

Project Narrative

Climate Change, Mitigation, and Adaptation In Corn-Based Cropping Systems USDA-NIFA A3101 Regional Approaches to Climate Change Cropping systems: cereal production systems (corn)

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Introduction. The United States has a social and economic corn-based system that supports the very successful production of food, fuel, and fiber. However, this system imposes a number of unintended environmental consequences, among them contributions to hypoxia in the Gulf of Mexico and production of greenhouse gases (GHGs). Increased climate uncertainty and change are likely to exacerbate environmental impacts and threaten long term sustainability and resilience unless mitigation and adaptive strategies are identified and implemented.

Our vision is to create a region-wide coordinated functional network to develop science-based knowledge that addresses climate mitigation and adaptation, informs policy development, and guides on-farm, watershed level, and public decision making in corn based systems. The project team is uniquely qualified to quantify Corn Belt GHGs, answer “what if” questions about potential impacts of climate variation, influence the societal challenge to mitigate and adapt to climate change, and increase the number and capacity of next generation scientists, educators, and extension specialists to respond to the challenges of climate and agriculture.

To accomplish our vision, we have assembled a team from 11 institutions across nine states in the Heartland (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, South Dakota, and Wisconsin) comprised of soil scientists, extension field specialists, sociologists, anthropologists, economists, agricultural engineers, modelers, and climatologists. Figure 1 illustrates the primary flow of information. We will establish protocols and collect baseline carbon (C), nitrogen (N), and water usage data from well-defined and carefully chosen plots across the states. We will evaluate the impact of selected management practices on C, N, energy, and water. These data will be combined with public climate data and applied to physical and climate models in an iterative way. We will evaluate the social and economic

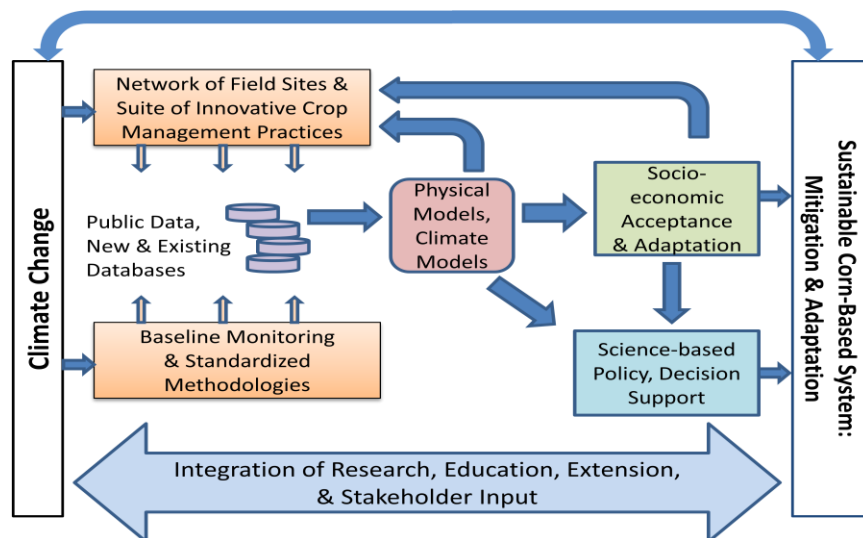


Figure 1. Flow of information. Long-term objectives are to enhance the productivity, resiliency, and diversity of corn-based systems in the North Central Region, aiming for the RFP’s goal of a 10% reduction in greenhouse gases, energy, and water, and a 15% increase in sequestered carbon by 2030.

acceptability of these practices to producers and stakeholders. Research, education, extension, and stakeholder input will be integrated across all aspects of the program.

More than 1/3 of the North Central Region farms produced corn (*Zea mays* L.) in 2007 on over 76.3 million acres, with nearly half of these acres tile drained. Our collective Land Grant Universities (both 1862 and 1890) and the Agricultural Research Service Centers have a several decades-long and productive history of studying soil and agronomic processes by monitoring and experimenting with interactions between N and plant growth, N loss and water fluxes, soil organic C (SOC) storage in relation to soil quality and crop yields, and tillage systems as best management practices (BMPs) for N loss, C storage contributions and water flux, and soil and soil organic C loss. Despite this scientific legacy, **gaps remain** in this body of work, particularly with respect to climate variation and climate extremes. These gaps include knowledge about coupled cycling of C, N, and water; estimates of the effects on C, N, and water fluxes of corn systems management practices; and the capacity/willingness of the agricultural community to adopt management practices to manage risk and enhance long-term sustainability by helping to mitigate unintended environmental consequences. **Our project addresses these gaps and builds a framework for science-based policy and decision making. Specifically, our long-term objectives are five-fold:**

1. Develop standardized methodologies for estimating C, N, and water footprints of corn production in the region and perform baseline monitoring. We will measure soil quality, carbon (C) sequestration, GHGs, inorganic N, and soil water and correlate these measurements with agronomic indicators such as yield for sets of carefully chosen sites across the region. These data will be archived in a publically available database.
2. Using the methods of Objective 1, perform field tests across 21 baseline sites in eight states to evaluate the impacts of a suite of crop management practices on C, N, and water footprints (see Figure 2). Each site has a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation that will be used for baseline measurements. Measurements from these control plots will be compared to plots employing a suite of crop management practices that have promise in reducing GHGs and N in tile flow, and that have potential acceptability to farmers. These practices include no-till (NT), extended crop rotations, drainage water management, cover crops, and canopy N-sensors. Data will be archived in the database.
3. Apply climate and physical models to synthesize results from the field tests and extend them to predict climate and economic scenarios. These include DAYCENT for coupling crop and climate models (Del Grosso et al. 2005), the Soil Landscape Interface Model (SoLIM; for extending the results to the on-farm scale, and SWAT (Arnold et al. 1998; Gassman et al. 2007) to extend these models to the watershed level and incorporate economic land-use models with physical and climate models.
4. Perform comprehensive life cycle analyses (LCA) of the proposed practices and evaluate the socio-economic-environmental willingness of producers and farmers to adopt new cropping systems through feedback loops between social science research, biophysical field research, monitoring, and modeling of agricultural production systems.

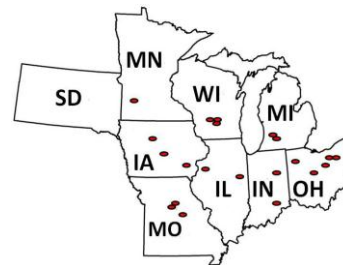


Figure 2. Location of 21 field sites.

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5. Integrate education, extension, outreach, and stakeholder participation across all aspects of the program. Focus will be on place-based education and outreach programs. Farmers will participate via I-FARM (<http://i-farmtools.org/>), an interactive tool to analyze the economic, agronomic, and social acceptability of these practices.

Together, these five objectives will address gaps in our knowledge and build a high-functioning, regionally coordinated network of science-based research, extension, and education that will inform decision and policy making.

Rationale and Significance. “Farming operations are set to face unprecedented stress for harmonizing productivity gains with the reality of global warming” according to the Coalition for a Sustainable Agricultural Workforce (CSAW 2010). The failure to be prepared for climate change can be the result of structural barriers in how we collect, process, and use information and the extent to which mechanisms for surprise-avoidance tasks (awareness, prioritization, and mobilization) are in place (Bazerman 2006). The new vision for environmental research in agriculture must be anticipatory, with long-term, systems-level research at multiple scales (Robertson et al. 2004). It must also be inclusive and reactive, to account for interactions among climate, biophysical, and social sciences, and regulatory, providing for the proper evaluation of new corn-based systems. This project addresses the fragmented research on corn-based systems by uniquely integrating individual, discipline-based findings into a trans-disciplinary and multi-state functional network that connects iteratively current and future scientists, farmers, educators, and extension specialists and facilitates learning and exchange of expert and local knowledge.

This coordinated program of multi-institutional cooperation addresses the RFP’s Program Area Priority of Cropping Systems: Cereal Production Systems. It addresses the mitigation, adaptation, education, and outreach goals of the North Central corn region. The program will contribute to the long-range improvement in and sustainability of U.S. agriculture and food systems by addressing one of the five USDA, NIFA-articulated challenges for the New Biology, namely the societal challenge to mitigate and adapt to climate change.

Approach for Objective 1. Develop standard methodologies and establish baseline monitoring. *Lal (leader, OSU), Castellano (ISU), Nkongolo (Lincoln), Sawyer (ISU), 4 graduate students, 2 postdocs.*

Our research team will use standard methodologies for measuring soil quality, C sequestration and emission of GHGs (CO₂, N₂O, CH₄) and will train the field researchers and graduate students (Obj. 2) in their deployment. We will use these data to perform baseline measurements and LCA related to ecosystem services such as agronomic yield. We will also develop a rigorous training and quality control process to ensure that the measurements are accurate and consistent across the network of field sites and over time.

Collectively we have world class and complementary expertise in all aspects of this research. Lal, Former President of the Soil Science Society of America, a member of IPCC, has extensive experience assessing soil quality and SOC sequestration (Lal 2004; Lal & Follett 2009). Castellano has published on N₂O fluxes (Castellano et al. 2009) and has experience using photoacoustic spectroscopy for measuring GHGs. Fausey & Kladviko (Kladviko et al. 1991; Allred

et al. 2003) are globally recognized scientists on subsurface drainage impacts on nitrate leaching and water quality, including cover crop use and drainage water management to reduce nitrate losses. Nkongolo has expertise in the measurement of CO₂ and agronomic productivity in relation to land use and management and Sawyer has published extensively on N fertilization, crop response to N application and tillage research (Sawyer et al. 2010).

Greenhouse Gases. Given the importance to this project of accurate monitoring of the concentration of GHGs (CO₂, N₂O, and CH₄), we have invested heavily to equip each set of field sites with a dedicated photoacoustic spectrometer (model 1412 Innova Infrared Photoacoustic Spectroscopy (PAS) gas analyzer from LumaSense Technologies, Oakland, NJ). PAS provides a significant advantage over traditional gas chromatograph (GC) methods for regional GHG monitoring; unlike GC methods, PAS systems are easy to use and data can be collected in real time without reagents. PAS systems measure CO₂ and N₂O concentrations at the soil-atmosphere interface with “identical” accuracy to a GC (Ambus & Robertson 1998). Moreover, recent analyses show that PAS and GC measurements of CH₄ flux from soils are “interchangeable” (Jungkunst et al. 2006). PAS provides real-time data that can be transmitted electronically to a database. The equipment is easy to operate and maintain - a graduate student can be instructed in its use in less than half a day.

During the snow-free periods, gaseous fluxes will be measured on most sites (see Obj 2) at GPS-guided locations weekly to fortnightly based on site proximity. Additional measurements will capture “hot moments” of GHG flux, which are not well represented in ecosystem models (e.g., Groffman et al. 2009) but account for a disproportionately large amount of annual GHG fluxes. Examples of “hot moments” include times after fertilization, tillage and heavy rainfall (particularly after dry periods). Measurements will be made in the morning and begin at a different replicate each day to avoid a time-of-day bias. Measurements will be made within row and inter-row areas to minimize spatial sampling errors (e.g., Parkin & Robinson 1989). Fluxes will be computed according to method of Rolston & Moldrup (2002).

Soil Organic Carbon. The dynamics of the SOC pool is the key determinant of soil quality because of its strong impact on soil properties and fluxes of GHGs, both factoring into mitigation and adaptation to climate change, ecosystem services, and economic profitability (Figure 3). The soil quality impacts of SOC are attributed to its effects on the chemical, physical, and biological properties of soil. Therefore it is important to characterize these properties at the outset of our project and to evaluate the subsequent changes in SOC over time caused by the range of corn-based cropping systems envisaged in the program.



Figure 3. Data analysis and synthesis in relation to evaluating the carbon footprint, conducting life cycle analyses and assessing the use efficiency of input for a suite of agronomic practices.

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To determine SOC values, baseline soil characteristics will be determined at selected field sites for the entire soil profile. Table 1 lists the measurements that will be made using the specific methodology. Once the baseline is established for the entire profile, subsequent measurements on key soil properties (SQI column, Table 1) will be made for the surface, 0-15 cm, and 15-30 cm depths. These measurements will be performed in triplicate and made at least once every other year. Changes in soil properties by the suite of crop management practices will also be measured, and the rate of change will be computed with reference to the baseline. Point measurements of SOC and N pools can be scaled up to the state or regional scale via modeling (Obj. 3).

- Carbon Sequestration and Calculation of Carbon Sequestration Index. Soil C and N profiles will be measured from the data on their respective concentration and bulk density for specific soil depth (Lal et al. 1998). C sequestration rate (kg C/ha/yr) will be measured with reference to the baseline.
- Soil Quality Index. Data obtained from the methods outlined in Table 1 will be collated to calculate the Soil Quality Index (SQI) (Islam & Weil 2000; Lal 1994; Gugino et al. 2009). SQI will be measured for all sites in year 1 and at least alternative years thereafter. SQI will be related to ecosystem services (e.g., crop yield, CO₂ offsets).
- Volumetric Soil Water Content at selected sites will be monitored during the growing season. The complete hydrologic budget including evaporative transpiration will be measured at the Coshocton, OH location using the monolith lysimeters (See Obj. 2).
- Weather Data, including precipitation, air temperature, soil temperature, and solar radiation will be collected for all sites using the standard methodology by the National Weather Bureau.
- Agronomic Indicators, including plant biomass, grain yield, grain moisture, grain total C, total N, and plant population will be determined for all sites.
- Written Protocols, Training, Data Handling and Quality Control. Production of high-quality results from this project hinges on obtaining data that are accurate, measured by the same methods, and do not drift over time. We will develop detailed written protocols for all field and laboratory measurements and will establish rigorous face-to-face training sessions for personnel making the measurements. For example, people monitoring the GHG fluxes will attend a training course run by an experienced PAS user (Castellano et al. 2009). Each PAS will be checked for accuracy every three months with Scott gas standards. When machines are not within analytical tolerance, recalibration by the vendor will occur. All Obj. 1 data obtained will be uploaded to the Central Database (Obj. 3) in a timely fashion.

Timeline and Milestones. Standard written protocols and training on the PAS spectrometers will take place within the first six months of this grant. Baseline measurements will be made in year 1. Field measurements and quality control will be ongoing. Soil measurement, to be made according to the standardized procedures (Table 1), will be done after the crop harvest (October/November) each Fall. Gaseous measurements (CO₂, CH₄, N₂O) will be made on a biweekly basis beginning after crop harvest in Fall, and throughout the year following the Julian calendar. Simultaneous soil measurements (moisture, temperature, and NO₃ concentrations in soil solution) will be related to gaseous fluxes and used in developing the SQI.

Table 1. Assessing management impacts on soil quality and soil C pool fluxes: characterization.

Parameter	SQI	Method	Data Synthesis	References
Physical Properties				
Bulk density	X	Clod/core	Total porosity	Grossman & Reinsch (2002)
Soil structure		Wet sieving	MWD, WSA	Nimmo & Perkins (2002)
p ^F curves	X	Pressure Plate, Tension Table	AWC, pore size distribution	Dane & Hopmans (2002a, 2002b)
Soil temperature		Thermocouple (5 cm depth)	Degree days	McInnes (2002)
Infiltration rate		Ring Infiltrometer	Transmissivity, sorptivity	Reynolds et al. (2002)
Soil moisture		TDR	Water (cm)	Topp and Ferré (2002)
Particle size		Hydrometer	Texture, uniformity coefficient	Gee and Or (2002)
Penetration resistance	X	Penetrometer	Soil strength, root growth	Lowery & Morrison (2002)
Soil erodibility		RUSLE	Erosion hazard	Romkens et al. (2002)
Chemical Properties				
p ^H and acidity	X	p ^H Meter	Liming requirements	Thomas (1996)
Salinity		Electrical cond.	Total soluble salts	Rhoades (1996)
Total organic C and org. matter	X	Dry combustion	SOC pool, C footprint, life cycle anal.	Nelson & Sommers (1996)
Organic matter characterization		Fractionation	Labile fraction	Swift (1996), Denef et al. (2009)
Total and organic N	X	Dry Combustion	N pool, N fluxes	Bremner (1996), Stevenson (1996)
CEC and exchangeable cations	X	Ammonium acetate	Base saturation	Sumner & Miller (1996)
NO ₃ concentr.		Colorimetry	N ₂ O emission	Mulvaney (1996)
Biological Properties				
Fractionation of SOM		Density method, colorimetrics	Humic components	Stevenson (1994), Islam & Weil (1998)
Particulate organic matter		Floatation	Mineralizable SOM	Camberdella & Elliot (1992)
Earthworm activity	X	Counting middens	Biochannels	Shuster et al., (2003); Klavdivko et al. (1991)
Soil C pool & changes		Layer summation	Life cycle analysis	Lal et al. (1998)
CO ₂ , CH ₄ , N ₂ O Flux		Static chamber	Global warming potential	Rolston & Moldrup (2002)

Approach for Objective 2. Perform field tests & evaluate a suite of crop management

practices. *Lauer (crop rotations leader, Wisconsin), Kladvko (drainage water leader, Purdue), Helmers (cover crops leader, ISU), Scharf (N-sensor leader, MO), Cruse (ISU), Fausey (ARS-OH-Columbus), Bonta (USDA-ARS Coshocton), Kravchenko (MI), Lal (OSU), Mullen (OSU), Nafziger (IL), Villamil (IL), Nkongolo (Lincoln), L. Owens (USDA-ARS Coshocton), P. Owens (Purdue), Sawyer (ISU), Strock (MN), Shipitalo (USDA-ARS Coshocton), 8 graduate students, 1 postdoc.*

The primary activity of Objective 2 is formation of a network of 21 carefully chosen field sites, each with multiple plots and subplots, across eight states. Each site has a corn-soybean rotation system that will be used for baseline measurements. Measurements from these control plots will be compared to results from plots subjected to a suite of crop and tillage management practices. These practices include no-till (NT), extended crop rotations, drainage water management, cover crops, and canopy N-sensors. Data will be archived in the Central Database. Finally, several farm-scale and watershed level experiments will be performed to test the scalability of the results obtained on the smaller plots.

Members of the Objective 2 team have substantial experience and expertise in different aspects of corn growth and production in the Midwest. Lauer's and Nafziger's expertise is in corn management and production systems. Kladvko has published extensively on subsurface drainage impacts on NO₃ leaching and water quality, including the use of cover crops and drainage water management to reduce NO₃ losses. Helmers has experience in evaluation of nutrient loss from subsurface drainage systems and the impacts of management practices including cover crops and drainage water management on nutrient loss. Scharf has documented wide variability in optimal N rate among and within corn fields, has extensively studied possible approaches to manage this variability, and has concluded that crop reflectance sensors offer the greatest potential for success. Shipitalo, Owens, and Bonta have the expertise and facilities to measure the impact of crop production on surface runoff at the watershed scale and the complete hydrologic budget using the monolith lysimeters at Coshocton, OH.

Choice of Sites. We have carefully selected the 21 field plots in our network to be representative of the range of soil types, topographies, climates, and tile drainage systems across the North Central Corn Region. Table 2 summarizes the plots of our regional monitoring network and lists the direct comparisons that will be made.

Baseline and Ongoing Measurements. Baseline measurements of soil quality will be made at all sites in Table 2 according to the methods described in Objective 1, Table 1, SQI column. Ongoing measurements at most sites include GHGs, weather, soil quality, and agronomic indicators as described in Objective 1. Selected sites will measure SOC sequestration, NO₃ in water, and soil NO₃ deep probe sampling.

Tillage. Use of NT versus conventional tillage has the potential to reduce GHG emissions in corn-soybean agricultural production systems thereby mitigating the impacts of climate change. At present the majority of corn-soybean fields throughout the Midwest U.S. Corn Belt use some type of tillage system. We will establish baseline C, N, and H₂O fluxes from the corn-soybean rotation and compare with and without tillage.

Table 2. Summary of 21 field sites to be utilized in the project (All sites consist of multiple plots and subplots and have a corn-soybean rotation as the base system). Not all crop management practices will be studied at each site.

State	# of Sites	PI	Measurements*	Till-age	Crop Rotations	Cover Crops	DWM	N-Sensors
IA	2	Helmerts	DWQ, SQI, CP, SM, GHG	X		X	X	
	1	Sawyer	SQI, CP, SM, GHG			X		X
IL	2	Nafziger	SQI, CP, SM, GHG	X	X	X		X
IN	2	Kladivko	DWQ, SQI, CP, SM			X	X	
MI	2	Kravchenko	SQI, CP, SM, GHG			X		
MN	1	Strock	DWQ, SQI, CP, SM, GHG				X	
MO	2	Scharf	DWQ, SQI, CP, GHG	X		X	X	X
	1	Nkongolo	SQI, CP, SM, GHG	X	X	X		
OH	1	Fausey	DWQ, SQI, CP				X	
	1	Lal	DWQ, GHG, SQI, SOC, CP, SM	X	X	X	X	
	2	Mullen	SQI, CP, GHG	X		X		X
	1	Bonta	SRQ, LWQ, SQI, CP, SM		X	X		
WI	3	Lauer	SQI, CP, GHG	X	X			

*DWM-drainage water management, DWQ-drainage water quantity and quality, SRQ-surface runoff and quality, SQI-soil quality and soil nutrients, CP-crop and plant production, SM-soil moisture, GHG-greenhouse gas emissions, LWQ-lysimeter water quantity and quality.

Crop Rotations. Crop rotations and cover crops have the potential to maximize SOC retention and sequestration thereby mitigating the impacts of climate change. Increasing the diversity of cropping systems has the potential to maximize resiliency of the corn-based system under variable climate conditions. Currently in the Midwest U.S. Corn Belt many counties have more than 85% of their agricultural land area in a corn-soybean crop rotation. Continuous planting of corn is often the rotation treatment of choice when price opportunities arise. Approximately 20% of all acres in the Midwest Corn Belt are in continuous corn. This number is likely to increase in the future as demand for corn grows.

Our hypothesis is that GHG emissions can be decreased and carbon retention and sequestration increased by using extended crop rotations. This hypothesis will be tested by using data collected from long-term (20 years) established rotation experiments and by performing a set of new experiments to compare no rotation (continuous corn), two-crop rotations (corn-soybean), and extended rotations including a third crop (e.g., winter wheat or oats) or another crop harvested multiple years (i.e., alfalfa). In year 1, previously collected data from long-term rotation experiments will be compiled into the Central Database (Obj. 3). The yield and quality data will be cross-referenced with weather data for the experimental sites.

This information will be used by modelers to project corn production levels for various climate change scenarios.

Cover Crops. Cover crops capture N and C in above-ground biomass, resulting in lower NO₃ quantities in the soil profile and ultimately higher SOC contents (Kaspar et al., 2008). They can also decrease erosion and losses of agrochemicals in surface runoff. Due in part to the increased level of management required to grow cover crops within a corn-soybean system, there has been little field implementation of cover crop systems despite their positive environmental benefits. Our results will provide comprehensive data across the Midwest Corn Belt on the impacts of cover crops on GHGs, soil quality, and leaching water quality.

Randomized complete block design experiments with 3-4 replications of a corn-soybean rotation with both phases of the rotation present each year and with and without a cereal rye (*Secale cereale* L.) cover crop will be established and monitored. In addition, 9 small watersheds in Ohio will be NT planted to corn-soybean rotation with and without the rye to assess the impact of this cover crop on surface runoff and 7 lysimeters (1/500 acre) at this location will be used to assess the effect of this management practice on the complete hydrologic budget, including evapotranspiration, in order to assess water use efficiency (see Table 2).

Drainage Water Management. Drainage water management (DWM) has the potential to reduce the impact of climate change on the productivity of agricultural systems by providing opportunities to increase water use efficiency and decrease N loss through drainage systems. It is estimated that at least 37% of the total cropland in the states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin is drained by surface and subsurface drainage (Fausey et al. 1995). At present, nearly all these drainage systems function such that outflow from the drainage systems can occur anytime the water table rises above the drain depth. DWM is a technology where the water table is managed within the agricultural field to reduce the overall volume of drainage water and thus the export of NO₃ to downstream water bodies. In addition, since water is being retained in the soil profile during certain times of the year there is the potential to increase water use by the main crop.

Our hypothesis is that drainage water management reduces drainflow and NO₃ loads from tile-drained fields. It may also in some years increase crop yield by supplying water to the crop that would have drained out of the soil profile under a free drainage condition. To test this hypothesis we will quantify water and NO₃ fluxes out the bottom of the root zone into tile drains. At the MN site we will install nests of piezometers along transects to estimate lateral seepage to get at the long-standing question about where the rest of the water and N go when DWM is employed.

Canopy Crop Sensors for Nitrogen. Canopy N-sensors have the potential to reduce the impact of climate change on productivity of the agricultural systems by providing a feedback mechanism for adaptive management. *Our hypothesis is the use of crop canopy sensors will improve N fertilizer rate decisions to more precisely meet actual crop need and simultaneously adapt N management to improved C management practices.* The optimal N rate for corn production varies widely from field to field (Lory & Scharf 2003), year to year (Nafziger et al. 2003) and place to place within a field (Scharf et al. 2005). Reasons for this variability are not fully understood, but appear to be primarily differences in how much N the soil supplies.

Tools for diagnosing optimal N rate have historically been little-used in corn production, largely due to inconvenience and limited accuracy. Crop reflectance sensors are a promising

new technology that predicts N rate accurately for corn (Dellinger et al. 2008; Scharf & Lory 2009; Barker & Sawyer 2010; Roberts et al. 2010) and can conveniently manage within-field variability in N need. Field experiments (Table 2) and treatments will include complete or near-complete factorial combinations of N (sensor-based N rate, in-season vs. typical producer N rate before planting), tillage system, and cover crop. We expect that over the project duration, sensor-based N rates will out-perform conventional pre-chosen N rates. In some cases this will mean reducing N use without reducing yield. This will reduce the double footprint of N fertilizer in climate change: the large amount of CO₂ released during N fertilizer production, and the radiatively active N₂O which is released after fertilizer application. We also expect that sensor-based N management will allow nimble adaptation to changes in soil C management.

Up-scaling Findings from Field Tests of Crop Management Practices to Larger Scales.

Uncertainty in the performance of corn cropping systems in the face of climate extremes is exacerbated by the lack of quantitative information on spatial variation of soil processes. Although considerable research on corn management practices at experimental scales exists, to date almost no testing has been carried out on the efficacy of mitigation strategies across entire fields and farms. One concern with up-scaling from the experimental field sites to larger scales is an interactive, potentially non-linear relationship between the effects of management systems and environmental conditions, i.e., soils, topography, historic land use. We will address performance of the conventional system (corn soybean rotation without cover crops) and an alternative system (corn-soybean rotation with a cereal rye cover crop) at multiple scales. Data from up-scaling field studies will serve as inputs for model calibration (Obj. 3).

Timeline and Milestones. Previously existing, long-term data will be compiled into the Central Database in year 1 and baseline data will be collected in year 1. Most management practices will begin in year 1 and continue annually, as will the farm-scale experiments.

Approach for Objective 3. Use physical models to synthesize results from field tests and extend them to predict responses to climate and economic scenarios. *Anex (co-leader, ISU), Arritt (co-leader, ISU), Bonta (USDA-OH), Castellano (ISU), Gassman (ISU), Herzmann (ISU), Kling (ISU), Miguez (ISU), P. Owens (Purdue), 2 graduate students, 1 postdoc.*

Objective 3 involves three main activities. First, we will oversee and maintain a Central Database for data collection and quality control that captures all data generated in this project. Second, we will combine process models, historical data, and climate projections with data from Objectives 1 and 2 to calibrate biophysical models at ever-larger scales: field, farm, and landscape. These models will be used to perform “what if” experiments about observed climate variability and projected climate change. Finally, we will develop a landscape-scale modeling system that integrates economic land use models with detailed biophysical models and projections from regional climate models. This modeling framework will be used to determine the optimal targeting of cover crops, drainage management, and other conservation practices within a corn-based cropping system under a variety of possible environmental goals.

Our team has the combined expertise required to achieve Objective 3. Arritt is renowned for his research in regional climate modeling, having served as a Contributing Author of the Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC; co-recipient of the 2007 Nobel Peace Prize). Anex has expertise in LCA and large-scale

model-based assessment of agricultural-industrial systems. Bonta has extensive experience in data analysis for watershed hydrology and water quality and precipitation modeling (e.g., Bonta 2004a, b; Bonta & Nayak 2008). Gassman and Kling have experience with models that couple crop production, climate, and economic scenarios in watersheds. Miguez has experience with field experimentation of corn cropping systems (Miguez & Bollero 2006), crop performance database and meta-analyses (Miguez & Bollero 2005; Miguez et al. 2008), model development (Miguez 2009), and statistical analysis of complex cropping systems (Villamil et al. 2008).

Building a Central Database for Data Collection and Quality Control. We will design and maintain a publicly available database to house, certify, and annotate all data obtained in this project. Consistent structure, design, and input formats are essential to developing a robust database and the people who are collecting the data must be a strong component of the design, as metadata describing their protocols and instruments used must be carried along with the data. To this end we have enlisted the assistance of David James, a geographic information specialist at the USDA National Laboratory for Agriculture and the Environment. He has extensive experience setting up such databases that are web-based and flexible. A letter of collaboration is attached. Daryl Herzmann, a nationally recognized leader in developing and managing environmental data bases and who received the 2007 NOAA Environmental Hero Award for his creation of the Iowa Environmental Mesonet, will have responsibility for the database. He is a Red Hat Certified Linux Engineer with expertise in statistics, data processing, data mining, and distribution of multi-terabyte sized datasets. He will oversee the database and assist members of the project in uploading data to and extracting data from it, as necessary. He will also ensure that all data are posted in a timely fashion.

Generalizing Our Results Through Use of Process Models. *We hypothesize that the suite of practices examined in our study will produce net benefits in terms of GHG fluxes (CO_2 , CH_4 , and N_2O) and watershed runoff quantity and quality across the range of climate regimes that typify our study region.* We will evaluate this hypothesis through the use of the integrative and widely-used DAYCENT model (Del Grosso et al. 2005) that will allow us to extrapolate observed results to climates of the recent past (1979-present) and near future (present-2050).

As with all agricultural systems, the outcomes of the crop management practices examined here will be strongly influenced by the physical environment, including weather and climate. Thus it is a concern that the five-year period of the study is short in terms of climate variability. For example, a typical El Niño-La Niña cycle is three to six years (van Oldenborgh et al. 2005), so it is likely that not even one such cycle will be included within the period of this project. This limitation underscores the need for a method to extrapolate the observed results to climate regimes not included within the study period.

DAYCENT uses inputs such as management practices, soil characteristics, and climate data (e.g., daily precipitation and maximum/minimum temperatures) and predicts a range of outputs for a cropping system, including fluxes of CO_2 , CH_4 and N_2O . We will use soil and terrain data gathered during the project along with management information as inputs to DAYCENT to evaluate GHG emissions under a range of weather and climate regimes. Climate data for the recent past (1979-present) will be taken from station observations in the Global Historical Climate Network (Peterson & Vose 1997). We also will extrapolate our results to the near future (present-2050) using results from the simulations currently being performed in support of the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5).

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GHG fluxes produced from DAYCENT for the period of study will be compared to actual measured fluxes (Objective 1) and this comparison will be used to calibrate the models via training methods. The robustness of DAYCENT can be inferred in part by comparing its predictions of GHG fluxes against fluxes from available monitoring locations for years preceding our study period, recognizing that there are relatively few of these so that the evaluation will be limited. These results will be used to extrapolate the findings from our field studies to climate regimes not observed during the period of the project.

Up-scaling from Plot-scale to Farm-scale. Data from farm-scale experiments (Objective 2) will be analyzed by the process-based membership classification used in DAYCENT and by a fuzzy membership-based method. The scaling methods include predictive soil mapping at a common 10 m resolution to estimate soil functional properties including soil carbon. The process involves disaggregating SSURGO soil data and re-aggregating based on repeatable soil patterns controlled by topography. Relationships between landscapes (within a common geomorphic unit) and soils are determined using frequency distributions of data extracted with Knowledge Miner Software (Qu & Zhu 2003). SSURGO soils information is extracted and compared to extracted pixel values for topographic terrain attributes such as Topographic Wetness Index, Valley Bottom Flatness and Altitude Above Channel Network. The frequency distributions are determined to set a rule-based classification within the SoLIM software. Once the relationship is determined the software provides estimates for soil properties as a continuous surface. Estimates are based on the representative values of SSURGO initially; however, as data from this project are collected the end-member values will be adjusted and incorporated into the fuzzy membership predictions. Once the maps are generated, any resolution can be adopted (including resolutions of kilometers) while maintaining data integrity.

Landscape-scale Modeling. A modeling framework will be used to determine the optimal targeting of cover crops, drainage management, and other conservation practices within a corn-based cropping system. Our modeling framework covers the Upper Mississippi River Basin (UMRB). It is built around the Soil and Water Assessment Tool (SWAT) model (Arnold et al. 1998; Arnold et al. 2010) and the Environmental Policy Integrated Climate (EPIC) field-scale model (William 1990; Izaurrealde et al. 2006) as described in several previous studies (Gassman et al. 2007).

The UMRB modeling system incorporates GIS capability; survey and laboratory input databases including topography, land cover, land management practices, weather, point sources, streamflow, and water quality variables; and economic costs of establishing land management practices (Gassman et al. 2006). The modeling system will be used to simulate land management practices used in our field study along with the effects of potential future climate change to evaluate the impacts of these changes on GHGs, sediment, and water quality. This capacity has been previously successfully applied to examine UMRB land use and land management scenarios in EPIC (Feng et al. 2004; 2006; 2007) and SWAT (Kling et al. 2006, Kling et al. in press; Rabotyagov et al. 2010) as well as climate change scenarios in SWAT (Jha et al. 2006; Takle et al. 2006, 2009; Lu et al. in press).

Timeline and Milestones. The Central Database will be functional by end of year 1. Historical climate data will be formatted for input into DAYCENT in year 1, IPCC AR5 results will be incorporated in year 2, and simulations and continued evaluation of results will be ongoing

from year 2-5. Preliminary runs to establish the potential environmental and yield effects of the targeted land management changes for corn systems will be undertaken with the UMRB model in years 1-2. Once experimental field trial results become available, the parameters used to simulate changing management and land use will be updated to reflect the newest scientific information. In years 3-5, the model will be used to design and evaluate cost-effective programs for adoption and optimal targeting of crop management practices within a corn-based cropping system. The sensitivity to future climate change will be evaluated by linking the UMRB model with regional climate models.

Approach for Objective 4. Evaluate the Social, Economic, and Environmental Acceptability of Cropping Systems. *Arbuckle (leader, ISU), Anex (ISU), Benning (ISU), Ingels (ISU), Morton (ISU), Today (SDSU), Tyndall (ISU), 5 graduate students.*

Objective 4 will 1) conduct research on the social, economic, and environmental acceptability of adaptive and mitigative cropping systems; 2) contribute to the development of feedback loops between biophysical field research, monitoring, modeling of agricultural production systems, social science research, and education, extension, and outreach activities; and 3) inform the development of policy and programming to encourage the adoption of appropriate systems across the region. It will accomplish these objectives through survey research, participatory farm-level scenario analysis and economic assessment of cropping systems, and comprehensive life cycle assessment (LCA) of corn cropping systems.

Our team of social scientists, systems engineers, and extension specialists has substantial expertise in key elements required for this program. Arbuckle is a natural resource sociologist with expertise in assessment of sociocultural dimensions of agricultural decision making (Arbuckle 2009). Tyndall is a natural resource economist with expertise in analyzing the financial/economic aspects and implications of farmer decision making. Arbuckle, Tyndall, and Morton have extensive experience in the implementation of farmer, landowner, and citizen surveys. Morton is well-known for research and extension work on civic engagement in water quality improvement projects (Morton 2008; Morton & Weng 2009). Anex is an internationally recognized expert in LCA of agricultural systems. Benning is an extension specialist with expertise in engaging farmers and facilitation of watershed projects. Objective 4 consists of three activities, all of which are tied to Objective 3 (modeling) and Objective 5 (farmer and stakeholder engagement):

- Survey farmers to assess the role of perception of climate change risk and socioeconomic factors in decisions regarding adaptive or mitigative agricultural practices.
- Engage farmers in participatory assessment of potential adaptation and mitigation scenarios through the I-FARM whole-farm model and decision tool.
- Perform complete LCA of adaptation and mitigation strategies for corn-based cropping systems using data collected from all aspects of this project.

Survey and Participatory Farm-level Research. While much research has focused on varied ways that agriculture could or should respond to climate change risk through adoption of adaptive or mitigative behaviors (Burton & Lim 2005; Cohen 2010; Lal 2010; McCarl 2010), farmer views on the potential implications of climate change have been left largely unexamined. The guiding research question for this activity will be: to what degree do farmers

view climate change as a threat to their livelihoods, and how do those attitudes impact their willingness and ability to adopt appropriate adaptation and mitigation strategies? *The central hypothesis of the research is that level of perceived threat will be an important predictor of willingness to mobilize resources to improve resiliency of agricultural systems.*

The farmer survey research will provide a comprehensive baseline understanding of how farmers view agriculture in face of climate-related risk and uncertainty. The stratified random sample survey of 2000 medium-to-large scale corn producers (assuming a 50% response, 4% confidence interval at a 95% confidence level) will draw samples from Iowa, Illinois, Indiana, and Ohio, and will focus on the relationship between perception of climate change risk and current and planned agricultural practices. Risk is an important yet understudied factor in agricultural decision making, especially regarding conservation (Marra et al. 2003). Action is in large part influenced by personal beliefs and attitudes (i.e., regarding risk) as they combine with social and economic values, goals, knowledge, and motivational factors (Burton 2004; McCown 2005; Morton & Weng, 2009). These, in turn, are shaped by external factors such as economics of farming systems (Marra et al. 2003), location within civic structure and social networks (Morton 2008), and prevailing institutional arrangements such as conservation incentives or risk management tools (Arbuckle 2009; Valdivia et al. 2009). If people do not feel the need to change, whether to avoid negative impacts or to pursue beneficial ones, they are unlikely to do so. For example, if farmers believe that crop insurance or disaster payments will cover potential losses, those institutional arrangements may serve as barriers to change. Accordingly, the survey will collect data on internal and external factors related to ability and willingness to adopt resilient systems. The Dillman Tailored Design method will be followed to ensure optimal response rates (Dillman et al. 2009). All Institutional Review Board Human Subjects protocols will be followed. Arbuckle and Tyndall will implement the survey in close collaboration with Anex as well as researchers implementing Objective 3 to ensure collection of data required for LCA and modeling.

Farm-level Scenario Analysis and Economic Assessment. This participatory research activity will 1) provide detailed information about how farmers assess alternative cropping systems, and 2) will engage extension educators and key stakeholders in the research process (see Objective 5). Extension educators in four states will conduct one-on-one interviews using the I-FARM model (<http://ifarmtools.iastate.edu/>). I-FARM is a web-based model that allows farmers to analyze the biophysical and financial characteristics of their current operations (accounting for crops/rotations, tillage, fertilization, planting, weed control, harvesting, and residue removal) and compare them to land-use scenarios that simulate incorporation of various GHG mitigating practices. Model output is based on simulations of farm product and various environmental output (Sendich et al. 2008). This scenario modeling will provide real-farm platforms for structured discussions between extension educators and producers regarding key decision variables such as: opportunity costs, capital budgeting, risk management, transaction costs, and key non-economic factors. All of this information is required to characterize the dimensions of farmer willingness to adopt and accept incentives to change practices and/or enter burgeoning mitigation markets. Fifty corn farmers will be selected via purposive sampling (e.g., “snowball” sampling with participant selection assistance from extension personnel) from each of the four states. In Iowa and Ohio, 25 participants will be selected from active farmer-led watershed groups described in Objective 5. These groups will serve as case studies to understand small

watershed level (HUC 12) implications of group interactions when I-FARM information is shared and resulting changes in awareness and implementation of mitigation and adaptive management practices. Tyndall and Benning will manage this activity to ensure its tight integration with Objective 5.

Life-Cycle Assessment is recognized as a leading decision making framework for reducing the environmental impacts of goods and services. LCA is the identification and evaluation of relevant environmental implications of a product, process, or system across its entire life span – from production to consumption. By considering the entire lifecycle, LCA can avoid “problem shifting” between lifecycle stages and receptors. The role of LCA in this project is to assess the sustainability of cereal-based crop production systems under climate change and elucidate the trade-offs inherent in the crop management scenarios. We will use an iterative approach that integrates experimental data and model results in a life cycle framework that will allow us to assess the potential of the socio-agro-ecological system to mitigate climate change through agricultural management. Another critical role of LCA in the study is to integrate and focus the research thrusts by providing feedback on how cropping system choices and management options will impact overall system performance and trade-offs between ecological services (e.g., water quality, habitat) and GHG emission targets.

The proposed study will: (1) estimate the LCA (e.g., productivity, water quality, SOC sequestration) of cereal cropping systems chosen to be resilient in the face of climate change and reduce GHG emissions; (2) evaluate the performance of these systems under climate change; and (3) provide data to and receive data from the farm-level scenario analysis and economic assessment activity and landscape modeling activity.

We will accomplish this by integrating a set of highly developed mechanistic models, providing a tool that will capture climate-soil-plant dynamics and yield the life cycle inventory performance data needed for more accurate assessments of current and future agricultural production systems. We will parameterize and integrate the SWAT/EPIC-based UMRB modeling system with the DAYCENT and I-FARM models in a spatially and temporally specific life cycle framework. We will build on previous work by Anex and colleagues under the Biomass Regional Partnership in which we have been developing a set of agro-ecosystem assessment tools that account for the spatial/temporal variation in agricultural production, emissions, and impacts. Broad Expected Outcomes. The primary outcome will be a vastly improved understanding of the social, economic, and environmental acceptability of cropping systems designed to mitigate and adapt to climate change. The comprehensive knowledge generated by the farmer survey, I-FARM assessment, and LCA will engage stakeholders and inform the development of policy and programming that encourage the adoption of approaches and practices across the region.

Timeline and Milestones. The farmer survey will be implemented in year 1, with data available in year 2 to aid in defining land use scenarios for landscape level modeling and to guide extension and educational activities. I-FARM research will take place in years 2 and 3 with data available as it is developed beginning at the end of year 2. The LCA models will be developed in years 1 and 2; field and modeling scenarios will be incorporated and intensifying in years 3-5.

Approach for Objective 5. Integrate education, extension, outreach, and stakeholder participation. Moore (leader, OSU), Grant (OSU), Benning (ISU), Ingels (ISU), Miller (ISU), Todey (SDSU), Tyndall (ISU), Cruse (ISU), Morton (ISU).

Objective 5 is a key integrative component of the project where a) the next generation of scientists, educators, and extension specialists learn about and develop the capacity to address the challenges of climate and agriculture and b) the exchange of expert and local knowledge among farmers, extension educators, and the project team associated with adaptation and mitigation of variable climate conditions and agricultural management decisions occurs. This objective consists of three types of activities 1) focused educational approaches, 2) extension facilitated and farmer participatory exchanges and actions, and 3) purposeful training, mentoring and career development of project graduate students.

There is a national need to attract the best and brightest students into careers as highly trained agricultural scientists (CSAW 2010). This multi-pronged approach utilizes place-based education at all levels (9-12, undergraduate, graduate, extension, and stakeholders) to increase learning and foster a new generation of scientists, farmers, entrepreneurs, and citizens. *Our hypothesis is those place-based educational opportunities that incorporate inquiry and interactive (constructivist) learning strategies are effective for increasing student understanding and performance in traditional academic subjects (e.g., STEM) as well as fostering awareness of environmental issues* (Cronin-Jones 2000, Leiberman & Hoody 1998; Habron 2005; Lord 1999; Van Tine & Knobloch 2005) and motivating stakeholder environmental mitigation and adaptive management practices (Morton 2008; Morton & Weng 2009).

The Objective 5 team has the complementary experience required to achieve the goals. Moore's expertise is in bridging the social and natural sciences (Moore 2009) through undergraduate and graduate education and the Sugar Creek Project farmer participatory research which has been recognized by the Carnegie and Kellogg Foundations for outreach and engagement. Benning is an Extension Specialist with expertise in water and soil quality research and specializes in facilitating farmer-led watershed projects. Morton has expertise in group development, social relationships, and the integration of local farmer knowledge with technical and scientific expertise as motivators for change in watershed management. Miller's expertise is in teacher education and experiential learning. Todey is South Dakota's state climatologist and President-elect of the American Association of State Climatologists. Tyndall is a natural resource economist with a specialty in analyzing the financial/economic aspects and implications of farmer decision-making.

Focused Educational Approaches. There is a need for K-12, undergraduate, and graduate education that builds the next generation of scientists and increases student awareness of their connectedness to the surrounding landscape and the communities in which they live and their responsibilities of being a good steward of their local environment (Caro et al. 2003; Smith 2002 a, b). A 2010 survey of U.S. adults revealed that about a quarter of the respondents didn't think that global warming was occurring (Leiserowitz et al. 2010; Krosnick 2010). If future generations are to be prepared to face the challenges of changing climate conditions and their impacts on our agricultural systems, they must learn about and actively experiment with the natural environment to discover the social-economic-ecological relationships.

Grade Band 9-12 Educational "Climate Discovery" Modules. Modules will be developed at Ohio State University in collaboration with Climatologist Todey at South Dakota State

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University and will be transferred to the network. Currently the Ohio State University NSF GK-12 grant “Linking Watershed Research and GK-12 Education within an Ecosystem Context” is a leading place-based training grant utilizing streams adjacent to schools for teaching and experiencing science (http://oardc.osu.edu/gk12/t01_pageview/Home.htm). The addition of climate discovery modules to the OSU grant offers an opportunity to pilot test the modules and provides a curriculum application beyond the life of this project. Climate Discovery modules will follow the national science content standards published by the National Science Education Standards (1996) and will be aligned with individual state science requirements. There will also be a career development aspect to these modules.

The audience includes the project network universities’ secondary agriculture and science education curriculum, which currently focuses on water quality, watersheds, and the effects of different land management practices on water and soil quality. The end-use application will be secondary science and agriculture students and instructors as well as FFA chapters. In the Ohio NSF case, the FFA chapter members used ideas from the stream ecology project modules to win both their state and national meeting competitions. The new discovery modules will include Climate Change Discovery using Corn, Climate Change Carbon and Water Footprints, and Climate Change Mitigation. For example, module #1 would be an interactive focus on corn tillage and planting dates and its association to calendar dates such as “knee-high by the fourth of July.” Over this project’s life we anticipate that these models will impact 3,000 students and 80 educators throughout all nine states. These modules will be posted to eXtension for national delivery via the internet, making the potential impact even greater.

Climate Short Courses for College Credit. We will develop and hold a two-week short course for college credit at Ohio State University, South Dakota State University, and Lincoln University/Iowa State University and transfer the curricula to other states in the network. The focus will be on climate change research in agriculture based on coupling natural and social systems. By year 2 we anticipate that 20 students in each state will attend these courses, with numbers growing as the short courses are rolled out to the other states. Iowa State and Lincoln University will jointly develop their short course targeted for minority students in the network.

Undergraduate Internships. Iowa State University will build on its Science with Practice Program (<http://www.ageds.iastate.edu/SWP/>) and Ohio State University on its summer intern program ORIP (<http://www.oardc.ohio-state.edu/orip/secondary.asp?id=222>) and extend these programs to the other universities and co-investigators associated with the project. The purpose is to provide opportunities for college students to learn and work experientially with faculty and staff in university research settings. This program will give students hands-on knowledge about research in agriculture and climate change. The faculty member is expected to provide a strong mentor-mentee environment and develop with the student a signed agreement outlining purpose, goals, and learning expectations. Students are expected to develop a poster for the project’s Annual Summer Convenings (see Management Section). Targeted recruitment will occur at 1890 universities for summer interns. Twenty-one summer interns per year are budgeted (assuming a 50:50 match).

Extension-Facilitated Participatory Exchanges and Action with Farmer-led Watershed Groups. Capacity building is needed within Extension to learn and transfer science-based knowledge of climate change and agriculture to stakeholders and stakeholders need to be aware and motivated to seek information and implement mitigation and adaptive practices. A

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network of established watershed groups (100 farmers) will serve as the structure for implementation—from field to watershed level—of the crop management strategies developed by this project (<http://www.soc.iastate.edu/extension/watershed/performance.html>). These farmer groups currently work with extension professionals and local residents to develop locally appropriate strategies that address water impairments by using field-level agronomic risk assessment tools as performance measures (e.g., soil conditioning index, whole farm P- index, etc.). The groups are experienced in testing new technologies and strategies and using group techniques to determine implementation and adaptation (Morton et al. 2006) and will be willing partners in this project. A critically important element of these capacity-building and knowledge-transfer activities will be farmer participation in the structured flow of information between Objectives 3, 4, and 5. The I-FARM participatory assessment activity outlined in Objective 4 will serve as a catalyst for farmer-led watershed groups to become engaged in the development of adaptive and mitigative strategies. The I-FARM activity will allow these key stakeholders to 1) help the research team to gain an in-depth understanding of the practical feasibility—both economic and sociocultural—of potential mitigation and adaptation practices and 2) be active partners in the adaptation and promotion of effective strategies. With their assistance, we will bring the watershed groups and other stakeholders together to discuss results from the I-FARM, survey, and LCA research activities. Further, farmer-partners will participate in ongoing discussions to assess strategies as they are developed and provide feedback that continually informs the design and improvement of practices, policies, and programs, including future education and extension programming for regional implementation.

Graduate Student Training, Mentoring, and Career Development. Activities will include: 1) Development of three cutting-edge, distance delivered graduate courses linking climate change, agricultural and corn-based systems for graduate students in the network; 2) unique student-centered learning sessions developed by graduate student teams for our annual meetings. Each team will create constructivist learning activities (CLAs) (see Mgmt Section) to increase the student's sense of their individual climate/agricultural science learning experiences and build a cohort community of scholars cross-trained in both climate change and agriculture, to expand the student's professional network, and to further strengthen interactions among the participants in the network; 3) mentoring of 20 graduate students a year with another five funded elsewhere. The participating faculty members already take very seriously their obligation to train, advise, mentor, and develop the careers of their students. Students will be expected to present either a poster or a talk at each annual meeting and encouraged to travel to professional society meetings to make presentations; and 4) a graduate student will have a seat on the project's Executive Committee (see Mgmt Section) to ensure that the voices of the students are heard and their issues attended to.

Timeline and Milestones. Education approaches will be developed in years 1 and 2 and extended to network universities in years 3-5. Extension educators will be trained in I-Farm and the development of farmer watershed groups in year 1. In years 2-5, farmer-led groups will conduct on-farm experiments based on I-FARM and exchanges with project team findings.

Pitfalls and Hazards. The short duration of the project may limit significant detection of change in soil carbon. Extremely dry or wet conditions will make data collection and management difficult. Research will be plot based, making some producers cautious about transferring results to their fields. Herbicides are the only hazardous potential.