0465

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ENDNOTES (IN TEXT REFERENCES)

Abendroth, L.J., R.W. Elmore, M.J. Boyer and S.K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Abbott, K.C., J.P. Harmon and N.S. Fabina. 2011. The challenge of predicting temperature effects on short-term predator–prey dynamics. Population ecology. 56(2):375-392. http://dx.doi.org/10.1007/s10144-013-0426-x

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science and Technology. 42:822–830. doi:10.1021/es0716103

Arbuckle, J.G., J. Hobbs, A. Loy, L.W. Morton, L. Prokopy and J. Tyndall. 2014. Understanding farmer perspectives on climate change to inform engagement strategies for adaptation and mitigation. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):505-516. http://dx.doi.org/10.2489/jswc.69.6.505

Arbuckle, J., L.W. Morton and J. Hobbs. 2015. Understanding farmer perspectives on climate change adaptation and mitigation: The roles of trust in sources of climate information, climate change beliefs, and perceived risk. Environment and Behavior. 47:205-234. http://dx.doi.org/10.1177/0013916513503832

Arbuckle, J.G. Jr., L.S. Prokopy, T. Haigh, J. Hobbs, T. Knoot, C. Knutson, A. Loy, A.S. Mase, J. McGuire, L.W. Morton, J. Tyndall and M. Widhalm. 2013. Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. Climatic Change. 117(4):943-950. http://dx.doi.org/10.1007/s10584-013-0707-6

Arbuckle, J.G. Jr., L.W. Morton and J. Hobbs. 2013. Farmer beliefs and concerns about climate change and attitudes towards adaption and mitigation: Evidence from Iowa. Climatic Change. 118:51-563. http://dx.doi.org/10.1007/s10584-013-0700-0

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

Arritt, R. 2016. Climate change in the Corn Belt. Cropping Systems Coordinated Agricultural Project (CAP): Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems, Iowa State University, Ames, IA. Pub. No. CSCAP-0193-2016.

Bale, J.S., G.J. Masters, I.D. Hodkinson, C. Awmack, T. M. Bezemer, V.K. Brown, J. Butterfield, A. Buse, J.C. Coulson, J. Farrar, J.G. Good, R. Harrington, S. Hartley, T. H. Jones, R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt and J.B. Whittaker. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology. 8:1-16. http://dx.doi.org/10.1046/j.1365-2486.2002.00451.x

Bale, J. S. and S.A.L. Hayward. 2010. Insect overwintering in a changing climate. Journal of Experimental Biology. 213:980-994. http://dx.doi.org/10.1242/jeb.037911

Bowling, L. 2012. The water balance. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0123-2012.

Cannon, R.J.C. 1998. The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. Global Change Biology. 4:785-796. http://dx.doi.org/10.1046/j.1365-2486.1998.00190.x

Castellano, M. 2012. Nitrous oxide and greenhouse gas. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0113-2012.

Church, S.P., T. Haigh, M. Widhalm, L.S. Prokopy, J.G. Arbuckle Jr., J. Hobbs, T. Knoot, C. Knutson, A. Loy, A.S. Mase, J. McGuire, L.W. Morton and J. Tyndall. 2015. Farmer perspectives on agricultural practices, information, and weather variability in the Corn Belt: A Statistical Atlas Volume 2. Pub. No. CSCAP-0184-2015. West Lafayette, IN.

Dermody, O., B.F. O'Neill, A.R. Zangerl, M.R. Berenbaum and E.H. DeLucia. 2008. Effects of elevated CO_2 and O^{-3} on leaf damage and insect abundance in a soybean agroecosystem. Arthropod-Plant Interactions. 2:125-135. http://dx.doi.org/10.1007/s11829-008-9045-4

Dick, W. 2012. No-tillage impacts on soil carbon, nitrogen and water. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0114-2012.

Dunbar, M.W., M.E. O'Neal and A.J. Gassmann. 2016. Increased risk of insect injury to corn following rye cover crop. Journal of Economic Entomology. http://dx.doi.org/10.1093/jee/tow101

Dunbar, M.W., M.E. O'Neal and A.J. Gassmann. 2016. Effects of Field History on Corn Root Injury and Adult Abundance of Northern and Western Corn Rootworm (Coleoptera: Chrysomelidae). Journal of Economic Entomology. *In press*.

Dunbar, M.W., A.G. Gassmann and M.E. O'Neal. Impacts of rye cover crop on beneficial arthropods. Environmental Entomology. *In review* (A).

Dunbar, M.W., A.G. Gassmann and M.E. O'Neal. Impacts of rotation schemes on epigeal beneficial arthropods. Environmental Entomology. *In review* (B).

Frankenberger, J. 2012. Drainage water management. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0111-2012.

Gassmann, A.L., J.L. Petzold-Maxwell, R.S. Keweshan and M.W. Dunbar. 2011. Field-evolved resistance to Bt maize by western corn rootworm. PLOS ONE. 6(7):e22629. http://dx.doi.org/10.1371/journal.pone.0022629

Haigh, T, L.W. Morton, L.S. Prokopy, C. Knutson, M. Lemos, Y.J. Lo and J. Angel. 2015. Agricultural advisors as climate information intermediaries: Exploring differences in capacity to communicate climate. Weather, Climate and Society. 7:1:83-93. http://dx.doi.org/10.1175/WCAS-D-12-00036.1.

Herzmann, D.E., L.J. Abendroth and L.D. Bunderson. 2014. Data management approach to multidisciplinary agricultural research and syntheses. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):180A-185A. http://dx.doi.org/10.2489/jswc.69.6.180A

Johnson, W.C., B. Werner, G.R. Guntenspergen, R.A. Voldseth, B. Millett, D.E. Naugle, M. Tulbure, R.W.H. Carroll, J. Tracy, and C. Olawsky. 2010. Prairie wetland complexes as landscape functional units in a changing climate. Bioscience. 60:128-140.

Kladivko, E.J., M.J. Helmers, L.J. Abendroth, D. Herzmann, R. Lal, M. Castellano, D.S. Mueller, J.E. Sawyer, R.P. Anex, R.W. Arritt, B. Basso, J.V. Bonta, L. Bowling, R.M. Cruse, N.R. Fausey, J. Frankenberger, P. Gassman, A.J. Gassmann, C.L. Kling, A. Kravchenko, J.G. Lauer, F.E. Miguez, E.D. Nafziger, N. Nkongolo, M. O'Neal, L.B. Owens, P. Owens, P. Scharf, M.J. Shipitalo, J.S. Strock and M.B. Villamil. 2014. Standardized research protocols enable transdisciplinary research of climate variation impacts in corn production systems. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):532-542. http://dx.doi.org/10.2489/jswc.69.6.532

Kravchenko, A. 2012. Soil organic carbon cycle. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0121-2012.

Lal, R. 2014. Societal value of soil carbon. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6):186A-192A. http://dx.doi.org/10.2489/jswc.69.6.186A

Lal, R. 2015a. Soil carbon sequestration and aggregation by cover cropping. Journal of Soil and Water Conservation. 70:329-339. http://dx.doi.org/10.2489/jswc.70.6.329

Lal, R. 2015b. A system approach to conservation agriculture. Journal of Soil and Water Conservation. 70:82A-88A. http://dx.doi.org/10.2489/jswc.70.4.82A

Laws. L., L.W. Morton, L. Abendroth, R. Anex, J. G. Arbuckle, B. Bailey, B. Basso, L. Bunderson, M. Castellano, N. Cook, B. Dalzell, V. Davis, D. Eastburn, K. Eastman, J. Frankenberger, M. Helmers, J. Hobbs, D. Hudgins, C. Ingels, E. Kladivko, C. Kling, A. Kravchenko, J. Kriva, A. Loy, M. McGinity, D. Mueller, R. Nagelkirk, M. O'Neal, D. Riecks, G. Roesch-McNally, J. Sawyer, P. Scharf, J. Strock, D. Todey, M. Widhalm and K. Wise. 2014. Resilient Agriculture. Cropping Systems Coordinated Project (CAP): Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems, Iowa State University, Ames, IA. Pub. No. CSCAP-0159-2014. http://store.extension.iastate.edu/Product/Resilient-Agriculture

Liebhold, A.M. and P.C. Tobin. 2008. Population ecology of insect invasions and their management. Annual Review of Entomology. 53:387-408. http://dx.doi.org/10.1146/annurev.ento.52.110405.091401

Loy, A., J. Hobbs, J.G. Arbuckle Jr., L.W. Morton, L.S. Prokopy, T. Haigh, T. Knoot, C. Knutson, A.S. Mase, J. McGuire, J. Tyndall and M. Widhalm. 2013. Farmer perspectives on agriculture and weather variability in the Corn Belt: A Statistical Atlas Volume 1. Cropping Systems Coordinated Agricultural Project (CAP): Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems, Iowa State University, Ames, IA. Pub. No. CSCAP 0153- 2013.

McCornack, B.P., D. W. Ragsdale and R. C. Venette. 2004. Demography of soybean aphid (Homoptera: Aphididae) at summer temperatures. Journal of Economic

Entomology. 97: 854-861. http://dx.doi.org/10.1603/0022-0493(2004)097

McGuire, J., L.W. Morton and A. Cast. 2013. Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. Agriculture and Human Values. 30:57-69. http://dx.doi.org/10.1007/s10460-012-9381-y

McGuire, J., L.W. Morton, J.G. Arbuckle and A. Cast. 2015. Farmer identities and responses to the social-biophysical environment. Rural Studies. 39:145-155. http://dx.doi.org/10.1016/j.jrurstud.2015.03.011

Meisner, M.H., J.P. Harmon and A.R. Ives. 2014. Temperature effects on long-term population dynamics in a parasitoid-host system. Ecological Monographs. 84:457-476. http://dx.doi.org/10.1890/13-1933.1

Melillo, J. M., T.C. Richmond, and G. W. Yohe (Eds.). 2014. Climate change impacts in the United States: The third national climate assessment. U.S. global change research program, 841 pp. http://dx.doi.org/10.7930/J0Z31WJ2

Mourtzinis, S., J.E. Specht, L.E. Lindsey, W.J. Wiebold, J. Ross, E.D. Nafziger, H.J. Kandel, N. Mueller, P.L. Devillez, F.J. Arriaga and S.P. Conley. 2015. Climate-induced reduction in US-wide soybean yields underpinned by region- and in-season-specific responses. Nature Plants. 1:1-4. http://dx.doi.org/10.1038/NPLANTS.2014.26

Morton, L.W. 2014. The science of variable climate and agroecosystem management. Journal of Soil and Water Conservation, Special Issue for Climate and Agriculture. 69(6): 207A-212A. http://dx.doi.org/10.2489/jswc.69.6.207A

Morton, L.W., J. Hobbs, J. Arbuckle and A. Loy. 2015. Upper Midwest climate variations: Farmer responses to excess water risks. Journal of Environmental Quality. 44(3):810-822. http://dx.doi.org/10.2134/jeq2014.08.0352

Morton, L.W., G. Roesch-McNally and A. Wilke. Upper Midwest farmer perceptions: Too much uncertainty about impacts of climate change to justify changing current agricultural practices. *In Review*.

Necpalova, M., R. Anex and A. Kravchenko. 2013. Detecting change in soil carbon stock. CSCAP Annual Conference, West Lafayette, IN. July 29-Aug. 1, 2013.

O'Neill, B.F. A.R. Zangerl, O. Dermody, D. Bilgin, C.L. Casteel, J.A. Zavala, E.H. DeLucia and M.R. Berenbaum. 2010A. Impact of Elevated Levels of Atmospheric CO_2 and Herbivory on Flavonoids of Soybean (Glycine max Linnaeus). Journal of Chemical Ecology. 36:35-45. http://dx.doi.org/10.1007/s10886-009-9727-0

O'Neill, B.F., A.R. Zangerl, E.H. DeLucia, C.L. Casteel, J.A. Zavala, and M.R. Berenbaum. 2011. Leaf temperature of soybean grown under elevated CO_2 increases Aphis glycines (Hemiptera:Aphididae) population growth. Insect Science. 18:419-425. http://dx.doi.org/10.1111/j.1744-7917.2011.01420.x

Prokopy, L.S., T. Haigh, A.S. Mase, J. Angel, C. Hart, C. Knutson, M.C. Lemos, Y.J. Lo, J. McGuire, L.W. Morton, J. Perron, D. Todey and M. Widhalm. 2013. Agricultural advisors: A receptive audience for weather and climate information? Weather, Climate, and Society. 5:162-167. http://dx.doi.org/10.1175/WCAS-D-12-00036.1

Prokopy, L.S., L.W. Morton, J.G. Arbuckle Jr., A. Wilke and A. Mase. 2015a. Agricultural stakeholder views on climate change: Implications for conducting research and outreach. Bulletin of Atmospheric Meteorological Society. http://dx.doi.org/10.1175/BAMS-D-13-00172.1

Prokopy, L.S., J.G. Arbuckle Jr., A.P. Barnes, V.R. Haden, A. Hogan, M.T. Niles and J. Tyndall. 2015b. Farmers and climate change: A cross-national comparison of beliefs and risk perceptions in high- income countries. Environmental Management. http://link.springer.com/article/10.1007%2Fs00267-015-0504-2

Ribaudo, M. 2011. Reducing agriculture's nitrogen footprint: Are new policy approaches needed? Amber Waves (September) Feature. USDA-ERS. www.ers.usda.gov/AmberWAves/September11/Features/NitrogenFootprint.htm/

Roesch-McNally, G., J.G. Arbuckle and J.C. Tyndall. 2016. What would farmers do? Adaptation intentions under a Corn Belt climate change scenario. Agriculture and Human Values. *In Press.*

Romero-Lankao, P., J.B. Smith, D.J. Davidson, N.S. Diffenbaugh, P.L. Kinney, P. Kirshen, P. Kovacs and L. Villers Ruiz. 2014. North America. In: Climate Change 2014: Impacts, adaptation, and vulnerability. part B: Regional aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1439-1498.

Sawyer, J. 2012. Soil nitrogen cycle. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0109-2012.

Scharf, P. 2012. Nitrogen sensing and impact on C, N, and H2O. CSCAP Annual Conference, Wooster, OH. Aug. 7-9, 2012. Pub. No. CSCAP-0124-2012.

Slovic, P. 2009. The perception of risk. Taylor and Francis, Earthscan Ltd. UK.

Strock, J. 2016. Drainage water management. CSCAP Webinar, University of Minnesota Southwest Research and Outreach Center, Lamberton, MN. Feb. 11, 2016.

U.S. Environmental Protection Agency (EPA). 2015. Inventory of U.S. Greenhouse gas emissions and sinks: 1990-2013. Washington, DC. https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf

USDA ERS (USDA Economic Research Service). 2014. Corn Production. Washington, DC. http://www.ers.usda.gov/topics/crops/corn.aspx

USDA National Agricultural Statistics Service (NASS). 2009. 2007 Census of Agriculture. Washington, DC: U.S. Department of Agriculture National Agricultural Statistics Service.

USDA National Agricultural Statistics Service (NASS). 2016a. Prospective plantings (March 2016). Washington, DC. http://www.usda.gov/nass/PUBS/TODAYRPT/pspl0316.pdf

USDA National Agricultural Statistics Service (NASS). 2016b. Quick stats. Washington, DC. http://quickstats.nass.usda.gov/results/1316A25E-AEAD-3514-809C-E564298005DC

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright Morton and L.H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin No. 1935. Washington, DC. 186 pp.

Wilke, A.K. and L.W. Morton. 2015a. Climatologists' patterns of conveying climate science to the agricultural community. Agriculture and Human Values. 32(1):99-110, http://dx.doi.org/10.1007/s10460-014- 9531-5

Wilke, A.K. and L.W. Morton. 2015b. Communicating climate science: Components for engaging agricultural audiences. Communication Science. http://dx.doi.org/10.1177/1075547015581927

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[1] List of CSCAP institutions
The Sustainable Corn CAP project (officially referred to as the Climate and Corn-based Cropping Systems Coordinated Agricultural Project) is a transdisciplinary partnership among 11 institutions: Iowa State University, Lincoln University, Michigan State University, The Ohio State University, Purdue University, South Dakota State University, University of Illinois, University of Minnesota, University of Missouri, University of Wisconsin, USDA Agricultural Research Service – Columbus, Ohio, and USDA National Institute of Food and Agriculture (USDA-NIFA). (Award No. 2011-68002- 30190) http://sustainablecorn.org.

[2] List of CSCAP PIs. See PART 5.

Appendix A

Abbreviations and acronyms used in this report.

BMP	Best management practice
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
DOC	Dissolved organic carbon
GDU	Growing degree unit
HEL	Highly erodible land
HUC	Hydrologic unit code
MRTN	Maximum return to nitrogen
N	Nitrogen
NH_4	Ammonium
NT	No-tillage
N_2O	Nitrous oxide
NO_3	Nitrate
P	Phosphorus
S	Sulfur
SOC	Soil organic carbon
SOM	Soil organic matter
WCR	Western corn rootworm

Appendix B

TABLE 2

States within the Sustainable Corn CAP project region and corresponding corn, soybean, and wheat acreage, yield, and production value (USDA NASS 2016a, USDA NASS, 2016b). Values shown per individual year per state. At the end of the table, five year total for the 9-state region is included.

State	Crop	Year	Area Planted (Million Acres)	Area harvested (Million Acre)	Grain Yield (Bu/ha)	Grain Production Value (Billion $)
Illinois	corn	2011	12.60	12.35	157.0	12.118
		2012	12.80	12.25	105.0	8.837
		2013	12.00	11.80	178.0	9.494
		2014	11.90	11.75	200.0	8.719
		2015	11.70	11.50	175.0	7.346
	soybean	2011	8.95	8.91	47.5	5.417
		2012	9.05	8.93	43.0	5.606
		2013	9.50	9.48	50.0	6.257

Cont.

State	Crop	Year	Area Planted (Million Acres)	Area harvested (Million Acre)	Grain Yield (Bu/ha)	Grain Production Value (Billion $)
		2014	9.80	9.77	56.0	5.581
		2015	9.80	9.72	56.0	4.899
	wheat	2011	0.80	0.77	61.0	0.308
		2012	0.65	0.64	64.0	0.292
		2013	0.88	0.84	67.0	0.367
		2014	0.74	0.67	67.0	0.224
		2015	0.54	0.52	65.0	0.130
Indiana	corn	2011	5.90	5.75	146.0	5.297
		2012	6.25	6.03	99.0	4.316
		2013	6.00	5.83	177.0	4.613
		2014	5.90	5.77	188.0	4.068
		2015	5.65	5.48	150.0	3.165
	soybean	2011	5.30	5.29	45.5	3.057
		2012	5.15	5.12	44.0	3.312
		2013	5.20	5.19	51.5	3.528
		2014	5.45	5.44	55.5	3.080
		2015	5.55	5.50	50.0	2.434
	wheat	2011	0.43	0.41	62.0	0.164
		2012	0.33	0.29	67.0	0.139
		2013	0.46	0.44	73.0	0.204
		2014	0.39	0.34	76.0	0.133
		2015	0.29	0.26	68.0	0.087
Iowa	corn	2011	14.10	13.70	172.0	14.610
		2012	14.20	13.70	137.0	12.988
		2013	13.60	13.05	164.0	9.609
		2014	13.70	13.30	178.0	8.783
		2015	13.50	13.05	192.0	8.770
	soybean	2011	9.35	9.23	51.5	5.989
		2012	9.35	9.31	45.0	6.033
		2013	9.30	9.25	45.5	5.513
		2014	9.85	9.77	51.0	4.963
		2015	9.85	9.80	56.5	4.790
	wheat	2011	0.02	0.02	45.0	0.005
		2012	0.02	0.01	50.0	0.005
		2013	0.03	0.02	52.0	0.007
		2014	0.03	0.02	49.0	0.004
		2015	0.02	0.02	52.0	0.003
Michigan	corn	2011	2.50	2.19	153.0	2.057
		2012	2.70	2.38	132.0	2.102
		2013	2.60	2.23	155.0	1.445
		2014	2.55	2.21	161.0	1.299
		2015	2.35	2.07	162.0	1.174
	soybean	2011	1.95	1.94	44.5	1.045

Cont.

State	Crop	Year	Area Planted (Million Acres)	Area harvested (Million Acre)	Grain Yield (Bu/ ha)	Grain Production Value (Billion $)
		2012	2.00	1.99	43.0	1.198
		2013	1.93	1.92	44.5	1.102
		2014	2.05	2.04	42.5	0.876
		2015	2.03	2.02	49.0	0.851
	wheat	2011	0.70	0.68	75.0	0.340
		2012	0.56	0.54	76.0	0.322
		2013	0.62	0.59	75.0	0.297
		2014	0.55	0.47	74.0	0.200
		2015	0.51	0.48	81.0	0.217
Minnesota	corn	2011	8.10	7.70	155.0	7.268
		2012	8.75	8.33	165.0	9.168
		2013	8.60	8.14	159.0	5.565
		2014	8.20	7.55	156.0	4.217
		2015	8.10	7.60	188.0	4.858
	soybean	2011	7.10	7.04	39.0	3.405
		2012	7.05	7.00	43.5	4.354
		2013	6.70	6.62	42.0	3.587
		2014	7.35	7.27	41.5	3.005
		2015	7.60	7.55	50.0	3.247
	wheat	2011	1.58	1.52	46.1	0.565
		2012	1.39	1.34	57.0	0.621
		2013	1.23	1.18	56.7	0.449
		2014	1.26	1.21	54.8	0.364
		2015	1.53	1.47	59.9	0.422
Missouri	corn	2011	3.30	3.05	114.0	2.225
		2012	3.60	3.30	75.0	1.817
		2013	3.35	3.20	136.0	1.989
		2014	3.50	3.38	186.0	2.226
		2015	3.25	3.08	142.0	1.596
	soybean	2011	5.35	5.21	36.5	2.377
		2012	5.40	5.27	30.0	2.292
		2013	5.65	5.61	36.0	2.646
		2014	5.65	5.59	46.5	2.597
		2015	4.55	4.48	40.5	1.633
	wheat	2011	0.79	0.69	50.0	0.230
		2012	0.78	0.68	58.0	0.272
		2013	1.08	0.99	57.0	0.368
		2014	0.88	0.74	58.0	0.230
		2015	0.76	0.61	53.0	0.134
Ohio	corn	2011	3.40	3.20	153.0	3.153
		2012	3.90	3.65	120.0	3.105
		2013	3.90	3.73	174.0	2.862

Cont.

State	Crop	Year	Area Planted (Million Acres)	Area harvested (Million Acre)	Grain Yield (Bu/ ha)	Grain Production Value (Billion $)
		2014	3.70	3.47	176.0	2.309
		2015	3.55	3.26	153.0	1.895
	soybean	2011	4.55	4.54	48.0	2.833
		2012	4.60	4.59	45.0	3.016
		2013	4.50	4.49	49.5	2.889
		2014	4.70	4.69	52.5	2.536
		2015	4.75	4.74	50.0	2.097
	wheat	2011	0.88	0.85	57.0	0.326
		2012	0.50	0.45	68.0	0.243
		2013	0.66	0.64	70.0	0.293
		2014	0.62	0.55	74.0	0.226
		2015	0.52	0.48	67.0	0.148
South Dakota	corn	2011	5.20	4.95	132.0	3.940
		2012	6.15	5.30	101.0	3.597
		2013	6.20	5.86	137.0	3.251
		2014	5.80	5.32	148.0	2.630
		2015	5.40	5.03	159.0	2.599
	soybean	2011	4.10	4.07	37.0	1.837
		2012	4.75	4.72	30.5	2.044
		2013	4.60	4.58	40.5	2.319
		2014	5.15	5.11	45.0	2.155
		2015	5.15	5.12	46.0	1.978
	wheat	2011	2.88	2.79	37.3	0.776
		2012	2.40	2.23	45.9	0.821
		2013	2.49	1.84	42.2	0.530
		2014	2.51	2.36	55.5	0.728
		2015	2.76	2.24	46.2	0.484
Wisconsin	corn	2011	4.15	3.32	155.0	3.098
		2012	4.35	3.30	120.0	2.649
		2013	4.10	3.03	145.0	1.924
		2014	4.00	3.11	156.0	1.781
		2015	4.00	3.00	164.0	1.673
	soybean	2011	1.62	1.61	47.0	0.938
		2012	1.71	1.70	42.0	1.000
		2013	1.58	1.55	39.0	0.774
		2014	1.80	1.79	44.0	0.788
		2015	1.88	1.87	49.5	0.787
	wheat	2011	0.35	0.34	65.0	0.135
		2012	0.27	0.25	75.0	0.139
		2013	0.32	0.27	58.0	0.094
		2014	0.30	0.25	65.0	0.077
		2015	0.23	0.21	74.0	0.069

Cont.

State	Crop	Year	Area Planted (Million Acres)	Area harvested (Million Acre)	Grain Yield (Bu/ ha)	Grain Production Value (Billion $)
Midwest United States			Five Year Total Planted Acres (2011-2015)	Five Year Total Harvested Acres (2011-2015)	Five Year Average Grain Yield (2011-2015)	Five Year Total Grain Production Value (2011-2015)
	corn		299.05	281.25	152.22	212.20
	soybean		249.85	247.43	45.40	132.66
	wheat		37.50	34.14	61.10	12.19

Appendix C

Institutional research farms with one or more experimental plots as part of the team research.

Agricultural Drainage Water Quality–Research and Demonstration Site, Iowa State University

Agricultural Engineering and Agronomy Research Farms, Iowa State University

Arlington Agricultural Research Station, University of Wisconsin

Bradford Research and Extension Center, University of Missouri

Davis Purdue Agricultural Center, Purdue University

Freeman Farm, Lincoln University

Hicks Farm, Southwest Research and Outreach Center, University of Minnesota

Lancaster Agricultural Research Station, University of Wisconsin

Marshfield Agricultural Research Station, University of Wisconsin

Michigan State University Agronomy Farm: Mason Research Farm

North Appalachian Experimental Watershed Agricultural Research Station, USDA-ARS, Coshocton, Ohio

Northwest Agricultural Research Station, The Ohio State University

Northwestern Illinois Agricultural Research and Demonstration Center, University of Illinois

Ohio Agricultural Research and Development Center, The Ohio State University

On-farm DWM site in Pusheta Creek watershed, Clay Township, Auglaize County, OH, The Ohio State University

Orr Agricultural Research and Demonstration Center, University of Illinois

Southeast Purdue Agricultural Center, Purdue University

Southeast Research and Demonstration Farm, Iowa State University

Variable Input Crop Management Study, University of Minnesota

Waterman Agricultural and Natural Resources Laboratory, The Ohio State University

W.K. Kellogg Biological Station, Michigan State University

Appendix D

Overall management practices studied at 1 or more research site within the Sustainable Corn CAP research network.

Tillage
No Tillage
Conventional Tillage

Crop Rotations
continuous corn
continuous soybean
continuous wheat
corn-soybean rotation
corn-soybean- wheat rotation
corn-soybean- oats/alfalfa-alfalfa rotation
continuous corn with cereal rye cover crop
corn-soybean with cereal rye cover crop
corn-soybean- wheat with mixed cover crop

Drainage Water Management
No drainage
Conventional drainage (“free”)
Controlled drainage (“managed”)
Shallow drainage
Drainage with subirrigation

Nitrogen (N) Management
No nitrogen fertilizer applied
MRTN application of N fertilizer in spring
Sensor based N application

Landscape position
Near-summit
Side slope
Toe slope

Appendix E

Biophysical data collected at one or more research sites following standardized protocols (Kladivko et al. 2014). Data collected at 10 or more locations included here; other data collected not included for brevity.

Agronomic

Corn
Plant population of corn
Corn vegetative biomass at maturity
Corn vegetative biomass total carbon
Corn vegetative biomass total nitrogen
Corn grain yield
Corn grain moisture
Corn grain total carbon
Corn cob total carbon
Corn grain total nitrogen
Corn cob total nitrogen
Corn cob biomass
Corn grain biomass

Soybean
Plant population of soybean
Soybean vegetative biomass at maturity
Soybean vegetative biomass total carbon
Soybean vegetative biomass total nitrogen
Soybean grain yield
Soybean grain moisture
Soybean grain total carbon
Soybean grain total nitrogen
Soybean grain biomass

Wheat
Wheat grain yield
Wheat grain moisture
Wheat grain total carbon
Wheat grain total nitrogen

Cover Crop
Cover crop (rye) biomass at spring termination
Rye biomass total carbon
Rye biomass total nitrogen

Weather

Precipitation (rain and melted snow)
Temperature of air, minimum
Temperature of air, maximum
Wind speed
Wind direction
Relative humidity
Solar radiation

Greenhouse Gas

Nitrous Oxide (N_2O-N)
Carbon Dioxide (CO_2-C)
Volumetric soil moisture (%) at 5 cm
Soil temperature at 5 cm

Soil

Dry bulk density
Water retention
Soil moisture
pH
Cation Exchange Capacity (CEC)
Soil Organic Carbon (SOC)
Total N
Soil Nitrate
Standard soil fertility routine analysis
Soil texture
Percent sand
Percent silt
Percent clay

Water

Nitrate-N concentration in tile
Dissolved Organic Carbon concentration (DOC)

The Climate and Corn-based Cropping Systems CAP (Sustainable Corn CAP) is a USDA-NIFA supported program, Award No. 2011-68002-30190. It is a transdisciplinary partnership among 11 institutions creating new science and educational opportunities. The Sustainable Corn CAP seeks to increase resilience and adaptability of Midwest agriculture to more volatile weather patterns by identifying farmer practices and policies that increase sustainability while meeting crop demand.

SUSTAINABLE CORN.ORG
CROPS, CLIMATE, CULTURE AND CHANGE

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

Participating Institutions

Agricultural Research Service
Iowa State University
Lincoln University
Michigan State University
The Ohio State University
Purdue University
SDSU South Dakota State University
Illinois
University of Minnesota Driven to Discover℠
Wisconsin University of Wisconsin–Madison
University of Missouri

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useful to usable

A portion of the socioeconomic research findings were from a joint survey conducted in partnership with Useful to Usable (U2U): Transforming Climate Variability and Change Information for Cereal Crop Producers (Award No. 2011-68002-30220).

Additional funding was provided by these partners to expand the scope and reach of research by the Sustainable Corn CAP team.

USB United Soybean Board
USDA United States Department of Agriculture Natural Resources Conservation Service
Annie's
Farmers Advocating for Organics
Sustainable Food Trade Association
Organic Valley