RESILIENT AGRICULTURE

AUGUST 2014

ACKNOWLEDGMENTS

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THANK YOU

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SUSTAINABLE CORN.ORG
CROPS, CLIMATE, CULTURE AND CHANGE

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

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The Sustainable Corn Project at a Glance

The Sustainable Corn Project began in 2011 thanks to a grant from the U.S. Department of Agriculture National Institute of Food and Agriculture, which was seeking to invest in sound science that helps producers adapt or transform their corn-based cropping systems to be more resilient and sustainable under changing weather patterns and more frequent and extreme weather events.

Field Trials, Analysis and Modeling
Project scientists are collecting and analyzing data from 35 sites in eight states in the Corn Belt, using standardized protocols and a centralized database. They also are measuring crop production, pests and carbon (C), nitrogen (N) and water footprints as they examine the effects of various crop management practices. They are using models to evaluate the impacts of the practices on C, N and water footprints for different climate and economic scenarios. The practices include no-till, extended and diverse crop rotation, drainage water management, cover crops and canopy N-sensors. Team members aim to develop a suite of practices for corn-based cropping systems that:

> Researching a suite of practices for corn-based cropping systems

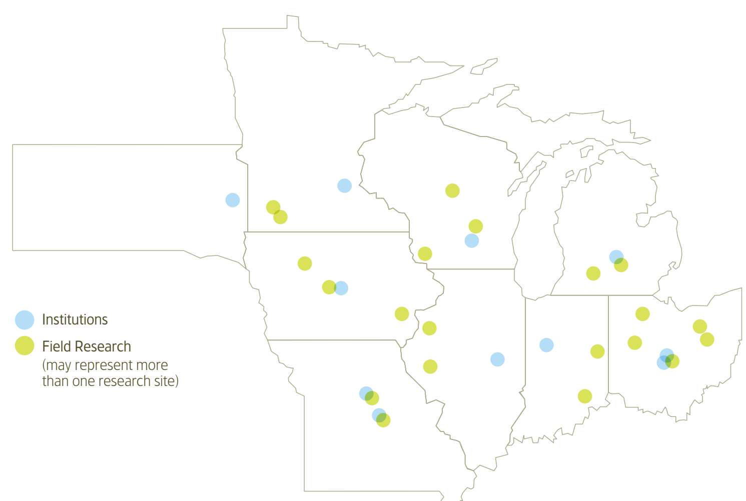
- Retain and enhance soil organic matter and nutrient and carbon stocks
- Reduce off-field nitrogen losses that contribute to greenhouse gas emissions and water pollution
- Better withstand droughts and floods
- Ensure productivity under different climate conditions

Social and Economic Research
The effectiveness of any adaption or mitigation action in Corn Belt agriculture depends on the degree to which the region's farmers are willing and able to act. Project social scientists are conducting social science research to assess farmers' understanding of climate change impacts and attitudes toward adaption and mitigative practices and strategies (pages 20–23).

Extension and Education
Through our extension team, who work at land-grant universities, we work with farmers to connect our science to their on-farm decisions and to learn from each other. And through the education aspect of the project, we involve graduate students (pages 44–45) and train teachers to ensure learning and scientific investigation of climate change impacts on Corn Belt agriculture continues.

On the following pages, the articles highlight the work of our team members and a portion of our findings, to-date. Read more about the Sustainable Corn Project, from the Director, on page 5.

FIGURE 1 | LOCATIONS OF PARTICIPATING INSTITUTIONS AND FIELD RESEARCH



Management Practices:
Corn-Soybean Rotation, Cereal Rye Cover Crop, Extended Crop Rotations, Organic Cropping System, Drainage Water Management, Nitrogen Fertilizer Management, Tillage Management, Landscape Position

SUSTAINABLE CORN TEAM

- 45 principal investigators (PIs)
- 11 project partner PIs
- 48 research or technical staff
- 23 extension educators
- 13 postdoctoral associates
- 53 graduate students
- 21 advisory board members

Team members are associated with the following institutions:

- University of Illinois
- Iowa State University
- Lincoln University
- Michigan State University
- University of Minnesota
- University of Missouri
- The Ohio State University
- Purdue University
- South Dakota State University
- University of Wisconsin
- USDA Agricultural Research Service, Columbus, Ohio

See Pages 47–49 for a complete team list, including Advisory Board members.

Resilience:

The ability of a system to absorb disturbances and still retain its basic function and structure … the challenge of servicing current system demands without eroding the potential to meet future needs.

EXCERPT FROM "RESILIENCE THINKING: SUSTAINING ECOSYSTEMS AND PEOPLE IN A CHANGING WORLD," BY BRIAN WALKER AND DAVID SALT

Researching Resilience: The Sustainable Corn Project

^ Sustainable Corn Project Director Lois Wright Morton (left) and Project Manager Lori Abendroth (right) discuss field layout and research plot design with team members Felix Heitkamp and Sandeep Kumar, at an Ohio State University field research site.

A MESSAGE FROM THE PROJECT DIRECTOR, LOIS WRIGHT MORTON, PH.D.

It is an exciting time to be in agriculture. The landscape is changing, bringing new opportunities, innovations, and more than a few challenges. In many ways, there has never been a better time to be farming. Our young people are energized by the promise of careers and livelihoods based in agriculture. However, with change comes uneven distribution of risks, vulnerability and opportunity. Past experiences with highly variable weather patterns and climate forecasts of more of the same suggest drought, saturated soils and extreme flooding, extreme heat and cold and greater weed and insect pressures. If farmers had only the information and tools to continue business as usual, we could expect increased off-farm losses of costly nitrogen and unacceptably high levels of nitrogen (N) and phosphorus (P) in water bodies, excessive soil erosion affecting fertility, corn yields ranging from 30 bu/ac to 350 bu/ac, volatile farmland prices and erratic markets that require constant adaptation for the unexpected.

But the underlying premise of the Sustainable Corn Project is that farmers are problem solvers and with sound science they are better able to identify and develop strategies necessary to adapt to economic, social and biophysical environments that are dynamic and continually surprising. Managing complex interconnected systems of carbon, water, and nitrogen takes science, intuition learned from experience that gives cues to stay put or do something different and a willingness to face risk head on, and use the results as feedback for future decisions.

Providing the science and training to new generations of farmers is the role of Land Grant Universities and the USDA Agricultural Research Service laboratories. We have a several decades-long and productive history of studying soil and agronomic processes and farmers' willingness and capacity to adapt to new technologies and changing conditions. We have monitored and experimented with interactions between nitrogen (N) and plant growth, N loss and water fluxes, soil organic carbon (SOC) storage in relation to soil quality and crop yields, tillage systems as best management practices for N loss, C storage contributions and water flux, and soil and SOC loss. Despite this scientific legacy, gaps remain in this body of work, particularly with respect to their long-term sustainability and resilience to climate variation and climate extremes.

. . . the underlying premise of the Sustainable Corn Project is that farmers are problem solvers and with sound science they are better able to identify and develop strategies necessary to adapt.

The Sustainable Corn Project, also known as the Climate & Corn-based Cropping Systems Coordinated Agricultural Project, is one of many investments USDA-NIFA has made over the last few years to better understand the impacts of a changing climate on the corn-soybean rotation and how to improve agriculture's capacity to manage the shocks and disturbances these weather trends bring. Funded in 2011, our charge is to increase what is known about a suite of practices that can help farmers create management systems that sustain a competitive agriculture and enhance the ecological integrity of the landscape. This project addresses the fragmented research on corn-based systems by uniquely integrating individual, discipline-based findings into a transdisciplinary and multi-state functional network that connects current and future scientists, farmers, educators, and extension specialists and facilitates learning and exchange of expert and local knowledge. A team of 140 current scholars (see pages 47-49) from 11 institutions across nine states are addressing these gaps with goals to identify adaptive strategies to prepare the North Central corn-based cropping system for increasingly variable and extreme weather.

In the pages that follow, our project team has selected some of our research findings to share with you. We hope our work helps you to think about climate uncertainty, impacts on agriculture and our water and soil resources, and what can be done to make the agricultural landscape both environmentally healthy and productive.

Lois Wright Morton, Ph.D., is a professor of sociology at Iowa State University and the project director for the Climate & Corn-based Cropping Systems Coordinated Agricultural Project, commonly known as the Sustainable Corn Project.

Corn Growth and Development: Climate Matters

BY LORI ABENDROTH

Corn is one of the world's most studied and geographically adaptable crops, with high yield potential making it a staple grain crop in the world. Incredibly proficient, it can produce more than 20,000 lbs/acre of above-ground dry matter in six months when supplied with ample sunlight, water and nutrients. For decades, U.S. corn yields have been increasing because of major advancements in plant breeding and crop management practices. Today, utilizing the best genetics and positioning them on the landscape appropriately remain important while good management within and across fields has never been more important. Understanding critical times and needs of corn development can help producers and agronomists weigh crop management options as climate patterns change and weather events more extreme.

> Corn roots can grow an inch per day and to a depth of 6 feet although most roots are in the upper two to three feet of the soil profile.

Corn development is correlated with air temperature and therefore, vegetative and reproductive development are predicted using growing degree days (GDD). The optimum temperature range for corn is 50° F to 86° F although growth does occur outside these temperatures to varying degrees. An important consideration is the impact changing temperature patterns have on the vegetative period as well as grain fill. A rise in nighttime temperatures can hasten development and is especially important during grain fill when starch is accumulating. High summer-time temperatures also will place additional stress on the vegetative period of development.

Extreme rainfalls, drought and timing of precipitation within and across seasons, are changing. Extreme rainfall early in the season heightens the risk of flooding and soil erosion as the crop is neither firmly established nor canopied. Prolonged, saturated soils or periods of flooding are detrimental to young seedlings as the whole plant may be submerged or the root system is in an anaerobic state for too long. Corn has two root systems with the initial helping to anchor the young plant, and the second, dominant system in place by knee-high (V6) (see photo on page 7) and at maximum size early in reproductive development. Corn roots can grow an inch per day and to a depth of six feet although most roots are in the upper two to three feet of the soil profile. Deep rooted plants in high organic soils, which have a higher water holding capacity, enable the crop to withstand moisture stress periods. Water stress mid-season is typically associated with shortages, not excess; as the plant is at its highest water use during the silking period (1/3 inch per day). This sensitivity to water stress can result in a reduction of kernels because of poor receptivity of the silks to shed pollen.

Prior to silking, the ear has 700 to 1,000 potential kernels; at harvest, it typically has developed 450 to 550 kernels. Following fertilization, stress will reduce yields early because of kernel abortion. Later in development, stress causes lighter kernels due to less starch accumulation. Overall, the development of grain takes approximately two months from silking to physiological maturity with the last month crucial for dry matter accumulation; temperature or moisture stress during this period will directly reduce yield.

A corn crop needs up to six months to progress through vegetative and reproductive development. During this time, the land and crops are exposed to variable weather, leaving the farmer to determine management strategies that can be employed pre- and mid-season to meet these challenges. The Sustainable Corn Project team is discovering and evaluating strategies that build greater resilience into our Midwest agricultural systems.

Lori Abendroth is the project manager of the Sustainable Corn Project with expertise in crop physiology and production and years of in-field agronomic research experience. She is lead author of the guide, "Corn Growth and Development," which is available at the Iowa State University Extension and Outreach store.

> Plant development from second leaf (V2) to physiological maturity (R6)

^ "Knee high" V6 corn.

Climate Change Impacts in the Corn Belt

BY DENNIS TODEY

Melting polar sea ice and rising sea levels are two large-scale impacts of a changing climate that are making the news. However, just as significant and newsworthy are the inland effects of climate change occurring within the Corn Belt that are impacting in-season crop development, where corn is grown, and changing the management decisions farmers face.

Precipitation

In the last 100 years, change in precipitation has been the most influential climate factor affecting the Corn Belt. While all locations in general have seen increased precipitation annually over the last 100 years, the largest increases are occurring in the northern and western Corn Belt. Summer season rainfall has increased nearly everywhere in the region. Fall precipitation has increased the most in the northwestern and far eastern Corn Belt with little change elsewhere. These trends have helped drive corn acreage expansion into the Dakotas and Minnesota, where precipitation has increased by over 15 percent.

> In the last 100 years, change in precipitation has been the most influential climate factor affecting the Corn Belt.

Consistent with long-term climate model projections, precipitation intensity also has increased, resulting in more precipitation occurring in larger events. These events often are detrimental to agricultural production, leading to increased soil erosion, flooding and other structural damage. The increases in precipitation and in-field flooding in recent years also have led to installation of more subsurface drainage tile.

Temperature

Historic temperature changes have been less pronounced and more seasonal. The most widespread temperature trend in the Corn Belt is generally warmer winters, especially over the last 30 years. The overall warmer trend has not eliminated colder winters (such as 2013–14). The trend has simply reduced their likelihood and severity. This increased temperature trend is stronger in the northern and western Corn Belt than elsewhere in the region. Warming winters impact the growing season length and winter-kill of insects. Warmer winters do not kill certain insects effectively and allow insects to overwinter further north, creating an easier path for migrating insects — both beneficial insects and pests — to be reintroduced.

^ Flooded fields and roads near Estelline, SD, April 2009. Extreme precipitation events are causing more frequent flooding.

Summer temperature trends in the region are largely flat overall with some minor upward (in the far east and north) or downward (in the west) trends. While the overall summer temperature trend is flat, there are differences in trends between maximum and minimum temperature. Average maximum temperatures are primarily flat. Average minimum temperatures are consistently rising during the summer and throughout the year across the whole Corn Belt.

The impacts of rising overnight minimum temperatures during the growing season are several. Increasing overnight minimums can lead to additional stress on crops during critical growth periods (as noted in the article by Lori Abendroth on page 6). Increasing frequency of warm overnight temperatures has reduced corn production in southern areas of the Corn Belt over the last 10 years. Warmer temperatures also contribute to disease potential.

Longer growing seasons

The warmer temperatures also are increasing growing season length. While still quite variable, frost-freeze dates are changing in the spring (earlier) and fall (later). Throughout the 20th century, the overall climate shifts have lengthened the growing season by 9-10 days or more across the Corn Belt. Agriculture has adapted to this, utilizing longer-maturity varieties and the extended growing season to create higher yielding crops. The largest impact of this change has been in northern areas of the Corn Belt where a lack of heat and shorter seasons have historically been limiting factors to corn production.

Dew point/humidity

Increased precipitation and changes in cropping system practices have increased the amount of moisture in the atmosphere. Change in atmospheric moisture content has been attributed to cropping changes, such as conversion of pasture/range to row crop and transfer away from wheat to corn/soybean rotation. The causes of overall increases in dew point still are being studied. Regardless of the causes, higher dew points create more humid conditions overall. For corn, higher humidity increases the potential for disease by allowing dew to form more frequently on the plant and to remain for longer periods of time, creating a longer disease potential period. The dew point increase also likely contributes to the rising overnight minimum temperature trend.

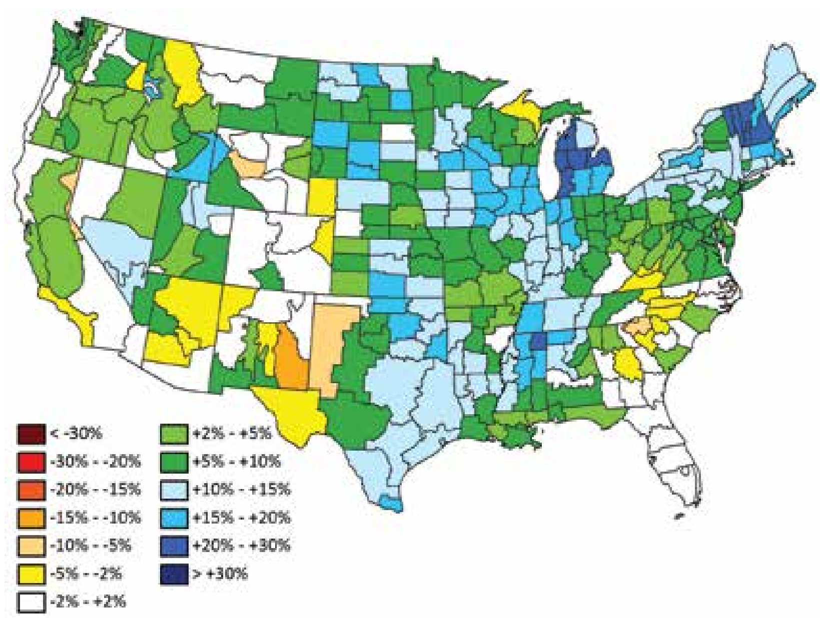
Final thoughts

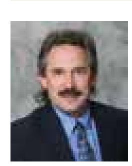
There is much more research needed to fully understand the role of local climate as a key factor in corn, soybean, and other cropping systems growth and development, and unintended poor environmental outcomes when climate patterns are not factored into farm management decisions. Increases in carbon dioxide and other greenhouse gases are larger scale climate drivers globally. However, local and regional changes in cropping practices and management are causing changes in temperature, soil and air moisture content and precipitation timing during the year.

^ Impact of 2012 drought in South Dakota. Corn near Beresford, SD, in early August.

FIGURE 1 | ANNUAL PRECIPITATION BY CLIMATE DIVISION

Linear trend changes in annual precipitation by climate division across the continental United States from 1895–2013. Values are percent changes over time. All of the Corn Belt has seen changes ranging from a few percent to 20+%. Image contributed by Brent McRoberts and John Nielsen-Gammon, Office of the State Climatologist, Texas A&M University.





Dennis Todey, Ph.D., is the South Dakota State Climatologist at South Dakota State University (SDSU), an associate professor in the Department of Agricultural and Biosystems Engineering at SDSU, and a principal investigator for the Sustainable Corn Project.

^ Bruno Basso and others at Michigan State University are working with farmers to test the use of Unmanned Aerial Vehicles to remotely and rapidly measure various plant and crop indices, such as nitrogen and phosphorus levels, crop disease, and much more.

Predicting the Impact of Increasing Temperatures on Corn Yield

BY BRUNO BASSO AND RYAN NAGELKIRK

Plants view time differently than people, not in minutes, hours or days, but in growing degree-days. Growing degree-days (GDD) are not actually days, but rather the accumulation of daily heat (temperature) units necessary for crops to develop, produce new leaves, reach the reproductive stage, and ultimately mature. The total number of GDD required to reach each of these steps is predetermined by the genetic characteristic of the cultivar (i.e. corn hybrid). Corn, for example, requires the accumulation of 52 degree-days for a new leaf to appear, or about 3,000 degree-days from planting to maturity for a 120-day corn hybrid. Degree-days are calculated by subtracting the plant base temperature (in the case of corn, 50° F) from the mean air temperature for each single day of the growing cycle. This means that the life span of a 120-day corn will vary depending on temperatures within the growing season.

Crop simulation models have been developed and used for nearly 40 years to predict and model crop yields, taking into consideration the interaction between management, weather, soils and genotype characteristics used in a particular field experiment. Crop simulation models predict the total biomass of a crop as the product of average growth rate (affected by photosynthesis) and growth duration (affected by optimum minimum and maximum temperatures). Changes in temperature, particularly very high or especially low temperatures as predicted by future climate scenarios, will have an effect on crop yield.

Highest yields of annual crops are achieved in cooler temperatures that maximize the duration of plant growth in the absence of any stressors. Under current climate projections, temperatures will rise by approximately 4.4° C (10° F) by the end of the century. That temperature increase for the state of Michigan, for example, can be envisioned as a shift in geographic locations (i.e. equivalent to the current mean temperatures of Indiana, Missouri or Oklahoma (Karl et al., 2009). The increase in temperatures will shorten the growing cycles, causing yield to decline. At the same time, in many cool places like the Midwestern United States, the last and earliest day of frost will change in a way that the total growing season could be longer by planting earlier and harvesting later (Fig. 1). These trends already have been observed over the last century: rising temperatures have extended the growing season two days per decade.

Highest yields of annual crops are achieved in cooler temperatures that maximize the duration of plant growth in the absence of any stressors.

In an effort to understand the likely effects of climate change on agriculture, maize and soybean yields in the Maumee River Watershed, in Ohio, were simulated using the Systems Approach to Land Use Sustainability (SALUS) crop model. SALUS calculates daily crop growth in response to changing climate, soil, and management conditions. We tested the hypotheses that despite any positive effects related to fertilization effects of increased carbon dioxide (CO_2) in the atmosphere, longer and warmer growing seasons will lead to excessive water- and heat-stress, resulting in lower yields under current management practices. The SALUS model was tested against measured county yield data and demonstrated the ability to reproduce the observed data and yield variation over the years (Fig. 2).

Corn yields in the Maumee River Watershed, Ohio, were modeled using low (B1) and high (A2) CO_2 emission scenarios from the Special Report on Emissions Scenarios (SRES) (Fig. 3). The middle line of each box represents the median yield for that scenario. The lines above and below that (the ends of the box) are the first and second quartile of the data (50 percent of the yields lie within the box). The ends of the bars represent the maximum and minimum values predicted within the watershed.

Decreased yield is projected for both scenarios, with the higher emissions scenarios showing the greatest decline. Yield is predicted to decrease under both scenarios and over time, with more drastic yield decline by the end of the century.

Bruno Basso, Ph. D., is an associate professor of agroecosystems sciences in the Department of Geological Sciences at Michigan State University in East Lansing and a principal investigator for the Sustainable Corn Project.

Ryan Nagelkirk is a graduate student on the Sustainable Corn Project and working on his Ph.D. at Michigan State under the supervision of Dr. Basso.

FIGURE 1 | POTENTIAL LENGTHENING OF GROWING SEASON DUE TO INCREASE IN TEMPERATURES

As a simple demonstration, when average daily temperatures are uniformly increased by the amount projected by the A1B SRES scenario (4.4° C), the growing season in northwest Ohio increases by 59 days.

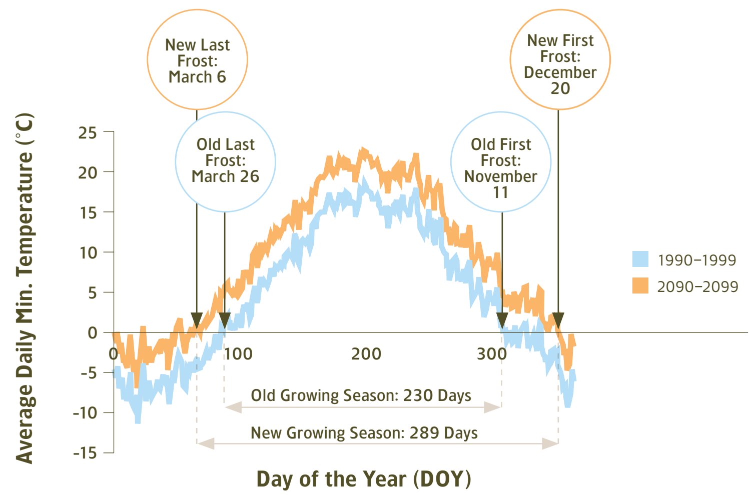


FIGURE 2 | COMPARING SALUS, A CLIMATE MODEL, TO ACTUAL YIELDS

Results are shown for backcasting yields in a single county within the Maumee River Watershed, Ohio. SALUS (orange) was able to match the direction and magnitude of change recorded by the USDA Agricultural Survey (blue) for many of the years.

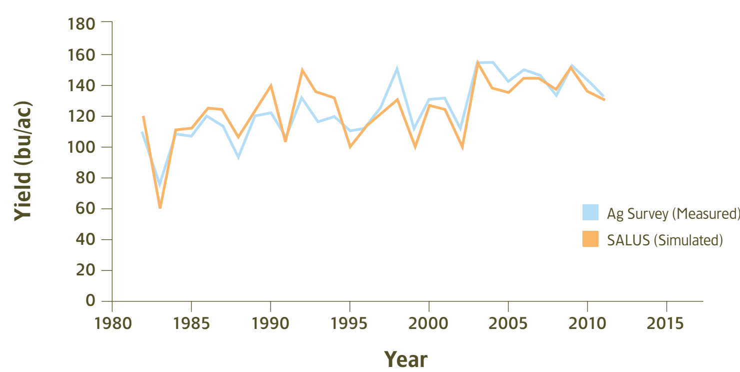
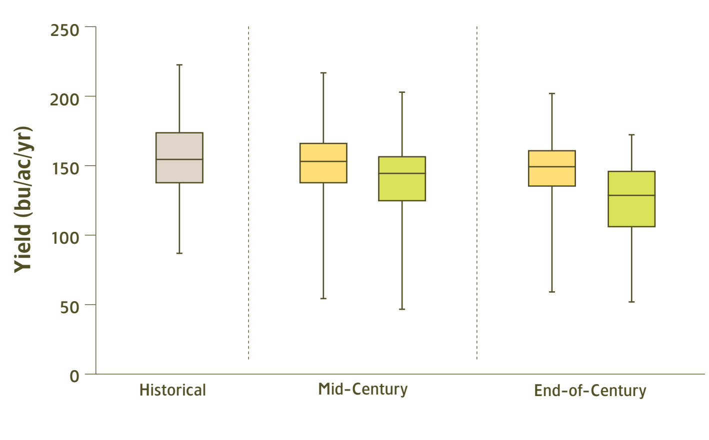


FIGURE 3 | MODELED EFFECT OF CLIMATE CHANGE ON CORN YIELD IN THE MAUMEE WATERSHED



Corn Belt States Create Nutrient Reduction Strategies to Address Gulf of Mexico Hypoxia

Sustainable Corn Project scientists are seeking to make agriculture more resilient by studying farm management practices that minimize losses in carbon, through soil erosion, and nutrients, such as nitrogen, during heavy rains. The scientists bring expertise and knowledge from their research in their individual states, including work on state nutrient reduction strategies.

Since 1985, the size of the hypoxic zone in the Gulf of Mexico has been measured every July via a cruise on the Pelican, a ship operated by the Louisiana University Marine Consortium under the direction of Dr. Nancy Rabalais. The hypoxic zone, colloquially referred to as a "dead zone," is an area where nutrient-enriched waters coming from freshwater rivers and streams in the watershed cause excess growth of plants which, in turn, deplete oxygen levels as they decompose. As a result marine organisms and the habitat they depend upon become oxygen starved and can no longer support the diverse aquatic life of the region. Last year's annual cruise revealed an area of low oxygen level of about 5,800 square miles, an area roughly the size of Connecticut. Significant sources of the nutrients that flow into the Gulf originate from agricultural row crop land in the Corn Belt.

To address this environmental problem, the multistate and multi-agency Mississippi River/Gulf of Mexico Watershed Nutrient Task Force was created in 1997. Their mission is to understand the causes and effects of the hypoxic zone and to coordinate activities to address it. In their 2008 Action Plan the task force called for the states in the Mississippi/Atchafalaya River Basin to develop strategies to achieve comprehensive reductions in nitrogen and phosphorus by 2013. A number of states have developed these plans. Many of them, including the state of Iowa, have undertaken an

< The Mississippi and Atchafalaya Rivers deliver vast quantities of sediment from the heart of the North American continent to the Gulf of Mexico every spring and summer. In the spring of 2011, NASA captured this photo where at least some of that sediment could be seen from space.

> "A major change in the landscape will be needed. New practices and new crops will be needed, new land uses such as wetlands will have to be constructed."

assessment of the effectiveness and costs of conservation practices to achieve reductions in nitrogen and phosphorus loading to the Gulf.

The science assessment developed by the team from Iowa identifies the type of practices that are most cost effective and the extent of the coverage needed to achieve the target nutrient reductions. "While developed for Iowa, much of the science will be directly applicable to other states in the Corn Belt," says Catherine Kling, one of the scientists on the Iowa science assessment team. Kling is a distinguished professor of agricultural economics at Iowa State University's Center for Agricultural and Rural Development and a principal investigator on the Sustainable Corn Project team.

Three categories of nitrogen and phosphorus reduction practices were identified and described in that effort: infield management practices, edge-of-field practices, and land-use changes. Infield management practices are actions that can be taken within a field to reduce the loss of nutrients from that field. Commonly advised practices such as cover crops, reducing nitrogen application rates, type, and timing fall into this category for nitrogen reduction and reduced tillage is a key option for phosphorus. Edge-of-field practices include buffers for phosphorus and wetlands targeted for water quality improvement for nitrogen. Bioreactors, an emerging technology to treat nitrogen, also are in this category. Finally, the planting of perennial crops for biofuels and the reintroduction of prairie plants on land previously planted in row crop are examples of land-use changes to reduce both nitrogen and phosphorus. "It is worth noting that in general, infield management actions are both less effective in reducing nutrient losses and less costly on a per acre basis than either edge-of-field practices or land-use changes. An important exception to this is cover crops, which is an effective management option, but relatively costly," says Kling. (A summary of the assessment findings can be found at https://store.extension.iastate.edu/Product/Reducing-Nutrient-Loss-Science-Shows-What-Works.)

The science assessment provided an important basis for understanding the change to the landscape that will be needed in agriculturally intensive landscapes. This analysis suggests that low-cost infield options by themselves will not be adequate to meet the water quality goals of the Hypoxia Task Force and that reliance on previously used best management practices will not be adequate. Historically, conservation practices such as no-till or reduced till, contour farming or terracing were designed to address soil erosion and, because phosphorus tends to move with soil, are often effective at retaining that nutrient. However, nitrogen moves with water and practices that may be very effective for phosphorus can have little or no impact on reducing nitrogen losses.

Kling says to successfully address the nutrient enrichment problem coming from agricultural fields, "a major change in the landscape will be needed. New practices and new crops will be needed, new land uses such as wetlands will have to be constructed in locations targeted to achieve nutrient cycling, and all of this will come at a cost."

The task force is calling for voluntary approaches to achieving this landscape transformation. "That means that producers will have to willingly adopt practices that reduce their bottom line and/or conservation programs will need to substantially increase their funding," says Kling.

^ Winter rye cover crop emerging in corn before harvest. Cover crops have been shown to reduce nitrate transport by 30–60 percent. Photo by Chad Ingels.

> For effective functioning, grassed waterways must be properly sized and constructed and have routine inspections and regular maintenance; otherwise, over time, gullies form on either side of the waterway as shown here. Photo by Richard Cruse.

Drainage Water Management in the Corn Belt

BY JANE FRANKENBERGER

Have you ever watched your tile drains flow in June and wondered how you could save some of that water for crops to use later in the summer? That is the idea behind drainage water management, a conservation practice that holds water in your field at times of year when more water won't harm the crop.

Drain tile systems do their job by draining away excess water, providing trafficable conditions for field work and increasing crop yields. However, water that is "excess" in the spring could be valuable later in the year when crop growth is at its peak and soil moisture cannot keep up with crop water demand. The potential benefits are especially evident in drought years. However even in normal years crops in most of the Corn Belt may experience some drought stress in July and August.

Drainage water management is the practice of installing a water control structure in a drain tile (photo right), which allows you to vary the depth of the drainage outlet. Raising the outlet level causes the water table to rise to the level of the outlet, storing water in the soil. The outlet is lowered sufficiently long before planting so that the field is fully drained. Drainage during the crop growing season is flexible — most producers raise the outlet as soon as possible after spring field work has ended to retain any available moisture (Fig. 1).

The practice was originally developed as a way to reduce the nitrate loss into streams and rivers that has been linked to water quality problems downstream such as hypoxia in the Gulf of Mexico. Holding the water back allows water to flow through longer pathways and seep into deeper soil layers. In addition to water quality benefits, it's possible that drainage water management also can boost crop yields.

^ Installation of a drainage water control structure in a drain tile.

FIGURE 1 | DRAINAGE WATER MANAGEMENT TIMELINE

A typical drainage water management timeline. The outlet is raised in the winter for water quality benefits, lowered several weeks before planting, then raised immediately after planting to hold back moisture for the crop.

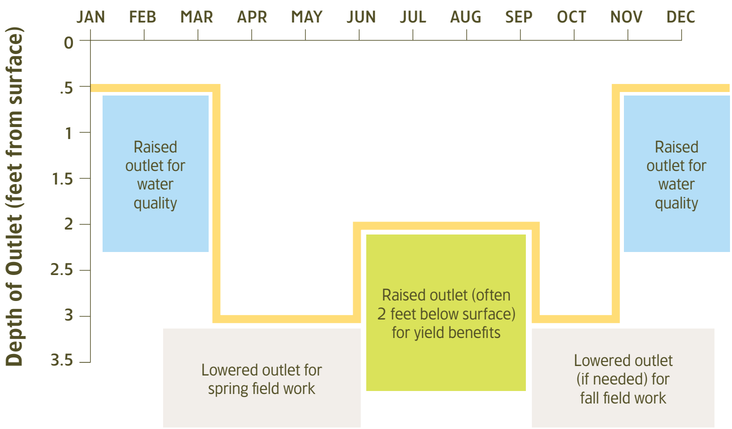
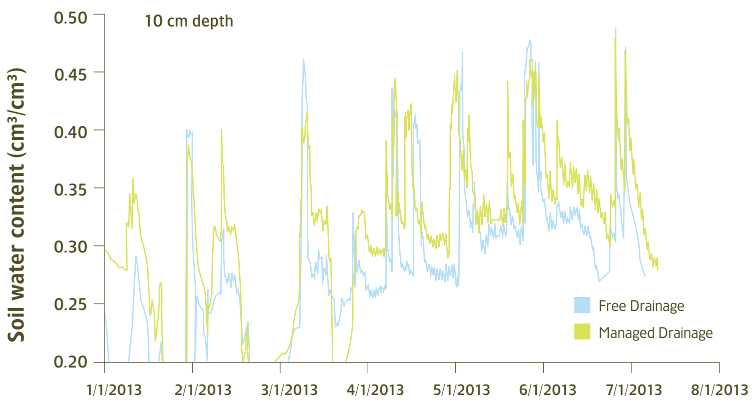


FIGURE 2 | DRAINAGE COMPARISON

This comparison, of conventionally drained fields to fields with managed drainage, illustrates that drainage water management stores water in the soil.



Brian Hicks, a corn producer in Redwood County, in southwestern Minnesota, has two corn fields that are a part of the Sustainable Corn Project's current drainage water management research. They have been a part of University of Minnesota research since 2005, when water control structures were installed in some of his fields. In the fields with managed drainage, Hicks says he has seen a "dramatic savings in nutrients every year since then."

"I spend a lot of money on my nutrients. The folks downstream in the Gulf of Mexico certainly don't want them. So, if I can keep them on my landscape, I'm happy with that," says Hicks.

Understanding yield benefits and soil moisture impacts
Researchers and producers know that holding drainage water in the soil provides some benefit, but the yield benefits vary by year, by climate, and by region, and are not yet fully understood.

Hicks says he has seen a yield advantage in the fields with managed drainage, but "the yield bump is not huge and not every year."

The Sustainable Corn Project is conducting research across the Corn Belt to better understand the varying impacts of drainage water management on soil moisture and crop yields. At four sites in Minnesota, Iowa, Indiana, and Ohio, researchers are comparing conventionally drained fields to drainage water management. Equivalent measurements are being taken of drain flow, water table depth, soil moisture at five depths, and crop yield in each field (conventional and managed drainage) (Fig. 2).

Holding the water back allows water to flow through longer pathways and seep into deeper soil layers. In addition to water quality benefits, it's possible that drainage water management also can boost crop yields.

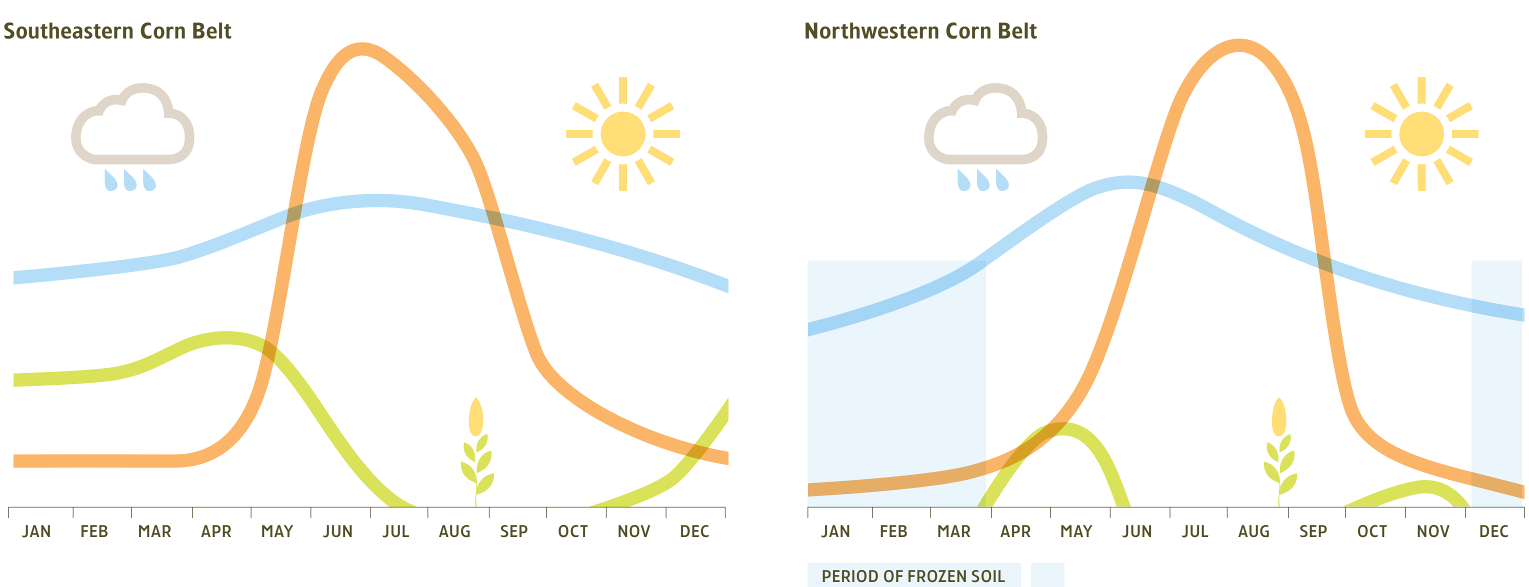
The effects of drainage water management are probably highest in the southern and eastern portions of the Corn Belt (i.e., southern Indiana and Ohio), because drains usually flow throughout most of the fallow season (November to May) (Fig. 3). In parts of the Corn Belt further north (i.e., Minnesota and the Dakotas) drains do not usually flow during the winter because the soil is frozen (Fig. 2). Other states fall in-between these extremes, and the project is helping to show the extent of the variability of the impacts of drainage water management across the region.

Results from research on this promising practice across the entire region will help producers make decisions about drainage water management, including selecting a timeline for raising and lowering the outlet in their own fields to protect water quality and maximize their crop yields — to create a more resilient and sustainable cropping system.

Jane Frankenberger, Ph.D., is a professor of agricultural and biological engineering at Purdue University and a principal investigator for the Sustainable Corn Project.

FIGURE 3 | ANNUAL WATER BALANCE

Components of the annual water balance for typical Corn Belt conditions. Evapotranspiration (orange line) exceeds precipitation (blue line) during the height of the growing season, but at other times, precipitation exceeds evapotranspiration leading to excess soil water and drainage flow (green line).



Cover Crops Produce Benefits in Wet and Dry Times

BY LYNN LAWS

Sustainable Corn Project scientists are field testing a winter rye cover crop at 10 sites in six Midwestern states, measuring their potential to add resiliency to corn-based cropping systems by holding nutrients and moisture on Midwestern farm fields during extreme rain events and drought. (See Project Participant and Field Site Locations map on page 4.)

"In a corn/soybean system, in the more eastern and southern parts of the studied states, a large part of the drainage flow and nitrogen losses leave from the bottom of the root zone and occur precisely during the fallow season, when nothing is growing. In the more northern and western states — in Minnesota and Iowa — a substantial part of the flow is during the fallow season, but there is also significant flow in May and June, at the beginning of the growing season," says Eileen Kladivko, a professor of agronomy at Purdue University and a principal investigator for the Sustainable Corn Project. "Whether you have a tile drain or whether the excess water is going towards ground water or flowing laterally to nearby streams, a large portion of what is lost from the root zone is lost at these times."

Ray Gaesser, an Iowa corn and soybean producer and 2014 president of the American Soybean Association, started testing cover crops in his operation in the fall of 2010.

"Our biggest reason is erosion control because of the extreme weather events that we've had the last several years. When we get four inches of rain in an hour, or six or eight or so inches of rain in a day, our no-till fields, terraces, waterways and turn areas — all those things that were adequate for 20 years — just can't handle those kinds of events. So we're adding cover crops," Gaesser says.

Gaesser says all his fields had a lot of crop residue from 20 straight years of no-till. But in the spring of 2012, when his fields with no cover crops received four inches of rain in an hour, "most of the residue floated away, water ran over the terraces and outside the waterways, and it created a few small ditches where it took all of the residue away. But where we had the cover crops, we had no erosion."

Matthew Helmers, a professor of Agricultural and Biosystems Engineering at Iowa State University and a principal investigator with the Sustainable Corn Project, says studies have shown that during wet seasons cover crops can reduce sediment and nitrate transport to downstream water bodies by up to 60 percent, depending on soil type, amount of biomass produced by the cover crop in any given year, and how and when the cover crop is terminated. In addition, adaptive management of the cover crop in wet springs may be needed to prevent the cover crop from keeping the soil too wet to plant. Farmers and researchers are developing experience and recommendations regarding this issue.

> "When we get four inches of rain in an hour, or six or eight inches of rain in a day, our no-till fields, terraces, waterways and turn areas — all those things that were adequate for 20 years — just can't handle those kinds of events. So we're adding cover crops."

Researching the effects of cover crops during times of drought also is important.

"I think farmers may have concerns that if they have a cover crop and it ends up being dry, that they might have used up soil moisture that would have otherwise been available for the cash crop. Our research indicates that would not be the case and that, in fact, it might provide some help just because it provides a mulching effect and shading after that cover crop is terminated," says Helmers.

^ Cereal rye cover crop (left in each photo) at Sustainable Corn Project research site in Ames, Iowa. The photo on the left was taken on March 29, 2012. The crop helped to hold soil in place over the winter. The photo on the right was taken on April 17, 2012, after terminating the rye. Once the rye is dead, it has a mulching effect — which increases soil drying time. This can be beneficial in times of drought, but can delay spring planting during wet times.

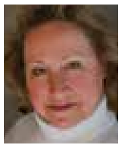
During the drought of 2012 the Sustainable Corn Project cover crop team gathered soil moisture data from Iowa and southeastern Indiana plots that had terminated a rye cover crop and plots that had not had a cover crop. They looked at soil moisture at five different depths in the soil profile continuously prior to the cash crops of corn and soybeans and throughout the growing season of the cash crops.

At one of two Iowa sites the team saw a statistically significant difference; the plot that had once had a cover crop had held more moisture. No statistically significant differences were seen at the other site in Iowa and the Indiana site, including a plot where the cover crop produced very little biomass.

“While this is just one year of data, to me it’s still important because the 2012 summer was extremely dry and because farmers have been concerned that a cover crop in spring might dry out the soil. Our work is showing that’s not the case,” says Helmers.

The cover crop group will continue their study into 2015 and publish results soon after. They will be watching to see if cover crops make corn/soybean systems more resilient and sustainable by doing the following things:

> improving soil quality (soil C, soil aggregation, water infiltration) to reduce year-to-year variability in yield and increase crop yield over the long-term;
> reducing nitrate export to tile drainage;
> conserving soil water, which results in reducing year-to-year variability in yield; and
> increasing crop yield in dry years.



Lynn Laws is a communications specialist for the Sustainable Corn Project and for Iowa State University, College of Agriculture and Life Sciences.

Understanding Water Needs of Diverse, Multi-year Crop Rotations

BY JEFF STROCK AND BRENT DALZELL

Crop rotation diversification is the most powerful tool that farmers have to reduce economic risk, disrupt pest cycles, increase soil resilience, and improve water quality (Teasdale et al., 2007). As investigators with the Sustainable Corn Project, we are now conducting studies to determine if diverse, multi-year rotations also can help crops thrive as precipitation patterns change in the Corn Belt.

In the upper Midwestern United States, annual precipitation is projected to increase mostly during the non-growing season while summer precipitation patterns are expected to become less predictable. Too much water early in the growing season can lead to delayed planting, crop loss, and environmental damage while too little water in the summer can lead to reduced yields or total crop loss.

Besides yield, water use efficiency is an important agronomic factor.

In our research we are quantifying soil water budgets and crop water use — the relationship between input and output of water within the soil and through a plant. We're also studying the environmental response of diverse, multi-year organic and conventionally managed crop rotations in order to identify which crop rotations and rotation lengths are most resilient under various climate conditions, including changing precipitation patterns. This is being accomplished through a combination of plot-scale studies and modeling.

Improved understanding of water use by more diverse cropping systems can help farmers determine which rotations are best suited for their particular location and precipitation pattern. Understanding the mechanisms for increasing soil water storage and plant water use efficiency will help farmers be economically competitive while also minimizing their environmental impact.

Water use efficiency is a quantitative measurement of how much biomass or yield is produced over a growing season, normalized with the amount of water used by a plant in the process. Besides yield, water use efficiency is an important agronomic factor, especially in agricultural systems because changing precipitation patterns, frequency, intensity and distribution will alter soil water availability for crop production.

Sustainable Corn Project Preliminary Results

Table 1 (below) shows the water use efficiency for selected crops and rotations during August to October 2013. During this partial season, corn from the 2-year conventional rotation (corn following soybean) was 1.3 to 1.5 times more efficient with respect to water use efficiency compared to corn from either of the 4-year rotations (corn-soybean-oat/alfalfa-alfalfa). There was no difference among soybean water use efficiency for any of the rotations.

The average changes in soil water storage for the represented cropping systems were not significantly different during this period of time. The data do indicate that the 2-year conventional rotation used less water than the perennial or extended rotations but the difference was not significant (Figure 1 next page).

Grain yield is shown in Figure 2 (next page). Grain yield and biomass yield (alfalfa) were similar between the organic and conventional 4-year rotations. Soybean yield for the 2-year rotation was similar to both 4-year rotations. In contrast, corn grain yield for the 2-year rotation was significantly greater than for both 4-year rotations.

Next Steps

Sustainable Corn Project researchers are only in the early stages of data collection. As more data are collected and analyzed, the information gained from this project will assist producers in making management decisions that will lead to increased water use efficiency, nutrient use efficiency and long-term conservation. This will help to make farming systems more productive and profitable while also minimizing their environmental impact.

TABLE 1 | WATER USE EFFICIENCY FOR SELECTED CROPS AND ROTATIONS DURING AUGUST TO OCTOBER, 2013

Component (in)	Organic 4-yr Rotation		Conventional 4-yr Rotation		Conventional 2-yr Rotation	
	CORN	SOYBEAN	CORN	SOYBEAN	CORN	SOYBEAN
Water Use Efficiency (WUE, lb/ac-in) (Higher numbers represent greater efficiency than lower numbers)	**1352**	345	**1149**	397	**1718**	380

FIGURE 1 | **SOIL WATER STORAGE**

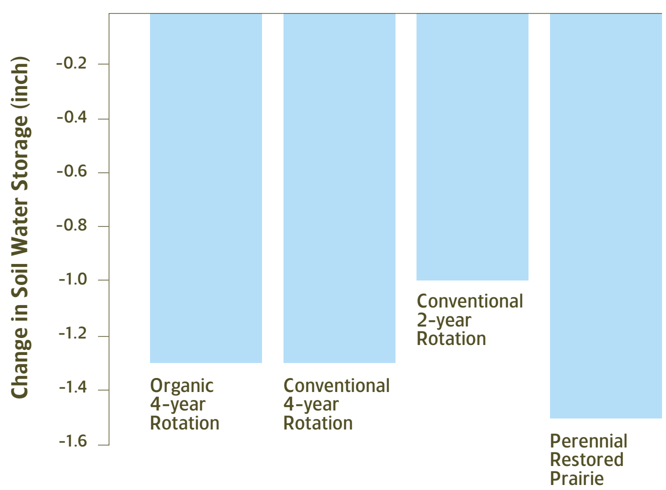
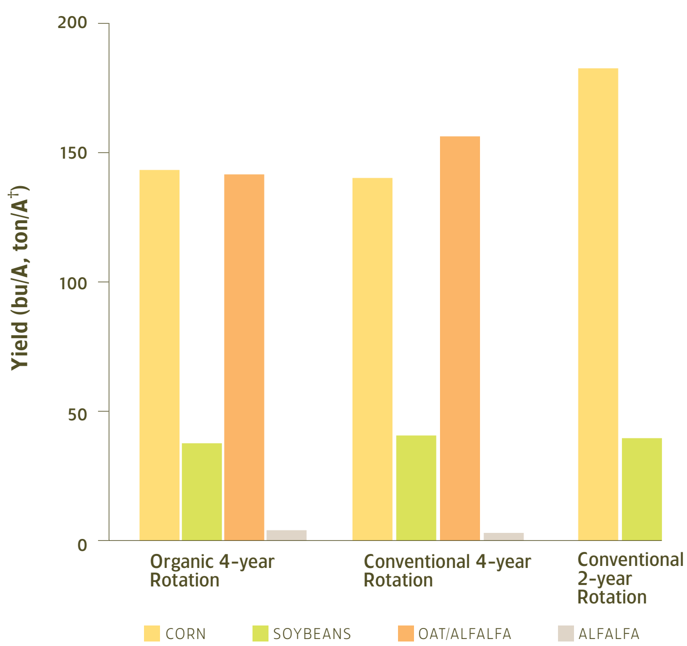


FIGURE 2 | **GRAIN YIELD**



Jeff Strock, Ph.D., is a professor and soil scientist in the Department of Soil, Water and Climate & Southwest Research and Outreach Center at the University of Minnesota and a principal investigator with the Sustainable Corn Project.

Brent Dalzell is a research associate and biogeochemist on the Sustainable Corn Project at the University of Minnesota.

WATER

Climate patterns in the central US are expected to become increasingly variable with changes in precipitation intensity and seasonality and changes in available soil water for crop production. Prevailing weather conditions, available water in the soil, crop species, and development stage influence crop water use. Water is an important factor in crop production. Approximate seasonal water requirements for corn, soybean and small grains are similar and range between 20–32, 18–28 and 18–26 inches, respectively, for optimum yield depending on variety, crop and water management. Seasonal water requirements for alfalfa are considerably greater and range between 32 and 63 in. Evapotranspiration (ET) plays a key role in the water cycle, affecting the water balance from local up to regional scales and causing feedback between soil, plants and the atmosphere. Because ET can comprise approximately 75-85% of the annual water budget in the upper Midwest, accurate representation of it in crop water budgets is crucial for quantifying the effect of changes in land use and management on water balances (e.g. diverse crop rotations, perennials, cover crops) (Hatfield et al., 2001).

Recently, it has been demonstrated that landscape-scale changes in cropping patterns can influence water, yield and nonpoint source pollution (Schilling et al., 2008). Furthermore, watershed-scale studies in south-central Minnesota have shown that water-yield differences, especially differences in the timing of ET, between row crops (corn-soybean) and perennial crops (prairie grass and switchgrass) may explain over 70% of current sediment export from some watersheds (Dalzell and Mulla, in prep).

< This soil moisture sensor, installed in organic and conventional rotations at the University of Minnesota, monitors plant-available water in the soil profile.

FARMER PERSPECTIVES
ON CLIMATE CHANGE

Corn Belt Farmers are Concerned, Support Adaptation Action in the Ag Community

BY J. GORDON ARBUCKLE JR.

Corn Belt agriculture — the source of much of the world's corn and soybean — is vulnerable to increasing weather extremes associated with climate change. Threats to agriculture also represent threats to long-term food security and societal stability. Calls for increasing the resiliency of Midwestern agricultural systems are on the rise. A central objective of the Sustainable Corn Project's social science research is to develop a better understanding of farmer perspectives on climate change and what should be done to prepare for predicted changes. This article presents results from the 2012 survey of farmers.[1]

What do farmers believe about climate change?
Beliefs differ. Most of the farmers surveyed (66%) believed that climate change is occurring (see Table 1 below). Only 41%, however, believed that humans are a significant cause. Almost one-third were still uncertain about whether climate change is happening or not.

Are farmers concerned about the potential impacts of climate change?
Many farmers are concerned about weather-related challenges that climatologists predict will become more difficult. Farmers are worried about increases in drought, heat, extreme rains, crop diseases, and weed pressure (Fig. 1). Level of concern varies with beliefs about climate change. Farmers who attribute climate change to human activity reported significantly higher levels of

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TABLE 1 | FARMER BELIEFS ABOUT CLIMATE CHANGE.

Climate change is occurring, and it is caused mostly by human activities	8%
Climate change is occurring, and it is caused more or less equally by natural changes in the environment and human activities	33%
Climate change is occurring, and it is caused mostly by natural changes in the environment	25%
There is not sufficient evidence to know with certainty whether climate change is occurring or not	31%
Climate change is not occurring	4%

FIGURE 1 | FARMER CONCERNS ABOUT PREDICTED IMPACTS

Farmer concern about predicted impacts of climate change, percent concerned or very concerned.

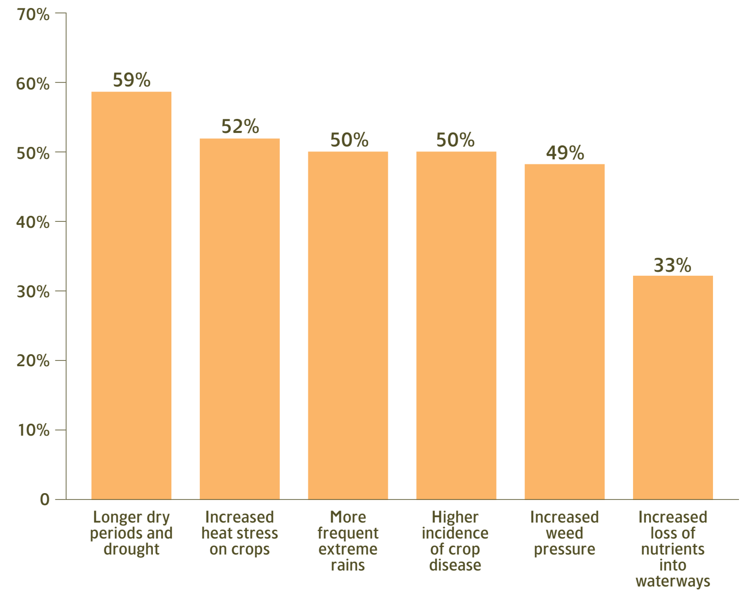
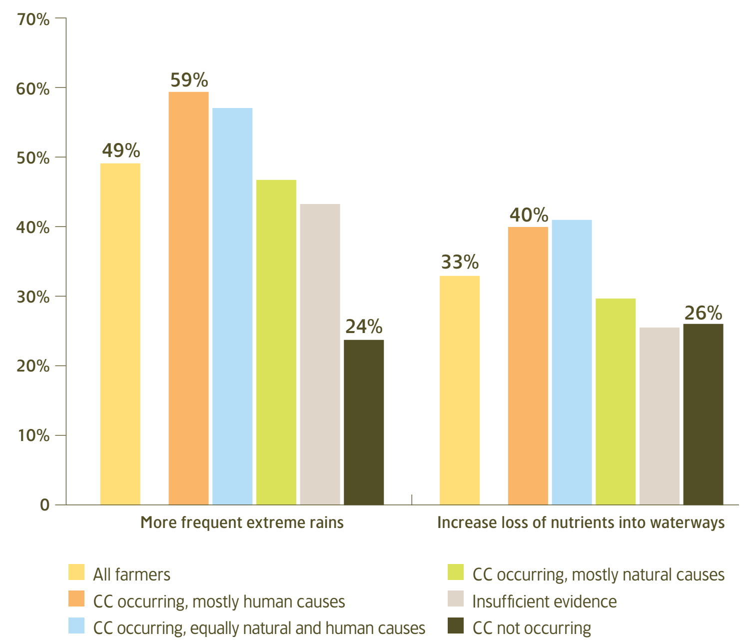


FIGURE 2 | FARMER CONCERNS BY CLIMATE CHANGE BELIEF

Percent concerned or very concerned about extreme rains and nutrient loss, by climate change (CC) belief.



1 Additional survey results are available at http://sustainablecorn.org/What_Farmers_are_Saying/Farmer_Perspectives_on_Ag_and_Weather_Variability_Stat_Atlas.html.

LEARNING FROM FARMERS

By Lynn Laws

Farmers are interested in talking about climate change and what it might mean for their operations, says Marilyn Thelen, an educator with Michigan State University Extension and member of the Sustainable Corn Project extension team. Throughout 2013, Thelen and 18 other extension educators on the project interviewed 160 farmers in Iowa, Illinois, Indiana, Michigan, Minnesota, Missouri, Ohio, South Dakota and Wisconsin. Investigators are beginning to pore over the results — over 8,000 transcribed pages of conversations with farmers. The interviews covered farmer perspectives on conservation in the context of climate change and increasingly common extreme weather events. They also explored farmer views on the challenges associated with use of the major conservation practices that biophysical scientists on the project are researching, such as nutrient management techniques, conservation tillage, cover crops, extended rotations, and controlled drainage water management.

A team of researchers on the project developed questions to guide the interviews, but farmers and extension educators talked freely.

"The interview process allowed us to begin a discussion of climate change and potential impacts on agriculture in a way that was non-threatening," Thelen says.

Gabrielle Roesch-McNally, an Iowa State University graduate research assistant on the project, who served as coach and coordinator of the interview process, says, "The team did a fantastic job engaging farmers in discussions about conservation challenges and successes in the face of a changing climate. The research team is learning so much from the transcribed interviews."

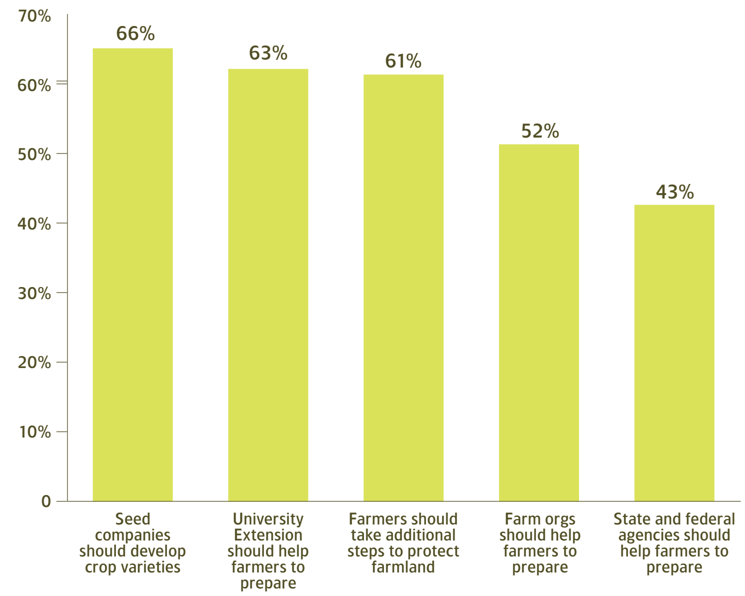
J. Gordon Arbuckle Jr., associate professor of sociology at Iowa State University and the lead social scientist on the Sustainable Corn Project, led the development of the project's 2012 survey that was completed by nearly 5000 farmers (see page 23) and assisted with the development of the questions for the in-person interviews. "Doing both a survey and in-depth interviews with farmers has deepened our understanding of their challenges and concerns and is helping to direct further research and extension activities."

Arbuckle says he, Roesch-McNally and the rest of the social science team will continue to analyze the survey and interview data and publish articles and reports over the course of the project. Together with the extension educator team, they are using the results to inform outreach strategies and activities.

Lynn Laws is a communications specialist for the Sustainable Corn Project and for Iowa State University, College of Agriculture and Life Sciences.

FIGURE 3 | FARMER SUPPORT FOR ADAPTATION ACTIONS

Support for adaptation action to prepare for "increased weather variability" (percent agree or strongly agree, five-point agreement scale)



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concern than those who believe it is due to natural causes, are uncertain about the existence of climate change, or do not believe it is happening (Fig. 2).

Do farmers support action?
Farmers were given a number of statements about potential actions that could be taken to prepare for or address potential changes in climate and asked to rate their agreement on a five-point scale from strongly disagree to strongly agree. Many of the statements focused on adaptation to increased weather variability.

Most farmers believed action should be taken. Two-thirds of farmers agreed seed companies should develop crop varieties adapted to increased weather variability. Similar percentages agreed that university extension should help farmers to prepare and that farmers themselves should take additional steps to protect their farmland (Fig. 3).

Insight into farmer beliefs, concerns, and support for action related to climate change can inform the development of engagement strategies lead to more resilient agricultural systems. There is a commonly held assumption that farmers are reluctant to discuss climate change. However, this research shows that many farmers are concerned about the predicted impacts of climate change and most are supportive of private and public sector action to help them to adapt to increased weather variability.

J. Gordon Arbuckle Jr., Ph.D., is an extension sociologist at Iowa State University and the lead social scientist on the Sustainable Corn Project.

< Chad Ingels (left), Iowa State University extension specialist, discusses survey questions with a farmer in northeast Iowa. Ingels leads the Sustainable Corn Project extension team. Photo courtesy Iowa State University College of Agriculture and Life Sciences.

Survey Says: Engage Farmers as Problem Solvers

"Adaptation is what farmers do; they are professional adapters."

Sustainable Corn Project social science researchers are working to better understand farmers' perspectives on climate change and related impacts. Increased knowledge of farmers' viewpoints will contribute to the development of extension and outreach strategies that effectively support their efforts to respond to increasing weather variability in the Corn Belt. Towards that effort, project researchers analyzed data from their 2012 survey of 4,778 farmers from 11 U.S. Corn Belt states. The research attempted to shed light on two related questions: (1) do farmers differ in their beliefs about climate change, experience with extreme weather, concerns about risks to agriculture, confidence in their ability to cope, and level of support for public and private action; and, (2) are there potential areas of common ground among farmers that can help improve engagement strategies?[1]

Data analysis revealed six distinct classes of farmers: the *Concerned* (14%), the *Uneasy* (25%), the *Uncertain* (25%), the *Unconcerned* (13%), the *Confident* (18%), and the *Detached* (5%). The *Concerned* tended to believe that climate change is happening and caused mostly by humans, had experienced the most extreme weather in recent years, and were most concerned about impacts of climate change. At the other end of the spectrum, the *Detached* tended to not believe that climate change is occurring, had not dealt with extreme weather, and were not concerned.

Despite a number of substantial differences, farmers were quite similar in terms of (1) confidence that they will be able to adapt to increases in weather variability, and (2) support for public and private efforts to help them adapt (Fig. 3).

"A lot of farmers do not believe that climate change is due to human activity, so focusing on mitigation may be ineffective with them," says J. Gordon Arbuckle Jr., a professor of sociology at Iowa State University and the lead social scientist on the Sustainable Corn Project.

Arbuckle says outreach and extension strategies should build on farmers' confidence in their ability to adapt to weather extremes. "Adaptation is what farmers do; they are professional adapters. People who work with farmers should approach them as active partners and leaders in the effort to increase the resilience of agricultural systems rather than passive consumers of information and recommendations."

Outreach efforts that (1) appeal to farmers' problem solving capacity and (2) employ terms such as "weather variability," instead of terms that evoke controversy — such as anthropogenic climate change — are likely to be more effective in engaging farmer partners in the quest for more resilient agricultural systems.

1 The survey was conducted in partnership with the Useful to Usable (U2U) project (www.AgClimate4U.org), another USDA-funded climate and agriculture project. The 22 HUC 6 watersheds that were surveyed account for more than half of all U.S. corn and soybean production. Farmers selected for the survey were those who grew corn and who had more than $100,000 in gross farm income in 2011; these large-scale farmers cultivate approximately 80 percent of the farmland in the region. The results reported in this article will be published in a forthcoming issue of the Journal of Soil and Water Conservation.

Corn Belt Farmers' Adaptation to Increased Precipitation

BY LOIS WRIGHT MORTON, JONATHAN HOBBS, J. GORDON ARBUCKLE JR. AND ADAM LOY

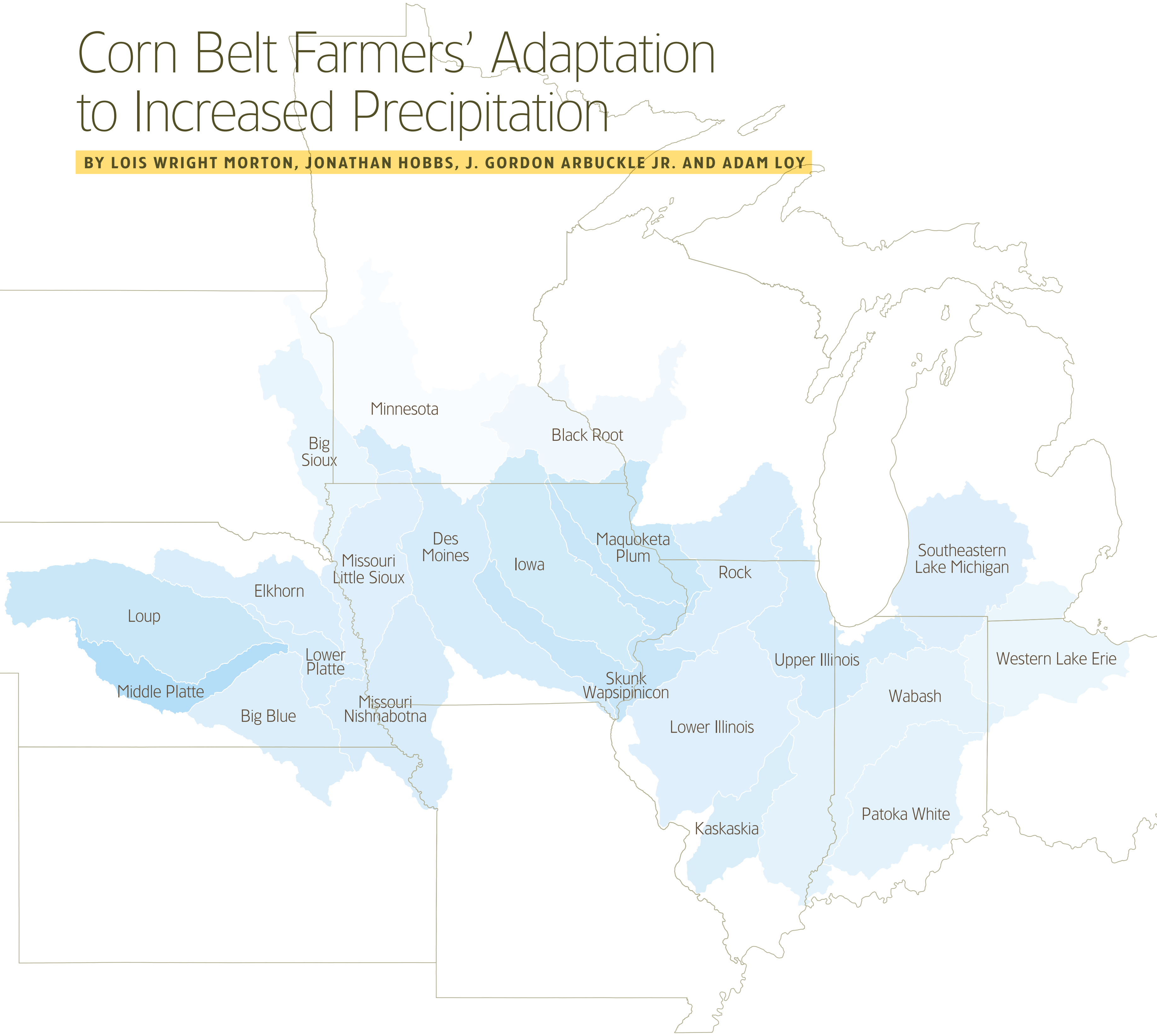
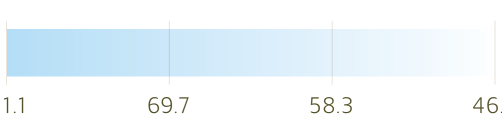


FIGURE 1 | 2007–2011 PRECIPITATION

Percentile rank of total April to September precipitation for 2007–2011 (compared to all data from 1971–2011). Watersheds with values above the 50th percentile were markedly wetter during 2007-2011 relative to the historical norm (1971-2011).



While climate change is a global phenomenon, it often has variable and unpredictable localized effects. From 2007 through 2011 the Upper Midwest recorded some of the highest levels of precipitation during the growing season (April–September) compared to the last 40 years (Fig. 1). The corn-soybean rotation is the dominant cropping pattern in the Corn Belt, which runs from Ohio west into the Great Plains. Recorded precipitation across this region is not evenly distributed and varies considerably, which impacts the timing of planting, nitrogen applications, and harvest dates, as well as pest vulnerabilities and corn development throughout the season. Consequently, when making decisions, each farmer must consider climate and weather data as well as the unique farm-specific soil, hydrology, and topographic geophysical conditions; past experiences with flooding, saturated soils, and erosion; diversification of production system; and anticipated markets.

The complexity of on-farm management decisions can be illustrated by three adaptive responses to precipitation (see Fig. 2) that Sustainable Corn Project scientists have been examining. Using data from a 2012 random sample survey of 4,778 Upper Midwest farmers (see article, page 23), three models were constructed to discover important factors that influence farmers' decisions to implement no-till and cover crops, and to plant more crops on highly erodible land (HEL) on their farms. Two noteworthy patterns were found:

1) Actual past climate and precipitation can have a significant effect on the type of management put in place.

2) Seasonal precipitation varies greatly across the upper Midwest and has a differential impact on the type of management.

It follows that under different climate conditions farmers are likely to make different management decisions based on their perceptions of risk and anticipation of future opportunities. Further, if they have a river running through their lands or marginal soils highly vulnerable to erosion or not generally suited to row crops, they are more likely to be using no-till. Cover crop management is associated with marginal soils, experience with flooding over the last five years, use of no-till, and diversified production systems and markets that include cattle.

In 2012, when this survey was conducted, we found that farmers' use of cover crops was negatively influenced by seed and farm chemical dealers. In more recent years there has been significant farmer utilization of cover crops to increase soil organic matter, reduce off-farm nitrogen loss to proximate streams, and hold soil in place. We suspect that if the survey were conducted today we would find that cover crop advice from agricultural advisors has changed.

One of the most worrisome trends across the region is the increase in crops planted to highly erodible lands. As illustrated in Fig. 2, this mal-adaptation is associated with marginal soils not suited to cultivated cropping systems, with farmers reporting increased erosion over the past five years and the use of cover crops. Diversified markets and production systems that include cattle and hogs are significant and seem to influence farmer decisions to plant their highly erodible lands. Increased planting to highly erodible land is significantly associated with two specific river basins: Iowa in the Upper Mississippi River Basin and Missouri-Nishnabotna.

FIGURE 2 | INFLUENCING FARMERS' MANAGEMENT DECISIONS

NS no significant influence **+** significant positive influence **–** significant negative influence

	Factors influencing adaptive management	No-Till	Cover Crops	Plant HEL
Geophysical context	River runs through/ nearby	+	NS	+
	Marginal soil	+	+	+
On farm experiences with too much water, diversification of production systems and markets	Saturated soils	–	–	–
	Flooding	NS	+	NS
	Erosion	NS	NS	+
	Diverse Corn Markets	NS	+	+
	Relationship with seed dealers and farm chemical dealers	NS	–	NS
	Cattle	NS	+	+
	Hogs	NS	NS	+
Suite of associated practices	Artificial Drainage	NS	–	–
	No-Till		+	+
	Cover Crops	+		+
	Plant HEL	+	+	
Climate across the region	Seasonal Precip Median	+	NS	+
Region specific climate	Region			
Seasonal precipitation percentile rank	04 — Great Lakes	–	NS	NS
	05 — Ohio	NS	–	–
	07 — Upper Miss. (IL)	NS	NS	NS
	07 — Upper Miss. (IA)	+	NS	+
	07 — Upper Miss. (MN/WI)	+	NS	NS
	10 — Missouri	+	NS	+

Lois Wright Morton, Ph.D., is a professor of sociology at Iowa State University and the project director of the Sustainable Corn Project; J. Gordon Arbuckle Jr. is the lead sociologist on the team; Jonathan Hobbs and Adam Loy were graduate students assisting in the analysis.

THE EXTENSION TEAM:
Bridging from Scientists to Farmers and Back

Extension educators are a bridge between Sustainable Corn Project scientists and farmers. They facilitate learning from each other. The educators disseminate the scientists' expertise and findings to farmers through hundreds of presentations and extension publications. In turn, extension educators carry back farmer concerns and experiences, learned through informal conversations and formal surveys, to project leadership and scientists. The process builds knowledge, trust and the mutual alignment of goals.

Sustainable Corn Project Extension Team, from left (All are extension educators unless otherwise titled):

1. Gabrielle Roesch, Ph.D. graduate student, Iowa State University
2. Ross Behrends, Heron Lake Watershed District, Minnesota
3. Richard Hoormann, University of Missouri Extension
4. Shawn Wohnoutka, Redwood Cottonwood Rivers Control Area, Minnesota
5. J. Gordon Arbuckle Jr., associate professor, Sociology, Iowa State University
6. Laura Edwards, South Dakota State University Extension
7. Marilyn Thelen, Michigan State University Extension
8. Richard Wolkowski, University of Wisconsin Extension
9. Jamie Benning, Water Quality Program Manager, Iowa State University
10. Dennis Bowman, University of Illinois Extension
11. Angie Peltier, University of Illinois Extension
12. Robert Bellm, University of Illinois Extension
13. Jon Neufelder, Purdue University Extension
14. John Tyndall, associate professor, Natural Resources Ecology and Management, Iowa State University
15. Chad Ingels, Iowa State University Extension
16. Charles Ellis, University of Missouri Extension
17. Todd Higgins, Lincoln University Cooperative Extension

Not all members are shown. A full list of extension team members is included in the team roster on pages 47–49.

^ Lori Abendroth and Martin Shipitalo examine soil aggregation and color at a Sustainable Corn Project research site in Coshocton, Ohio. Abendroth is the project manager and Shipitalo is a soil scientist with the National Laboratory for Agriculture and Environment in Ames, Iowa, and was a principal investigator with the Sustainable Corn Project in 2011.

Scientists Explore Crop Management Options for Storing Soil Carbon

BY LYNN LAWS

Sustainable Corn Project scientists are exploring agricultural practices, which are known to build soil organic matter, to assess their capacity to increase carbon retention and sequestration (i.e. storage). If the practices show increased long-term carbon storage in field tests, they could provide farmers with options for increasing the fertility of their fields, while, at the same time, contributing to reductions in greenhouse gas emissions.

Sasha Kravchenko is a principal investigator with the Sustainable Corn Project and a professor of crop and soil sciences at Michigan State University, specializing in statistical analysis tools as applied to soil properties and soil organic matter. She and other researchers on the team are conducting studies at 10 sites in six Corn Belt states to explain the mechanisms by which cover crops increase the amount of carbon stored in the soil and to what extent that affects greenhouse gas emissions.

"In short-term experiments we might not necessarily be able to detect a change in the total soil organic matter (SOM)," says Kravchenko. "At least five to seven years are needed to start detecting increases in SOM. But some SOM components react

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more quickly to changes in management, such as particulate organic matter. We know if we start to see positive differences in those components, it is a sign that the management system is going in the right direction of increasing SOM and has greater potential for carbon sequestration," Kravchenko says.

Indeed project investigators are seeing those differences.

"In our Michigan sites, after just three years, we are starting to observe greater particulate matter levels in plots with cover crops than in conventional plots," says Kravchenko. Soil properties are measured and compared at depths of 0–10 and 10–20 cm.

> "... use of cover crops may counteract some of the carbon losses due to tillage."

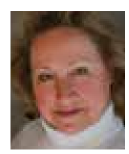
Emerson Nafziger, a professor of crop sciences at the University of Illinois, is a principal investigator with the Sustainable Corn Project who is examining the effects of various crop rotations and tillage on soil carbon. He says crop residue on or incorporated into the soil can take a long time to decay, but much of it eventually returns back to the atmosphere as carbon dioxide. One form of carbon that remains sequestered, however, is the carbon in the stable fraction of soil organic matter. Organic matter is said to be stable only after it is in a chemical form that does not break down any further.

"Indications are that soil organic matter at some point reaches a steady state in farmed soils, with additions about equal to losses over years," says Nafziger. "But it may be possible, depending on what crops are grown and how they and soils are managed, for some soils to begin to regain, ever so slowly, stable soil organic carbon."

Kravchenko says studies have shown that SOM increases in at least the top two inches of soil in a no-till system. "But what studies have also shown is that to continue that increase or keep that higher level of SOM it would have to remain in no-till. Even one tillage event will do a lot of damage to that freshly accumulated soil organic matter. A lot of it will disappear. So that restricts how useful no-till can be for carbon sequestration."

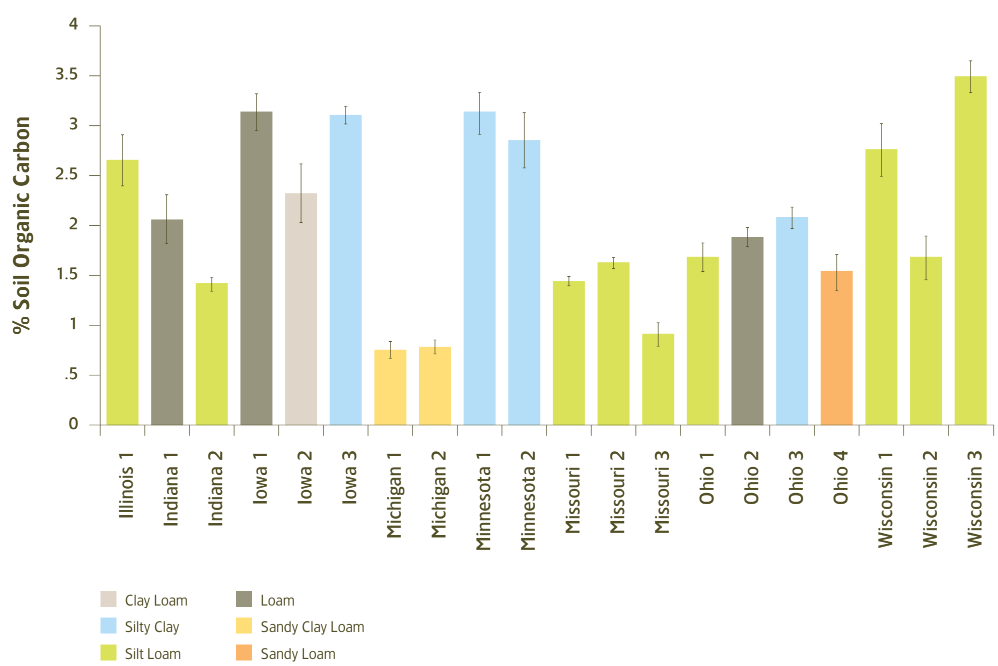
"So, with cover crops, the carbon appears to stay there despite the tillage. In my opinion, cover crops provide more flexibility for the farmer, when choosing tillage options," Kravchenko says.

"We also are observing that cover crop effects are different in various topographies. We hypothesize, and are now seeing first signs of support to this hypothesis, that we will reap greater benefits from cover crops, in terms of improvement of soil structure and increase in SOM, in parts of the terrain with poorer soil — areas that are more eroded, low in SOM, or have inadequate aggregation."



Lynn Laws is a communications specialist for the Sustainable Corn Project and for Iowa State University, College of Agriculture and Life Sciences.

FIGURE 1 | SOIL ORGANIC CARBON



Increasing a soil's level of organic matter can make your crops less susceptible to drought. In fact, a one percent increase in soil organic matter (SOM) can result in an additional water holding capacity of 25,000 gallons per acre. This figure shows the variation in Soil Organic Carbon (SOC) across the Sustainable Corn Project sites. SOC is an indirect way to measure SOM. SOC comprises roughly 58% of SOM.

Sustainable Corn Researchers are collecting a suite of agronomic, soil, water, and greenhouse gas datasets to better determine the nitrogen, carbon, and water footprints of our Midwest corn-based cropping systems. Data are collected spanning 2011 to 2016 from across our teams' 35 site research network (see page 3) and encompasses 45 treatments and 115 types of measured data. An example of this unique data set is shown in the figure to the right, which showcases the range in soil carbon of some of the team's research sites.

Data interpreted and compiled by Landon Bunderson, Sustainable Corn Project data manager.

^ Soil organic carbon is part of soil organic matter (SOM). Mollisols (left), which are 5–15% carbon, and alfisols (right), which are 1–5% carbon, are the two dominant soil orders farmed in the North Central Region. Photos courtesy USDA Natural Resource Conservation Service.

SOIL CRITICAL TO GLOBAL CARBON BALANCE

While soil carbon comprises only one to six percent of total soil mass, it plays a key part in the earth's carbon cycle. In fact, the organic matter currently in the world's soil contains 1500 petagrams (or 1,000,000,000,000,000 grams) of carbon, more than twice the carbon in living vegetation (560 petagrams). These facts draw interest from policy makers and scientists seeking ways to retain carbon in soil and reduce carbon dioxide emissions. Soil carbon is most highly concentrated in the top 8 inches and decreases with soil depth down to approximately 3 feet. Thus, soil carbon contained within the tillage layer is more likely to be affected by management practices than carbon in the deeper rooting zone.

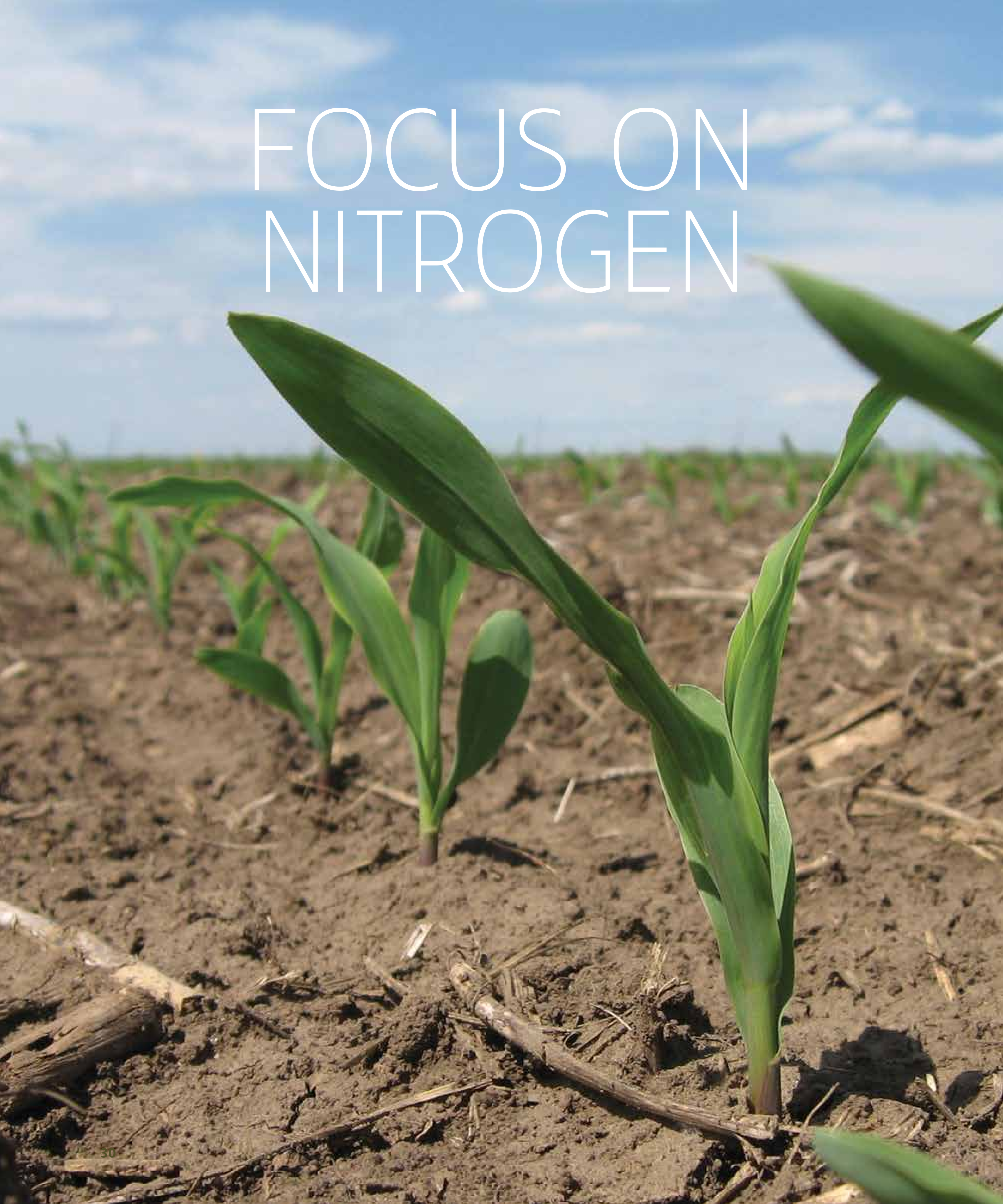
SOIL ORGANIC MATTER AND CARBON'S ROLE IN SOIL HEALTH

Soil organic matter (SOM), a key component of healthy fertile soil, is made up of previously living plant and animal residues that are in different stages of decomposition. SOM has important nutrients needed for plant growth and development, such as nitrogen, phosphorus, sulfur, and micronutrients.

SOM is one of the major binding agents of soil aggregation. It holds particles together and creates soil pores within and between aggregates to provide air and moisture to the roots and drain excess water. About 58% of SOM is carbon. Soil organic carbon (SOC) is the main source of food for soil microorganisms. Soil aggregates can be disrupted by tillage thereby increasing the availability of carbon to microorganisms which can result in release of carbon dioxide back to the atmosphere.

> In addition to other physical characteristics, like aggregation, one can tell if soil has high carbon content by its color. Darker soil has high carbon content; light soil is low in carbon. Photos by J. Simmons, Michigan State University.

FOCUS ON NITROGEN



Lifecycle Benefits and Costs of Inorganic Nitrogen Fertilizer

BY LYNN LAWS

Nitrogen is a primary component of a plant's photosynthesis machinery. The ability of a plant leaf to capture sunlight and carbon through photosynthesis is directly related to how much nitrogen is in the leaf. The agronomists who helped bring about the "Green Revolution" capitalized on this relationship by breeding varieties of corn, wheat and rice that have higher nitrogen-absorbing potential. Known as "high-yielding varieties," they outperform other varieties when given adequate inputs of nitrogen, water, sunlight and other nutrients.

Robert Anex, a professor at the University of Wisconsin and a principal investigator for the Sustainable Corn Project, says plant scientists have bred corn to have roots that grow deeper and seek soil moisture. "But the roots are also chasing the nitrogen, because a lot of the nitrogen put on a field is available as ammonium and nitrate in the soil moisture. Corn breeders have done lots of things to make corn grow better. The leaf angle is steeper and there are more leaves to capture more sunlight and moisture, for example. But at the end of the day, all the breeding in the world will not save you if you don't have nitrogen."

20 to 40 percent of the greenhouse gas emissions associated with farm production are due to the production of nitrogen fertilizer.

By the time high-yielding varieties of cereal grains became available commercially, scientists had developed a process to create inorganic nitrogen fertilizer in order to fulfill the higher demand. Crop yields and acres harvested increased year after year, as did the use of nitrogen. By the mid-20th century, this green revolution helped to avoid widespread famine in Asia and saved millions of lives.

But these super crops come with downstream and upstream costs.

Downstream costs

"Right now the system is leaky," Anex says, referring to conventional corn-based cropping systems. "On average, 70 percent of plant-available nitrogen in the soil comes from applied inorganic fertilizer. Depending on how it is applied, only 40 to 60 percent of that goes to the plant. The rest of it is leaking out of the system somewhere."

Whether from organic matter in the soil or added during fertilizer application, mobile nitrogen not taken up by vegetation can move with water flowing through soil after rains and snow melt, and into streams and rivers where excess nitrogen can cause adverse effects on water conditions, aquatic organisms and habitats. Also, after fertilizer is applied, if conditions are right, microbes in the soil can convert the nitrogen into gases such as nitrous oxide that can escape into the atmosphere. Nitrous oxide emissions have a negative impact on air and water quality and result in ozone-depletion. Regardless of how the fertilizer is lost, it has a negative impact on the natural environment as well as a producer's bottom line.

Upstream costs of inorganic fertilizers

Anex says the upstream costs in the lifecycle of inorganic nitrogen fertilizer, i.e., the costs incurred to make it, are significant, too. Inorganic nitrogen fertilizer is made from natural gas and nitrogen from the air. (Seventy-eight percent of the air we breathe is nitrogen.)

"Air consists of nitrogen, oxygen, and other gases like carbon dioxide. In the fertilizer manufacturing process, natural gas which is methane (CH_4) is split apart with the carbon molecule combining with oxygen (O) to make carbon dioxide (CO_2). The hydrogen reacts with nitrogen from the atmosphere (N_2) over a catalyst to make ammonia: NH_3," says Anex. "For every 10 pounds of ammonia made, about eight pounds of natural gas are used up. When I put nitrogen on the field, it's like I'm putting natural gas on the field." Each of those pounds of ammonia also comes with about 1.9 pounds of CO_2.

In addition to natural gas, large amounts of electricity are required to make the reaction happen. "Ammonia is equivalent to natural gas plus the energy it took to make it. It's an energy-intensive product," Anex says.

Greenhouse gas emissions from the industrial process are another lifecycle cost. In fact, 20 to 40 percent of the greenhouse gas emissions associated with farm production are due to the production of nitrogen fertilizer.

continue on next page >

Big impacts make good targets for environmental and financial goals

"When up to 45 percent of the energy use associated with corn production is due to upstream nitrogen production and close to 40 percent of the greenhouse gas emissions are from the upstream process, it really creates an incentive to try to reduce fertilizer use," says Anex. "And then there's the economic incentive – nitrogen is expensive."

> Reducing energy use while maintaining yield improve the bottom line and is good for the environment.

Farmers now have another economic incentive to reduce nitrogen: nutrient credit trading markets. The Delta Institute of Chicago announced February 19, 2014, that through its new nitrogen credit program, it will work with farmers across the Midwest to encourage voluntary changes to fertilizer applications to reduce emissions of nitrous oxide. Anex says more programs, like this one, are "just around the corner."

Central to these programs will be nitrogen-use protocols that give farmers guidance regarding qualifying practices. The practices that will qualify will likely be those that have shown consistent results in scientific peer-reviewed literature, such as the practices that the Sustainable Corn Project researchers are studying. Drainage water management, nitrogen sensing, split application of nitrogen, extended rotations, and use of cover crops, for example, are some of the practices that help farmers use nitrogen more wisely and/or limit its release into the environment.

"Given that using nitrogen properly can save farmers money and can reduce the upstream and the downstream environmental impacts, it's a win, win, win," says Anex.

Lynn Laws is a communications specialist for the Sustainable Corn Project and for Iowa State University, College of Agriculture and Life Sciences.

FIGURE 1 | BENEFITS OF VARIABLE RATE N SYSTEM

This plot is the like a target where all values are smaller at the "bulls-eye." We prefer to use less energy to produce a ton of corn while releasing less environmentally harmful emissions. Therefore, on three of "spokes" of this plot we would prefer to be near the "bulls-eye" and the fourth – the corn yield per hectare – we would prefer to be as far out as possible. What this graphic shows is that the variable rate N system (represented by the solid green line) is superior to fixed rate application (represented by the red, dashed line) in all dimensions except yield – which is unchanged. Reducing energy use while maintaining yield improves the economic bottom line and is good for the environment.

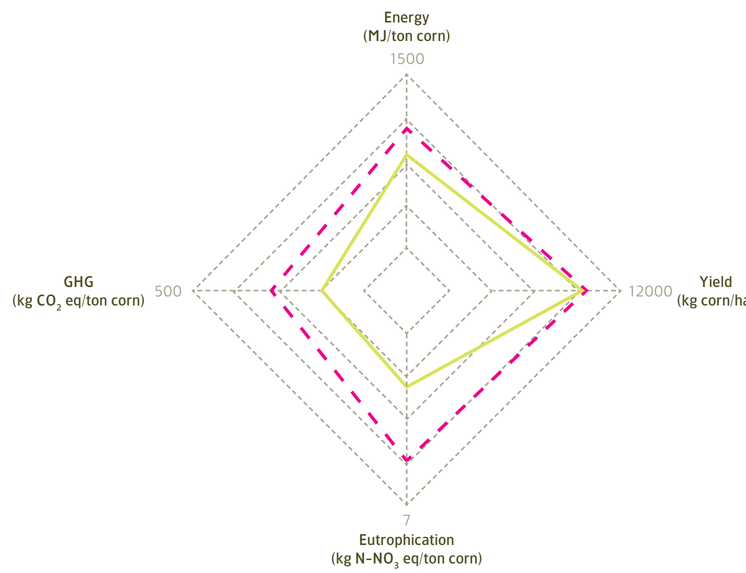
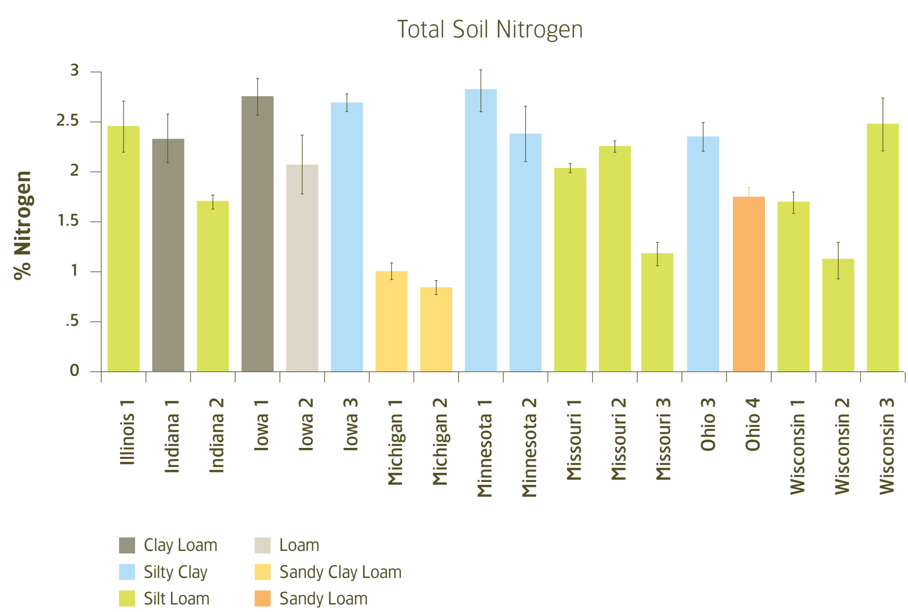


FIGURE 2 | TOTAL SOIL NITROGEN

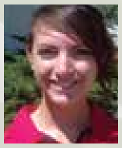
Total Nitrogen: Soil can act as a nutrient reservoir. Most of the nitrogen contained in a soil is not immediately available to the plant. It has to go through a process called mineralization in order to become available. Mineralization occurs as microorganisms convert organic nitrogen to inorganic forms. If the rate of mineralization exceeds the rate of crop uptake, the mobile inorganic nitrogen is vulnerable to leaching from the soil which can have downstream environmental impacts. Nitrogen leached from the soil must be replaced to maintain fertility, costing the farmer money and creating upstream impacts due to fertilizer manufacturing. Nitrogen mineralization is closely linked with total nitrogen content. The chart to the right illustrates the measurements of total nitrogen in the soil at some of the Sustainable Corn Project field sites. Data interpreted and compiled by Landon Bunderson, Sustainable Corn Project data manager.



Investigating the Impact of Weeds and Nitrogen on Nitrous Oxide Emissions

BY BECKY BAILEY AND VINCE DAVIS

The objective of our research is to determine the impact that weed management and nitrogen (N) use have on N_2O emissions in Midwest corn and soybean production. Weeds compete with crops for water and soil available N, and soil moisture and N fertility are major contributors to N_2O emissions in crops. By reducing soil N and water, we hypothesize that weeds managed with post-emergence (POST) herbicides could potentially reduce N_2O emissions while growing. However, previous research indicates that plant residues can increase N_2O emissions, and thus weed residues remaining on the soil surface after POST herbicide termination also may contribute to higher emissions by later increasing soil moisture and encouraging N cycling. We're investigating questions such as: Do weeds reduce N_2O emissions while growing? Do dead weed residues increase emissions? Are cumulative emissions (before and after weed termination) the same for a given rate of N independent of weed density?

Vince Davis is an assistant professor at the University of Wisconsin-Madison and a principal investigator for the Sustainable Corn Project. Becky Bailey participates on the Sustainable Corn Project and is an M.S. graduate student at the UW-Madison.

^ A 2009 central Missouri nitrogen experiment showed the cost of N loss in wet years. The row on the right received 180 lb N/acre at planting and yielded 96 bushels per acre. A great deal of the N applied at planting was lost before June and July when the corn really needed it. The row on the left received 153 lb N/acre when it was knee high and yielded 164 bushels per acre.

In-season N Applications Increasing in Response to More Frequent Wet Springs

Annual precipitation has increased overall in the Corn Belt over the last 100 years. In addition, many areas are experiencing more extreme rainfall events and higher total precipitation in the spring. In those areas, farmers report they are adapting by waiting to apply nitrogen (N) closer to crop N uptake.

Peter Scharf, professor of plant sciences at the University of Missouri and principal investigator on the Sustainable Corn Project team, says wet springs were widespread in the Corn Belt from 2008 through 2011, and so was nitrogen deficiency, based on aerial and windshield surveys of corn fields that he undertook in those years. Nitrogen deficiency is expressed by light green to yellow leaves. Scharf estimates that what he saw was two billion bushels of lost yield potential during those four years. He says applying N fertilizer during the growing season could have recovered much of the lost yield.

In 2013, much of the Corn Belt was blanketed with more than 16 inches of rain from April through June (Fig. 1). Scharf estimates the area represented 48 percent of all corn acres in the United States. Recently, Scharf undertook a study to see how 21st century spring rains compared to longer-term data in the Corn Belt. He obtained rainfall maps going back to 1900, from the Midwest Regional Climate Center. He discovered that the wet spring of 2013 covered more square miles than any other spring during the past 114 years.

More important than what happened in 2013 are the patterns over time that Scharf found in the data (Fig. 2). He analyzed the data using several different models and found that the best-fitting model showed two patterns: little to no change in the size of the wet area from 1900 through 1980, but from 1980 to 2013 the average size of the wet area has more than doubled.

“...we actually increased our yields 17.5 bushel to the acre.”

Scharf also found, through a series of three informal surveys, that corn producers applied in-season N in 2013 at rates far exceeding any previous year. Many of them had experienced wet springs, nitrogen loss, and the resulting yield limitation several times in the past six years.

Ray Gaesser, an Iowa corn and soybean producer and 2014 president of the American Soybean Association, started testing nitrogen rates in the early 2000s, looking for the right rate and timing for his fields. He says he “didn’t see any difference in corn yields for spring-applied nitrogen versus fall, until I started seeing heavy spring rains.” Now he uses “less upfront and more in-season applications” and is experiencing better yields overall. Gaesser also has incorporated cover crops in his rotations and has seen reduced erosion from heavy spring rains.

Garry Niemeyer, past president of the National Corn Growers Association, farms 2100 acres in central Illinois. “We put in 28 percent nitrogen as we plant the corn for a starter fertilizer, and then we come back and apply dry urea with a nitrogen stabilizer about the first week of June. And by doing that — this is the third year that we have experimented on our own — we actually increased our yields 17.5 bushel to the acre. So we did not use any more nitrogen; we just applied it at the appropriate time. And that to me is what we could do every year, no matter what the weather is going to do, because it makes the most sense. It keeps the nitrogen on the farm, in the crop, and not in the river. It’s a win-win,” says Niemeyer.

Wet springs affect not only soil and fertilizer nitrogen, but every field operation. Getting field operations completed becomes that much harder in a wet spring. Using USDA-NASS data, Ray Massey of the University of Missouri has shown that the time from Missouri’s corn crop being 25 percent planted to 75 percent planted has increased by three days over the past 30 years.

“This is not because farmers are working shorter days, using smaller equipment, or losing logistical prowess. It’s because weather has slowed them down,” says Scharf.

Scharf suggests that producers should prepare to deal with more wet springs.

“Larger equipment, starting earlier when possible, hiring more custom work, and adapting operations to the year even if it increases cost are all reasonable strategies. Adding in-season nitrogen applications to that list seems daunting, but pays off in wet years,” Scharf says.

In an experiment that he conducted from 2007 to 2013, in-season N out-yielded all-preplant N by a total of 265 bushels/acre, for the four year period, while using 120 lb/acre less N. The yield advantage all came in the wet years of 2008, 2009, 2010, and 2013.

FIGURE 1 | 2013 PRECIPITATION

Area outlined in red received 16 or more inches of precipitation from April 2013 through June 2013. Image courtesy of University of Missouri Division of Plant Sciences.

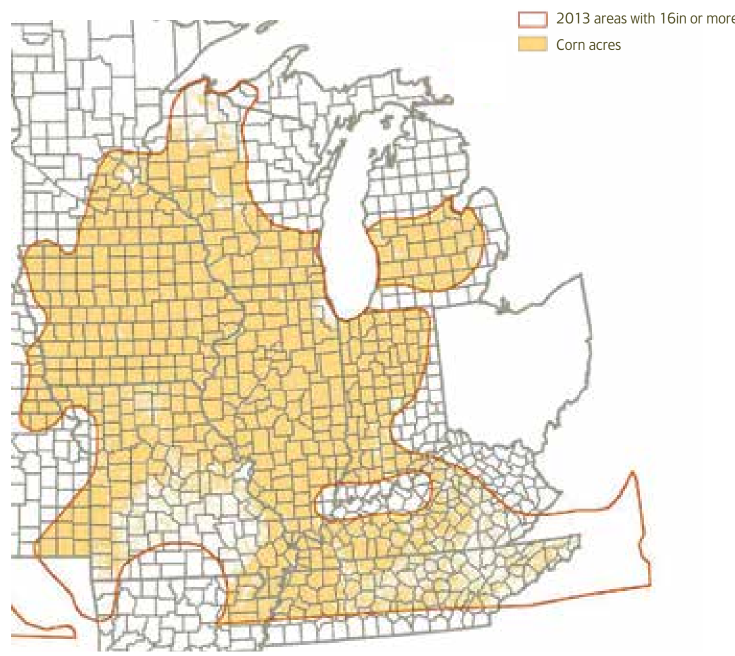
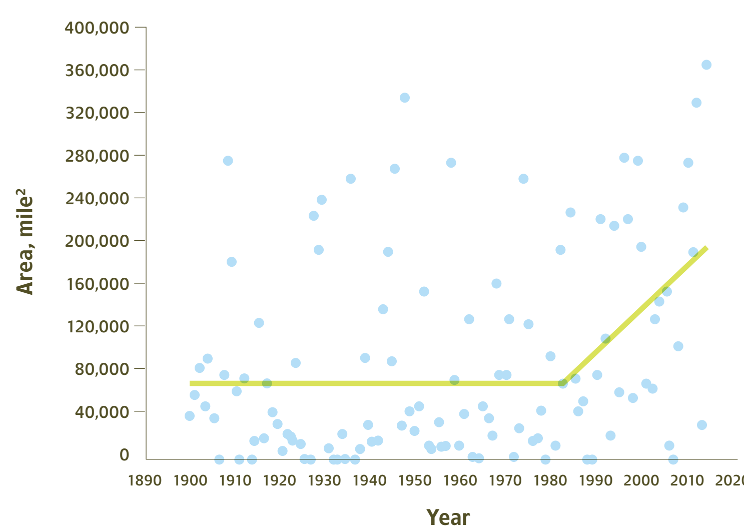


FIGURE 2 | AREA WITH ≥ 16 INCHES OF RAINFALL, APRIL–JUNE

Each dot on the graph represents the area for one year, and the higher the dot the greater the area that had over 16 inches from April through June. The dot at the top right is for 2013, higher than any other year.



Winter Rye Cover Cropping System: A Long-term Investment

BY LYNN LAWS

While it's known that cover crops improve soil health by increasing soil aggregation, water infiltration, organic carbon, and soil biological activity, project scientists want to know if those improvements lead to improved crop yields over time as well as less year-to-year variability in crop yields.

John Sawyer, professor of agronomy at Iowa State University and a principal investigator on the Sustainable Corn Project, has been studying the effects of cereal rye winter cover crops at five Iowa field sites for the Sustainable Corn Project and the Iowa Department of Agriculture and Land Stewardship.

"A lot of people expect really big benefits for yield and reductions in N [nitrogen] fertilization need. But from 2009 to 2013 we have found a slight yield decline in corn, no yield effect in soybean, and little difference in economic optimum N fertilization rate," says Sawyer.

The five sites are in a corn-soybean rotation, with and without winter cereal rye cover crop each year, early sidedress fertilizer nitrogen, and all are no-till. At the sites, six N rates are studied: zero to 200 lb. of N per acre. Using several N-rates allows researchers to look at where an economic optimum rate is reached and the yield of the corn at the economic optimum.

"So we hone in across a wide range of environments—soils and climatic conditions—and study them to see if there is a net difference in fertilization requirement in a system with rye cover crops. We conduct rye crop biomass sampling, soil nitrate sampling in the spring and fall, and corn canopy sensing to look at the effects of the cover crop on the corn canopy. We also look at total N uptake by the corn at the end of the season," says Sawyer.

"What's the economic value of a 31 percent reduction in nutrient loss?"

Sawyer says the results have shown "almost no difference in N-fertilization rate requirement. It averages out about 10 pounds more when there was a rye cover crop preceding corn. It's so small that I wouldn't even suggest a change."

He says his findings are consistent with what some earlier N-rate studies on corn in the Midwest have shown. "An N-fertilization rate reduction was found in coarse textured, sandy soils, with a rye cover crop, but we don't have many sandy soils in Iowa or in the other study states. In finer soils like we have in Iowa, the cover crop was not found to change the needed N application rate."

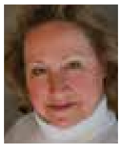
^ Does not always occur, but sometimes an early corn growth difference is found between with and without rye. The corn on the right in this photo was preceded by a rye cover crop; the corn on the left was not. Photo taken at a Sustainable Corn Project field test site in Ames, Iowa.

Regarding corn yields in Iowa, Sawyer says, "At best it's the same with and without the rye, but once in a while yield will decrease and that has averaged about 5 percent across the sites and years of the study." Results show no yield difference in soybean with or without the rye cover crop.

Sawyer says a 5 percent average corn yield loss could result in a loss of $40 to $50 an acre. "When you add on the cost of the cover crop seed, and associated seeding and labor costs, it adds up to a competitive disadvantage for the corn producer in the short-term."

But he is quick to point out that Sustainable Corn Project studies and others have shown erosion control and soil benefits that pay off in the long term do not currently have an annual economic value assigned to them, which producers could use to weigh the benefits and disadvantages of cover crops and make on-farm management decisions. "What's the economic value of a 31 percent reduction in nutrient loss during a heavy rain? We don't yet have a value for farmers on that."

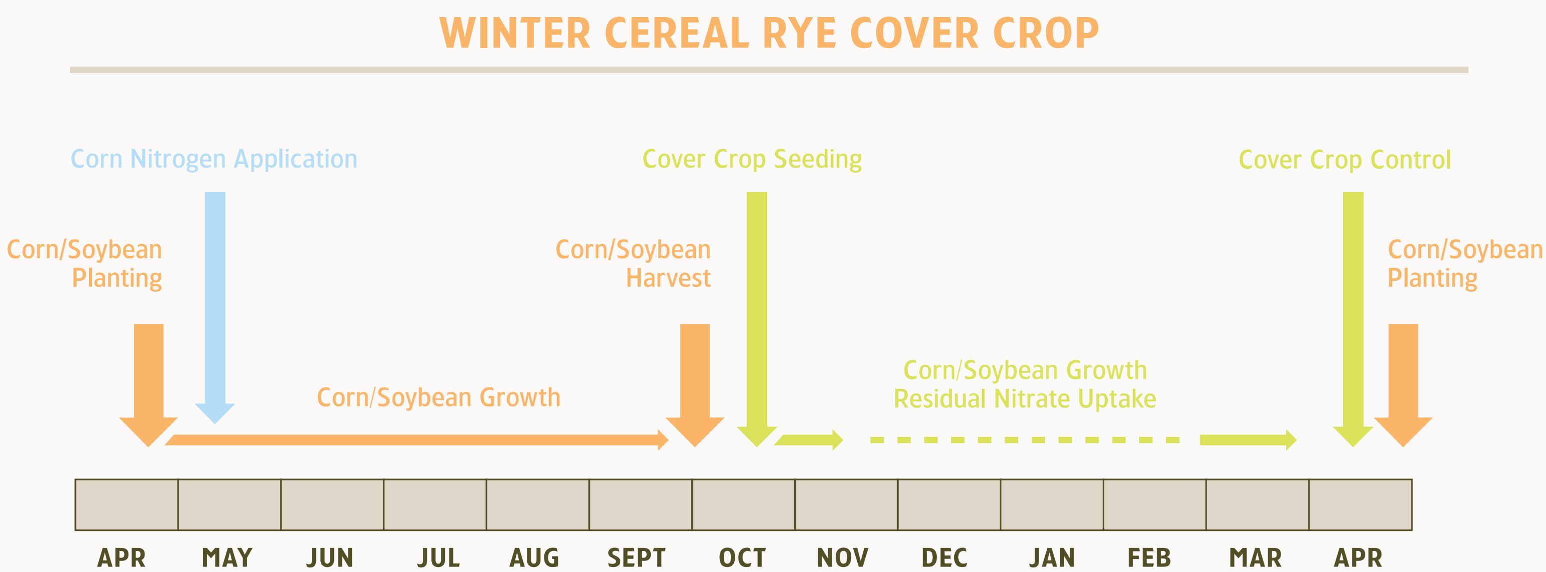
Using a different cover crop, other than cereal rye, could reap different results. The Sustainable Corn Project team opted to include the cereal rye cover crop in their research as it is the most widely-adapted cover crop across the 8-state project.



Lynn Laws is a communications specialist for the Sustainable Corn Project and for Iowa State University, College of Agriculture and Life Sciences.

FIGURE 1 | **COVER CROP CONTROL**

Timeline for incorporating rye into a corn/soybean rotation.



^ At the Ames Sustainable Corn Project field sites, the rye cover crop is drilled after harvest, typically in late September to mid-October. Some farmers are aerial seeding rye before harvest, often in early in September.

^ Optimal nitrogen fertilizer rate varies widely within a field. Using equipment to sense the nitrogen needs in the corn canopy while applying N fertilizer is a promising approach to diagnose and treat the variation in real time. Two sensors are mounted on either side of the tractor, in front. A computer in the cab reads the sensors, calculates N rate and directs the controller to apply a particular rate of fertilizer.

Research Shows Soybeans Provide Consistent Reduction in Nitrous Oxide Emissions

BY MICHAEL CASTELLANO

The opportunity for farmers to profit from reductions in greenhouse gas emissions has resurfaced. The Climate Trust and Delta Institute are partnering to verify and purchase greenhouse gas reduction credits from upper Midwest corn farmers. Credits result from modified farming practices that reduce emissions of the greenhouse gas nitrous oxide (N_2O) from surface soils by improving nitrogen fertilizer use efficiency.

Although agriculture accounts for a relatively small proportion of total U.S. greenhouse gas emissions, approximately 2/3 of U.S. greenhouse gas emissions from the agricultural sector are due to N_2O that is emitted from nitrogen fertilizer applications. With a warming potential of about 300 times that of carbon dioxide (CO_2), nitrous oxide is among the most effective heat trapping gases in the atmosphere. Reductions in nitrogen fertilizer inputs reduce N_2O emissions. However, farmers and greenhouse gas trading programs require N_2O reduction strategies that maintain or increase yield.

> "...inclusion of soybeans in the cropping system is a simple, effective, and relatively consistent way to minimize agricultural N_2O emissions"

With the potential for farmers to cash in on emissions reductions, researchers with CSCAP have been testing the magnitude and consistency of several N_2O reduction strategies. There is a positive relationship between nitrogen fertilizer application and N_2O emissions. The first step in reducing N_2O emissions is to ensure that N fertilizer inputs do not exceed the profitable rate. In Iowa, this would be approximately 176–201 pounds of nitrogen per acre for corn following corn and 122–146 pounds of nitrogen per acre for corn following soybeans.

Research from the Sustainable Corn project has shown that soybeans provide a consistent reduction in N_2O emissions, largely independent of the nitrogen fertilizer input to corn in the preceding year. Three years of research demonstrates that N_2O emissions from the soybean year (without nitrogen fertilizer inputs) of a corn-soybean rotation are typically 30–60 percent lower than N_2O emissions from the corn year of the rotation (when corn receives Iowa State University extension-recommended nitrogen fertilizer inputs). Moreover, nitrogen fertilizer inputs to the corn year in excess of profitable rates do not consistently increase N_2O emissions from the following soybean crop. Only in 2013, the year following the drought of 2012, were N_2O emissions from soybeans affected by the amount of nitrogen fertilizer inputs to the previous corn crop. These results suggest inclusion of soybeans in the cropping system is a simple, effective, and relatively consistent way to minimize agricultural N_2O emissions.

In addition to examining the potential for soybeans to contribute to lower agricultural sector greenhouse gas emissions, we have investigated the potential for cover crops to reduce N_2O emissions. In Iowa field experiments, no consistent effect of a winter rye cover crop on N_2O emissions from corn or soybeans in a corn-soybean rotation was found. In general, the effect of cover crops on N_2O emissions was observed to be highly variable. To understand why cover crops sometimes increase, decrease or have no effect on N_2O emissions, published studies were analyzed. What we found is that leguminous cover crops have more potential to increase N_2O emissions than non-leguminous cover crops. Also, incorporation of the cover crop into the soil may increase N_2O emissions. However, these analyses do not provide a complete picture of the cover crop effect on nitrogen fertilizer use efficiency or environmental losses of nitrogen fertilizer. And when considering all environmental goals of an operation it's important to know that, in contrast to N_2O emissions from the soil surface, cover crops consistently reduce nitrate leaching by a wide margin — in the range of 30 to 60 percent. Some of the nitrate that is lost downstream is eventually transformed to N_2O. Accounting for this transformation process will be an important goal of future Sustainable Corn Project work as we broaden our understanding of cover crop effects on yield, nitrate leaching and N_2O emissions.

Nitrogen fertilizer rate and climate are the two dominant factors affecting N_2O emissions. Science-based strategies that recognize and explain these sources of variability can provide farmers with cost-effective practices to reduce N_2O emissions while potentially earning credits for these reductions through new climate-based trading programs.

Michael Castellano, Ph.D., is an assistant professor of agronomy at Iowa State University and a principal investigator for the Sustainable Corn Project. Photo by Bob Elbert.

^ GHG measurement locations in corn.

Nitrogen fertilizer rate and climate are the two dominant factors affecting N_2O emissions.

^ Installing photoacoustic spectrometer in soybeans to measure greenhouse gases.

^ Measuring N_2O with a photoacoustic spectrometer.

Cover Crops Shown to Suppress Soybean Diseases

BY DARIN EASTBURN

Farmers plant cover crops for a number of reasons including preventing soil erosion and increasing soil organic matter. Now there may be one more reason — suppressing plant diseases.

In a study funded by a grant from North Central SARE (Sustainable Agriculture Research and Education), Illinois researchers who also participate in the Sustainable Corn Project investigated the effects that cover crops have on soybean diseases. They found significantly lower levels of disease in soybean crops growing in soils previously planted to a cover crop than in crops planted in fallow soils.

One of the cover crops studied was cereal rye which was integrated into a standard corn/soybean rotation, with the cover crop planted after corn harvest, usually in late September. The cover crop was then killed and/or incorporated into the soil the following spring, several weeks before planting a soybean crop.

These study results provide support for adding cover crops to rotations as a way to reduce root and foliar diseases in soybean, especially in areas where Rhizoctonia root rot has been a problem.

The effects the cover crop had on soybean diseases were somewhat variable, with the biggest effects seen when disease potential was high. In 2011 and 2013, in plots intentionally infested with the Rhizoctonia root rot fungus, soybean stand counts were significantly higher in plots previously planted with a rye cover crop, as compared to plots which had not had a cover crop. In addition, lesions of Rhizoctonia root rot were measured on three-week-old seedlings. Measurements consistently showed lower disease levels on plants growing in the rye. Greenhouse tests on soil taken from cover crop plots also showed that, for some years and locations, the soils sampled from the rye were more suppressive to Rhizoctonia root rot than was the soil from the fallow plots.

Other measurements of root and foliar diseases showed mixed effects of the cover crops. Lower levels of sudden death syndrome (SDS) were observed in rye plot soils in some years and locations, but the effect was not consistent. In one location, the severity levels of Septoria brown spot were much lower on soybeans growing in the rye cover crop plots when compared to those growing in the previously fallow plots. In addition, egg counts of soybean cyst nematodes were consistently lower in soils taken from rye plots when compared to levels in fallow plot soils at multiple locations, supporting the findings of a preliminary study that showed lower levels of soybean cyst following a rye cover crop.

These study results provide support for adding cover crops to rotations as a way to reduce root and foliar diseases in soybeans, especially in areas where Rhizoctonia root rot has been a problem.

Darin Eastburn is an associate professor of Plant Pathology in the Department of Crop Sciences at the University of Illinois and a principal investigator on the Sustainable Corn Project. Project cooperators included Loretta Ortiz-Ribbing, Minnesota Department of Agriculture; Jason Bond, Southern Illinois University Carbondale; and Joel Gruver, Western Illinois University.

^ A healthy soybean root (left) compared to roots infected by *Rhizoctonia solani* (right). Photo by Alison Robertson.

^ Early *Rhizoctonia* symptoms. Infected seedlings have reddish-brown lesions on the hypocotyls at the soil line. Photo by Daren Mueller.

^ Sudden death syndrome (SDS) of soybean produces foliar symptoms appearing as yellowing and death of tissue between leaf veins. Photo by Daren Mueller.

Cover Crops Shelter Beneficial and Harmful Insects

BY MATTHEW O'NEAL

Entomologists expect that the addition of cover crops within a corn-based cropping system will affect both pests and beneficial insects. As more corn and soybean farmers incorporate cover crops, researchers are working to understand how the modified environment is affecting insect populations.

Currently, the soil of most farms in the Midwest from fall through spring is left uncovered. This provides little habitat for insects to survive, especially those that migrate from the south to the Midwest in the spring. Cover crops can provide habitat for migrating insect pests and beneficials in a way that bare soil does not. One group of insects that migrate into the Midwest is moths, like the armyworm *(Pseudaletia unipuncta)*, which arrives from the south during April and May. The adults fly to the Midwest looking for a mate, food and sites to lay eggs. Crop damage is done by the caterpillars that come from these eggs. The damage to corn with or without a cover crop can be highly variable, even within a single farm. Some factors that contribute to this variation are the timing of the migratory flights, the planting date and emergence of corn as well as the presence of ground cover. Estimating the risk of these outbreaks requires a greater understanding of how these and other factors contribute to the risk of insect pest outbreaks.

The incorporation of cover crops can contribute to conserving beneficial insects that attack pests. Many of the predatory insects that feed on herbivores like armyworm also require habitat to survive Midwestern winters. Research being conducted within the Sustainable Corn Project is measuring the response of these beneficial insects to cover crops. This research is not yet complete. However, previous research has demonstrated that cover crops significantly increase the abundance of predatory insects compared to bare soil, which translated into greater removal of crop pests.

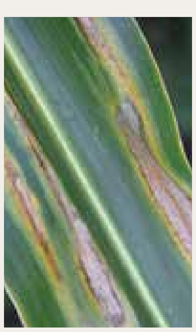
< True armyworm larvae can cause severe defoliation. Early season problems occur in no-tilled fields following pasture or sod or that have high grassy weed populations. Fields with a winter rye cover crop are at a higher risk of infestation.

A two-year study in Virginia compared the amount of natural enemies that feed on armyworms in corn planted into a rye cover crop and the method of removing the cover crop — mowed versus herbicide. More predators of armyworms were found in the mowed cover crop compared to the herbicide sprayed plots. However no difference was observed in the abundance of parasitoid wasps that attack armyworm larvae.

It is not yet known how much cover crops increase the risk of insect damage to corn but we do find that beneficial insects remain within the cover crop regardless of how the cover crop is removed.

Farmers will need to continue to scout corn early in the spring to assess the risk to farm fields and pay attention to cover crop management.

Matthew O'Neal is an associate professor in the Department of Entomology at Iowa State University and a principal investigator on the Sustainable Corn Project. His research is focused on developing economically and environmentally sustainable methods to manage insect pests of annual crops. He and his graduate student, Michael Dunbar, are contributing to the Sustainable Corn Project by studying the response of both pests and beneficial insects to extended rotations and cover crops.



MORE IPM/COVER CROP STUDIES NEEDED

A better understanding of the interaction between crop disease organisms and cover crop hosts will help researchers and extension personnel design management plans that minimize risk to the primary crop of interest. For example, recent greenhouse research determined that the cover crop annual ryegrass hosts the bacteria *Clavibacter michiganensis var. nebraskensis*. This bacterial species causes Goss's wilt on corn (as in the photo to the left) which is a potentially destructive foliar disease. While the role of annual ryegrass in the disease cycle of Goss's wilt is still unknown, research is underway in Indiana to determine if and when annual ryegrass could influence Goss's wilt levels in corn.

Kiersten Wise, Assistant Professor, Purdue University; Principal Investigator, Sustainable Corn Project

< Goss's wilt is a bacterial disease of corn appearing as long, grayish-green to black, water-soaked lesions with wavy edges. Photo by Adam Sisson.

Advice for Young Farmers

BY MAGGIE MCGINITY

This spring I had the pleasure of interviewing a diverse group of established cash crop farmers for a Sustainable Corn Project video. These farmers had a few big ideas about what young farmers should do to be successful, as well as some short and simple tips.

Cover with Crop Insurance

"I think without a doubt they need to buy crop insurance," says Jack Enderle, a farmer in south central Michigan. "And don't bite off more than you can chew. Kind of work into it gradually, because it's like going to Las Vegas, only bigger — it's a gamble."

Like gamblers in Las Vegas, farmers run the risk of losing a large amount of money in just one or two growing seasons. Ken Jochim, a farmer from southwestern Indiana, recommends covering this potential loss with the purchase of crop insurance. "Manage risk, keep it at a manageable level, do what you can to control costs and try to do the best you can," Jochim says.

"Having a good, sound business plan that involves insurance to help them get through those tough times is really important. And the right attitude," says Ray Gaesser. Gaesser currently serves as the president of the American Soybean Association and farms soybean and corn in southwestern Iowa. "But to me the most basic thing that we need to do is to keep that soil where it belongs, keep those nutrients in place and manage the way we farm to address those issues."

Sustain the Soil

"My number one thing is: take care of the soil," says Chris Mulkey, who farms corn, wheat, bean and hay in southwestern Indiana. "Be a good steward. Leave it to the next generation better than when you started. Be productive, but realize you need to keep the soil to be productive."

Garry Niemeyer, former National Corn Growers Association president and farmer in central Illinois, also emphasizes the link between good stewardship and productivity. Niemeyer says a farmer's ability to profit from the land "begins with sustainability — with proper farm management."

> Be a good steward. Leave [soil] to the next generation better than when you started. Be productive, but realize you need to keep the soil to be productive.

Extreme Weather

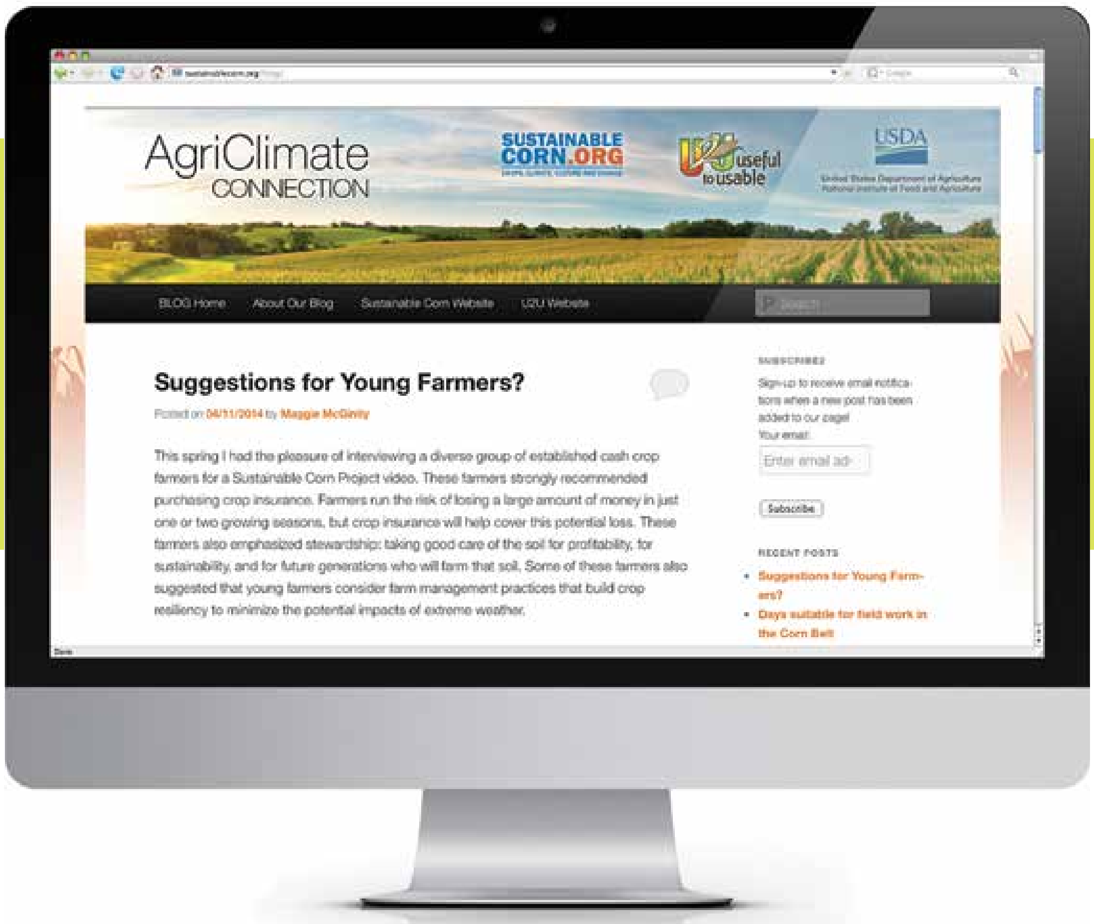
Pat Feldpausch, a farmer from south central Michigan, suggests farm management practices that build crop resiliency to minimize the potential impacts of extreme weather. "The better environment we give the crop that we're trying to grow, the more chance we've got of sustaining through extreme weather," Feldpausch says.

"Have a lot of patience to start with," Niemeyer says. "It's a tough thing because, since 1970, we've seen practically every kind of weather event that probably could take place. And this is where it's important to get good research from universities, cooperative extension services and everybody working together to find those things that work the best."

Feldpausch says even though changes to improve farming through new technology are exciting, young farmers should not "throw the basics out the window."

"The calendar just lets you know when you're supposed to pay taxes and when your birthday is. Mother Nature will tell you when to plant corn."

Maggie McGinity is a senior in journalism at Iowa State University and a videography intern for the Sustainable Corn Project.



AgriClimate Connection, an Interactive Blog for Farmers

AgriClimate Connection is an interactive blog where farmers, agricultural specialists, and scientists from across the Corn Belt can share knowledge, new approaches, and solutions to some of the most challenging problems facing agricultural production today and tomorrow. The blog features timely information and discussions about cutting-edge farm management strategies, weather and climate conditions, nutrient management tips, and much more. Stay informed of the latest news and join the conversation at www.AgriClimateConnection.org.

STAY INFORMED ABOUT:

- Cover crops
- Planting decisions
- Technology and tools
- Weather and climate trends
- Nutrient and pest management
- Drainage and water management

Strength In Numbers

AgriClimate Connection is a collaborative effort among scientists and extension specialists from two USDA-NIFA supported projects, the Sustainable Corn Project and Useful to Usable (U2U). Blog contributors come from a diversity of backgrounds and disciplines, providing a unique and holistic look at issues affecting the Corn Belt. Together, the Sustainable Corn Project and U2U boast a network of 200+ faculty, staff, and students with expertise in Corn Belt agriculture and related issues.

About Useful To Usable (U2U)

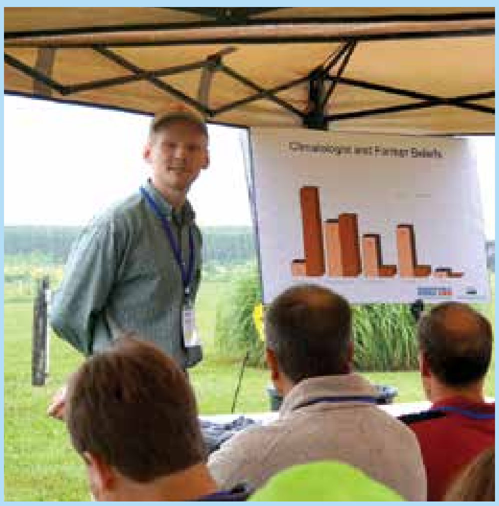
Useful to Usable (U2U): Transforming Climate Variability and Change Information for Cereal Crop Producers is a five-year project focused on improving climate information for Corn Belt agricultural production by developing user-driven decision support tools and training resources. *U2U* strives to help producers make better long-term plans on what, when and where to plant and also how to manage crops for maximum yields and minimum environmental damage.

U2U has launched two web-based decision support products to help farmers and agricultural advisors manage variable and changing climate conditions. AgClimate View$_{DST}$ and Corn Growing Degree Day$_{DST}$ provide user-friendly access to historical climate and crop data to assist with on-farm planning and decision making. These tools can be accessed for free on the *U2U* website at http://www.AgClimate4U.org.

Join the conversation at AgriClimateConnection.org

The Future of Agricultural Science

Next Generation Scientists Rising to the Challenge of Climate Change



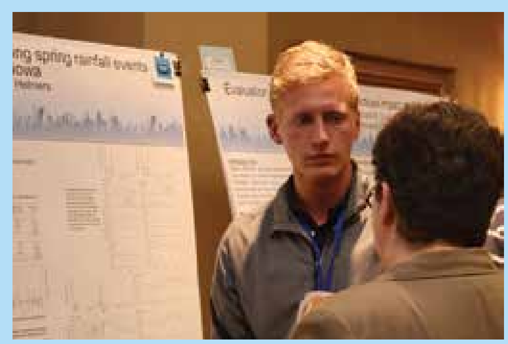
^ Adam Wilke, who is working toward his Ph.D. in sociology at Iowa State University, provides a workshop on science communication to team members.

^ Gabrielle Roesch-McNally (right), Ph.D. graduate student in sociology and natural resources ecology and management at Iowa State University, prepares to film a video on field scouting for the Sustainable Corn project's YouTube channel.

^ Project graduate students pose for a photo at the conclusion of a team meeting in Wooster, Ohio, in 2012.

^ Chelsea Smith (left), research assistant at Ohio State University, demonstrates her methods for measuring crop pests at a team meeting in Wooster, Ohio. Environmental science M.S. graduate student at Lincoln University (2011–2013), Jason Williams (center), takes a close look at the insects she has collected.

^ Mike Dunbar, Ph.D. graduate student in entomology at Iowa State University, gathers insects for a field demonstration.



^ Jonathan Hobbs, as a Ph.D. graduate student at Iowa State University (2011–13), presents his research work at a team meeting in Wooster, Ohio. Jon currently is employed with the Jet Propulsion Laboratory at NASA.

^ Ryan Goeken, M.S. graduate student in agricultural and biosystems engineering at Iowa State Universitys (2011–2013), visits with USDA representative Mary Ann Rozum about his research on how rye cover crops affect soil water content in a corn-soybean rotation in Iowa.

Addressing the complexities of climate and cropping system resilience requires Sustainable Corn project graduate students to work hard to excel as scientists within their own discipline, as well as learn how to work collaboratively with scientists in other disciplines. Each graduate student is housed within a land-grant University and must meet their institutional requirements as well as contribute to project goals. They progress in their comprehension and ability to participate in transdisciplinary work as they advance through their program at their university and participate in the opportunities offered through the project, such as field and lab research, team meetings, science webinars, and sharing what they've learned with fellow team members through field demonstrations and poster presentations.

^ Jason Williams, an M.S. graduate student in agriculture and environmental science at Lincoln University in Missouri (2011–13), provides the operations team with a tour of the university field plots.

^ From left: Michael Dunbar (current) and Jonathan Hobbs (2011–13), Ph.D. graduate students at Iowa State University, join current Ph.D. graduate student Jenette Ashtekar (Purdue) and Melissa Erickson (research assistant at Michigan State University 2012–13) to present their science at a team meeting in Wooster, Ohio.

^ Scott Lee, Ph.D. graduate student in agronomy at Iowa State University, demonstrates how he measures the moisture infiltration capacity of the soil.

^ At a team meeting in Wooster, Ohio, Maciek Kazula, current Ph.D. graduate student in agronomy at the University of Wisconsin, presents his research poster on corn rotation effects on greenhouse gas emissions from Wisconsin soils.

^ Graduate students join in a discussion with scientists, advisory board members and project farmers at a team conference in Wooster, Ohio.

^ Andrea Basche, a Ph.D. graduate student in agronomy at Iowa State University and 2012–2013 graduate student representative on the project's leadership team, presents a poster contrasting and combining the results from different studies on cover crops and nitrous oxide emissions.

^ Dinesh Panday, agriculture and environmental science M.S. graduate student, collects soil samples for soil nitrate analysis at Lincoln University in Missouri.

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CROPS, CLIMATE, CULTURE AND CHANGE

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