Developing Greenhouse Gas Emissions Offsets by Reducing Nitrous Oxide (N_2O) Emissions in Agricultural Crop Product

Project Overview and Preliminary Results from Years 1 and 2

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Technical Update 1, October 2008

EPRI Project Manager

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PRODUCT DESCRIPTION

This report covers the first two years of a three-year long project entitled "Developing Greenhouse Gas Emissions Offsets by Reducing Nitrous Oxide (N_2O) Emissions." This EPRI-sponsored project is investigating an innovative approach to developing large-scale and potentially cost-effective greenhouse gas (GHG) emissions offsets that could be implemented across broad geographic areas of the U.S. and internationally. The tools and information developed in this project will broaden the GHG emissions offset options available to electric companies and others, and can serve as a mechanism to develop and strengthen partnerships between electric companies and the agricultural communities that they serve.

The project has five primary objectives:

1) To determine the technical potential and economic cost to offset GHG emissions by reducing N_2O emissions in agricultural crop production across representative soil and crop types in the U.S.;

2) To confirm, through field testing, that rate of movement of N_2O from soil to the atmosphere (i.e., N_2O flux) can be reduced substantially by decreasing the amount of nitrogen fertilizer applied to cropland with little or no loss in crop productivity;

3) To further refine existing computer simulation models so they can be used to predict the relationship between N_2O flux and crop yields;

4) To identify, describe and analyze socio-economic factors that may encourage or inhibit farmers from participating in N_2O emissions reduction projects, and identify approaches to overcome potential farmer reluctance to participate; and

5) To identify incentives that may be needed to encourage farmers to change cropping practices to achieve N_2O reductions.

Keywords
Climate change
Nitrous oxide (N_2O)
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CO_2 abatement

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In addition, EPRI would like to express its thanks to Michigan State University (MSU) for partnering with EPRI to conduct the on-the-ground research and development and analytic modeling necessary to implement this project. Specifically, we'd like to thank G. Phillip Robertson, Ph.D., Principal Investigator and his Co-Principal Investigators Ron Gehl, Ph.D., and Peter Grace, Ph.D. for their ongoing efforts to implement this project and assist EPRI with evaluating the potential for N_2O-based GHG emissions offsets to reduce global GHG emissions and mitigate global climate change.

CONTENTS

GLOSSARY OF TERMS

1605(b)	The U.S. Department of Energy's program for *Voluntary Greenhouse Gas Reporting*. This program was created pursuant to Section 1605(b) of the Energy Policy Act of 1992 (42 U.S.C. 13385(b)).
C_{equiv}	Carbon-equivalent. A unit of measure that allows all greenhouse gases to be compared relative to that of CO_2 based on Global Warming Potentials.
CO_2	Carbon Dioxide. A GHG with a 100-year Global Warming Potential of 1.
CH_4	Methane. A powerful GHG with a 100-year Global Warming Potential of 21.
GHG	Greenhouse gas. This term usually is used to refer to the collection of all six types of GHGs regulated by the Kyoto Protocol (CO_2, CH_4, N_2O, SF_6, PFCs and HFCs)
GIS	Geographic Information System. A type of computer system that makes it possible to display geographic information in layers that represent different geographic or analytic attributes. ArcGIS is a commercially-available software program for creating and viewing GIS databases.
Global Warming Potential (GWP)	The radiative warming caused by a molecule of gas relative to that of CO_2 for a defined period, usually 100 years. By definition CO_2 has a GWP of 1; N_2O has a GWP of 296.
IPCC	The United Nations Intergovernmental Panel on Climate Change. The U.N. organization responsible for evaluating the scientific basis of global climate change pursuant to the UNFCCC.
KBS	The W.K. Kellogg Biological Station of Michigan State University. KBS is the largest off-campus facility of MSU, is part of the Michigan Agricultural Experiment Station, a National Science Foundation Long-term Ecological Research (LTER) site, and hosts the DOE Great Lakes Bioenergy Field Research Center.
Kyoto Protocol (KP)	A protocol under the United Nations Framework Convention on Climate Change (UNFCCC) where, *inter-alia*, industrialized countries took on binding commitments to reduce their greenhouse gas emissions in a first commitment period (cp1), 2008-2012.
N	Nitrogen.
NRCS	That Natural Resources Conservation Service of the U.S. Department of Agriculture.
N_2O	Nitrous oxide. A powerful GHG with a 100-year GWP of 296.
N_2O Flux	The rate of movement of N_2O from soil to the atmosphere.
Nitrification/Denitrification	Nitrifiction is the microbial oxidation of NH_4^+ to NO_3^-. Denitrification is the microbial reduction of NO_3^- to N_2O and then to N_2.
MSU	Michigan State University.
Offset	A GHG emission reduction, sequestration or avoidance that typically is achieved outside of an organization's internal operations and outside the regulatory and geographic boundaries of any associated GHG cap and trade program. Typically, offsets are required to be *real, additional, permanent and verified* to qualify for use as a compliance instrument.
Pg	Petagram. Equal to 10^{15} grams or 10^9 metric tons. Equal to gigaton (GT) and 1000 million metric tons (MMT). Approximately equal to 1000 million U.S. "short" tons.

SOCRATES	Soil Organic Carbon Reserves And Transformations in EcoSystems model. SOCRATES is a process-based simulation model designed to estimate changes in topsoil carbon and nitrogen with a minimum dataset set of soil, climate and biological inputs.
Tg	Teragram. Equal to 10^{12} grams or 10^{6} metric tons. Equal to 1 million metric tons (MMT). Approximately equal to 1 million U.S. "short" tons.
UNFCCC	United Nations Framework Convention on Climate Change, the multilateral environmental agreement to address the risk of global climate change.
Wm-2	Watt/meter^{2}. A measure of "radiative forcing" of greenhouse gases.

1
OVERVIEW

While debate continues nationally and internationally about how to respond to global climate change, it is becoming increasingly clear that U.S. electric companies may face future carbon constraints that could require them to substantially reduce or offset their greenhouse gas (GHG) emissions.

Nitrous oxide (N_2O) is a significant GHG that contributes to global climate change. Each ton of N_2O emitted into the atmosphere is equivalent to emitting 296 tons of CO_2 in terms of its Global Warming Potential (GWP). Therefore, GHG emission offset projects that reduce even relatively small amounts of N_2O emitted into the atmosphere can have a proportionately larger effect on reducing radiative forcing associated with climate change than similar changes in CO_2 emissions. This sensitivity to small changes provides a strong impetus for including N_2O and other non-CO_2 GHGs in the development of effective GHG mitigation strategies.

In fall of 2006, EPRI launched a three-year long project to investigate the potential to reduce nitrogen fertilizer use in agricultural production. N_2O emissions reductions from crop production may offer an approach that can generate large-scale and potentially cost-effective GHG emissions offsets that could be implemented across broad geographic areas of the U.S. and internationally.

This EPRI project is expected to be completed in 2009. The tools and information developed in this project will broaden the GHG emissions offset options available to electric companies and other sectors of the U.S. and international economies, and can serve as a mechanism to develop and strengthen partnerships with the agricultural communities that they serve.

In this second year of the project the EPRI-MSU project team has made expected progress towards achieving all tasks identified in the project's Statement of Work. This includes:

- Assembling the geospatial databases needed for regional modeling work, linking these databases to the SOCRATES-N_2O model, exercising the model, and submitting a peer-reviewed journal article that provides a regional estimate for fertilizer-derived N_2O emissions from maize production in the North Central Region (Task 1);
- Establishing the second year of N_2O test plots fertilized at different rates on commercial growers' fields and measuring N_2O fluxes from these plots (Task 2);
- Continuing to measure at the MSU Kellogg Biological Station (KBS) N_2O fluxes from a set of field crops fertilized at different rates using a near-continuous automated N_2O measurement system (Task 3);
- Continuing farmer focus group activities (Tasks 4 and 5).

Below we provide details regarding each of these activities and preliminary results.

2

ACHIEVING N_2O EMISSIONS REDUCTIONS IN AGRICULTURAL CROP PRODUCTION

Carbon dioxide (CO_2) currently accounts for about 49% of the radiative forcing of the atmosphere that is attributable to GHGs (3.0 Wm^{-2}; IPCC 2001a). Tropospheric ozone, black carbon, and the well-mixed GHGs—principally methane (CH_4), nitrous oxide (N_2O), and various halocarbons—are responsible for the remainder. Changes in the non-CO_2 GHGs, whether engineered or unintentional, could thus have a substantial impact on the radiative forcing of future atmospheres.

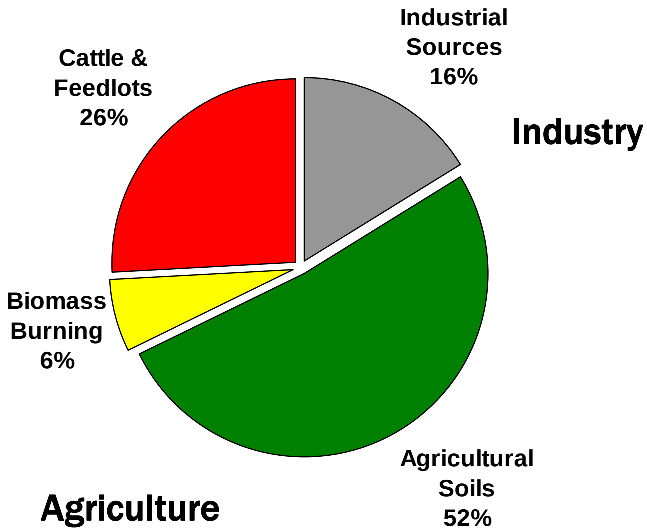
All of the well-mixed non-CO_2 GHGs are more potent than CO_2. For the so-called "biogenic gases," the 100-year Global Warming Potentials (GWPs) range from 23 for CH_4 to 296 for N_2O. Consequently, small changes in the net fluxes of these gases can have a proportionately larger effect on radiative forcing than similar changes in CO_2 flux. This sensitivity to small changes provides a strong impetus for including the non-CO_2 GHGs in the development of effective climate change mitigation strategies. For example, keeping one kg of N_2O from being emitted into the atmosphere is equivalent to removing 296 kg of CO_2 from the atmosphere. The total anthropic flux of CH_4 (344 Tg CH_4 y^{-1} is equivalent to 2.2 Pg C_{equiv} y^{-1} and that of N_2O is equivalent to 1.0 Pg C_{equiv} (Prinn 2004; Robertson 2004). Together these fluxes are similar to the net annual loading of CO_2 to today's atmosphere (4.1 Pg C; Raupach et al. 2007).

Until recently, plans to mitigate the buildup of atmospheric GHGs have focused primarily on CO_2. Strategies include both reducing CO_2 emissions and capturing emitted CO_2 in biological and other sinks. More recently mitigation activities have grown to include the non-CO_2 gases (Calderia et al. 2004). There is growing recognition that many of the sources of non-CO_2 gases are manageable and that small changes in flux can be important and have long-term impact. For example, in one analysis, Hansen et al. (2000) argue that the rapid, observable climate warming of recent decades has been driven mainly by the non-CO_2 gases owing to the offsetting climate forcings of CO_2 versus aerosols from fossil fuel burning. They suggest that mitigating the non-CO_2 gas fluxes plus black carbon could lead to a faster decline in the rate of global warming than similar reductions in fossil fuel burning. Although the role of non-CO_2 GHG emissions in climate change is still controversial (Wuebbles 2002, Schneider 2002, Hansen 2002), the argument that non-CO_2 GHGs deserve greater attention is well-taken. Clearly a combination of climate change mitigation strategies is warranted (Hoffert et. al. 2002).

Nitrous Oxide in Row-Crop Agriculture

Globally, agriculture is responsible for more than 20% of anthropic GHG emissions. The United Nations' Intergovernmental Panel on Climate Change (IPCC 2001a) estimates that agricultural activities emit 21–25% of all anthropic CO_2 fluxes, 55–60% of total CH_4 emissions, and 65–80% of total N_2O fluxes. CO_2 emissions are derived from deforestation and fossil fuel use; CH_4 emanates from enteric fermentation, rice cultivation, biomass burning, and animal wastes; and N_2O emissions come from cultivated soils, animal wastes, and biomass burning. The magnitude of these fluxes and their sensitivity to management makes agriculture an attractive target for many CO_2 stabilization schemes. Also, because most of these fluxes are interdependent, there are numerous opportunities to exploit synergies.

N_2O emissions from agricultural soils accounts for more than 50% of the global anthropic N_2O flux, as shown in Figure 2-1. N_2O is formed during nitrification and denitrification.[1] Nitrifiers are especially active in well aerated soil with available NH_4+, and denitrifiers in poorly drained soils with available C and NO_3-. Denitrifiers are also active in well-aerated soils, particularly following rain events and in anaerobic or partially anaerobic microsites such as the interior of soil aggregates (Robertson 2000).



Source: IPCC 2001, Robertson 2004. Prinn 2004.

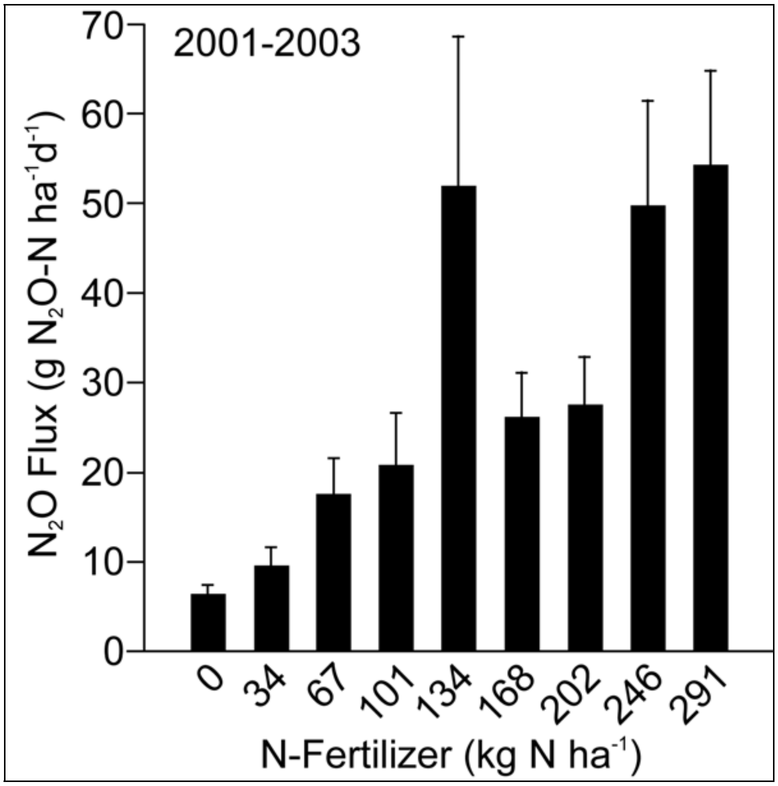
Figure 2-1
Anthropic sources of N_2O globally; the total anthropic flux is 1 Pg C-equivalent y^{-1}

Direct efforts to abate N_2O fluxes in agricultural soils have met with limited success. There are no specific inhibitors of denitrifiers, and nitrifier inhibitors such as nitrapyrin, nitrogen dicyandiamide, and CaC_2 are expensive and work inconsistently. Soil nitrogen availability appears to be the best predictor of soil N_2O flux, and total nitrogen inputs currently are used to estimate soil N_2O contributions to national GHG inventories (IPCC 2007). **It follows, then, that increasing the efficiency of crop N use by manipulating the magnitude, placement, and timing of nitrogen fertilizer holds the most promise for mitigating field crop N_2O production** (CAST 2004, Robertson 2004).

Experiments at MSU's Kellogg Biological Station (KBS) (McSwiney and Robertson 2005) underscore this fact and suggest greater payoff for fertilizer abatement than suggested by IPCC guidelines. Three years of flux measurements along a nitrogen fertility gradient that includes nine levels of fertilizer N ranging from 0 to 290 kg N ha^{-1} shows a non-linear response of N_2O to soil N inputs (see Figure 2-2). Rates of N_2O flux are low until some point along the gradient

[1] Nitrification refers to the microbial oxidation of NH_4^+ to NO_3^-, and denitrification refers to the microbial reduction of NO_3^- to N_2O and then N_2.

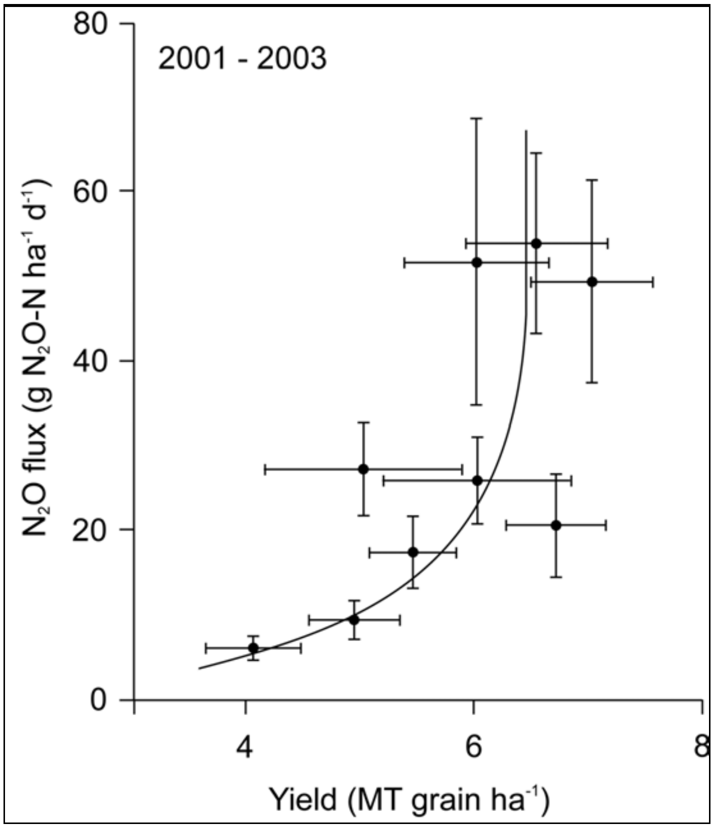
at which fluxes accelerate. This point is usually close to the fertilizer level at which crop yields level off, which makes good biological sense: plants and microbes compete for available soil N, and when plant needs are satisfied there is more soil N available for microbes and N_2O fluxes increase. A similar pattern has been found for nitrate leaching.



Source: McSwiney and Robertson 2005.

Figure 2-2
Nonlinear response of N_2O flux to N-fertilizer levels in continuous corn over a 3-year period

The significance of this finding becomes apparent when N_2O flux is graphed against crop yield, as shown in Figure 2-3. At low yields, while the crop is still limited by nitrogen, N_2O fluxes are low, whereas at high yields N_2O fluxes range from modest to very high – reflecting the fact that at high nitrogen levels crop yields are similar to those at modest nitrogen levels, but N_2O fluxes are *much* higher than at lower fertilizer levels. Thus, if nitrogen fertilizer were applied only to the point of optimum crop yield, then N_2O fluxes could be kept low without much affect on crop yield; in other words, a modest reduction in fertilizer should have little if any impact on yield but substantial impact on N_2O flux. **These results suggest that a significant decrease in N_2O flux could be achieved with little impact on crop yields.**



Source: McSwineyand Robertson 2005.

Figure 2-3
N_2O flux as a function of yield (nitrogen availability) in continuous corn at a site in southwest Michigan

Developing a Credible N_2O Abatement Strategy

To develop this preliminary finding into a useful N_2O mitigation strategy requires three specific goals to be achieved. Achieving these three goals is the basis for this EPRI supplemental project.

1. Confirmation in farm fields that N_2O flux can be reduced with lower nitrogen inputs and little yield penalty;
2. Development of quantitative models that can be used to predict the relationship between N_2O flux and yield in major cropping systems and soil/climate regimes; and
3. Identification of factors that would lead to farmer acceptance of strategies to reduce N_2O emissions from agricultural crop production.

3

TASK 1: POTENTIAL FOR REGIONAL N_2O ABATEMENT AND ECONOMIC COST

We are using quantitative biogeochemical modeling to estimate fluxes of N_2O from field crop ecosystems across major U.S. field crop regions. Initially the project team is concentrating its efforts on the USDA's North Central Region (the so-called Corn Belt, which includes the states of Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Dakota, and Wisconsin). However, at the same time, the MSU project team is gathering and preparing the GIS databases required to model all other areas with significant corn, soybean, and wheat production as shown in Figure 3-1.

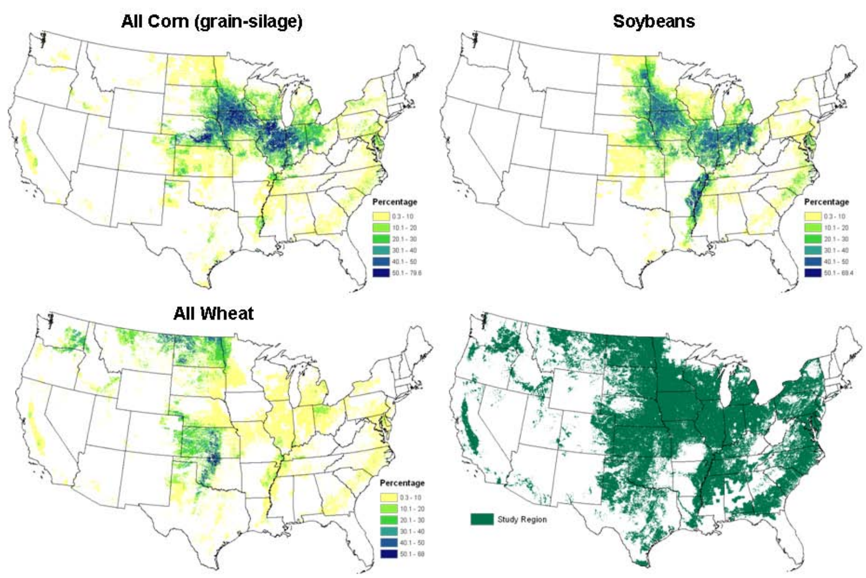
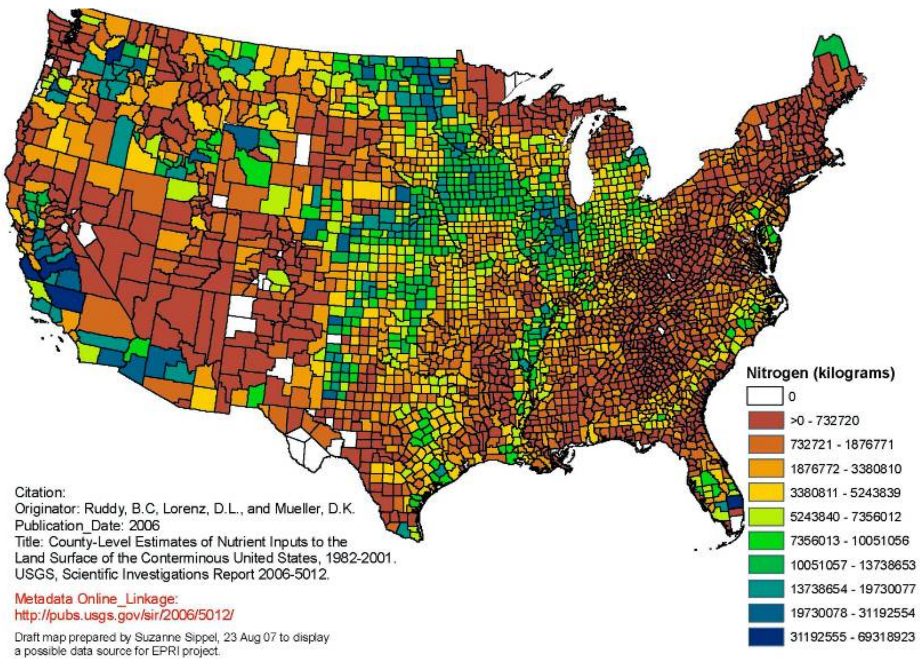


Figure 3-1
Regions for N_2O assessment modeling based on the percentage of corn, soybean, and wheat acreage with respect to total cropland 2000-20006. At bottom right is a composite map showing the spatial extent for all three crops

Soils information is derived from the NRCS Statsgo database (USDA 1994); climate data from the PRISM database, with monthly and yearly precipitation and temperatures available at 1 km resolution for the U.S.(Gibson *et al*. 2002); and land cover information from the National Land Cover Database (NLCD) (Homer *et al*. 2007). Presettlement vegetation, used to establish a pre-agriculture flux, is derived from the Kuchler's pre-settlement vegetation database.

The dependence of N_2O flux on N-fertilizer means that MSUs modeling also will need to include detailed information on fertilizer use. A new database (Ruddy et al. 2006), recently developed by USGS to help address the Gulf hypoxia problem – together with an earlier compilation (Alexander and Smith, 1990) – provides annual N fertilizer data from 1945-2001 by county for the conterminous U.S., as shown in Figure 3-2. This database now has been added to the set of geospatial layers described above.[2]



Source: Ruddy et al. 2006.

Figure 3-2
Nitrogen fertilizer use (kg N) by county in the conterminous U.S. Data shown are for 1997; data available in this database are from 1982-2001

These four geodatabases – soils, climate, land cover, and fertilizer use – are the primary drivers needed by our biogeochemical model (SOCRATES; Grace et al. 2006a) to predict N_2O flux (see below). The unit of analysis in our modeling efforts is the STATSGO polygon. The proposed region to be modeled comprises more than 26,000 polygons (Figure 3-1, right-bottom). Our specific strategy is to develop three historical scenarios and a number of mitigation scenarios. The historical scenarios include the pre-European settlement period to establish the likely pre-industrial N_2O flux for the region; 1990 to estimate fluxes for the Kyoto Protocol's baseline year; and contemporary (the latest year for which fertilizer use is available). We will then build a set of mitigation scenarios that include different combinations of crop rotations and fertilizer use in establish the degree of effort (and productivity trade-offs, if any) that would be necessary to meet specific mitigation targets.

Because the relationship between N_2O fluxes and N-fertilizer additions to maize are non-linear, this provides an opportunity to estimate regional N_2O fluxes based on estimates of maize yields, rather than as a simple percentage of N inputs. In our first regional estimate we combined a

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[2] The MSU project team is using ArcGIS 9.2 for its spatial modeling as part of this project.

simple empirical model of N_2O production with the SOCRATES soil carbon model to estimate N_2O and other sources of global warming potential (GWP) impact across 19,000 cropland polygons in the North Central Region of the U.S. over the period 1964-2005. The results shown in Figure 3-3 indicate that the loading of greenhouse gases from maize production in the North Central Region were 7.7-26 Gigatons (Gt) CO_2e, with N_2O production from nitrogen inputs representing 86-95% of these emissions. Of the 1,360 Mt of N fertilizer applied from 1964-2005, we estimate that 47 Mt N were emitted based on our non-linear model of N_2O loss, equivalent to 3.5% of the applied N. This estimate is three-fold higher than the IPCC Tier 1 model estimate of 14 Mt N_2O-N (Table 3-1) and better matches estimates from top-down atmospheric approaches (Crutzen et al. 2008).

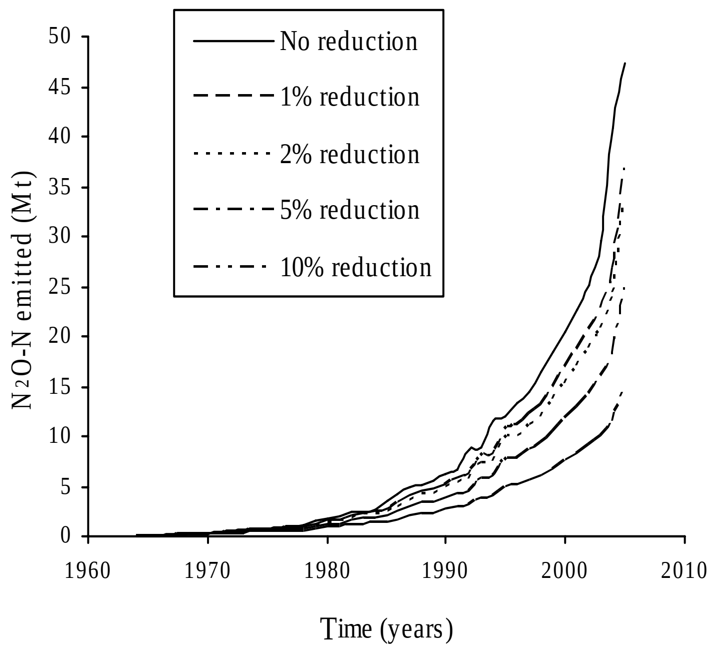


Figure 3-3
Cumulative N_2O emitted from the North Central Region from 1964-2005 (solid line). Dashed lines represent cumulative N_2O loss under different yield reduction scenarios

Table 3-1
Estimated N_2O emissions (Mt N_2O-N and Gt CO_2e) from maize production in the North Central Region of the USA from 1964-2005 calculated using both a non-linear N_2O loss function and the default IPCC methodology. From Grace et al., submitted

	IL	IA	IN	KS	MI	MN	MO	ND	NE	OH	SD	WI	NCR
N_2O-N (Mt)													
Non-linear	13.2	13.8	3.5	3.5	0.2	4.5	0.8	0.1	5.6	1.3	0.3	0.3	**47.3**
IPCC[1]	2.8	1.4	2.7	0.5	0.5	1.2	0.6	1.8	0.2	0.9	0.4	0.6	**13.6**
CO_2e (Gt)													
Non-linear	6.0	6.3	1.6	1.6	0.1	2.1	0.4	0.0	2.6	0.6	0.1	0.1	**21.6**
IPCC[1]	1.3	0.6	1.2	0.2	0.2	0.5	0.3	0.8	0.1	0.4	0.2	0.3	**6.2**

4

TASK 2: FIELD TESTS FOR N_2O REDUCTION

The MSU team is extending findings from experiment station test plots (which are on the order of 15 x 50 feet in size) to farm fields (which are on the order of several hundred acres in size) by recruiting farmers to apply nitrogen fertilizer to field plots at levels lower than the usual rates for that field. The team then measures at different times during the growing season rates of N_2O flux using N_2O flux chambers. A comparison of N_2O fluxes vs. crop yield for fields fertilized at different rates allows the construction of N_2O-yield curves (e.g., Figure 2-3), which establish the effects of different levels of N_2O abatement on yield.

The team established on-farm N_2O field experiments at four sites in Michigan in April 2007 and at four additional sites in April 2008. In each year, two sites were located in Tuscola County, one in Ingham County, and one at the W.K. Kellogg Biological Station (KBS) in Kalamazoo County. The approximate locations of these sites are shown in Figure 4-1. All sites are production fields and have recently been farmed in a corn-soybean cropping system typical for Michigan. All on-farm sites are managed by the cooperating producers as part of the entire field with the exception of N fertilizer management. The KBS site is a Michigan State University experiment station and is a production-scale field. This field was managed similarly to the other sites following general production practices and to satisfy the objectives of the study. Typical tillage at the sites included fall chisel plow and a seedbed preparation pass, and weed control included preplant and/or post-emergence herbicides. Corn was planted at each site in either 0.76-or 0.71-m row widths at a density of approximately 12000 seeds ha^{-1}.

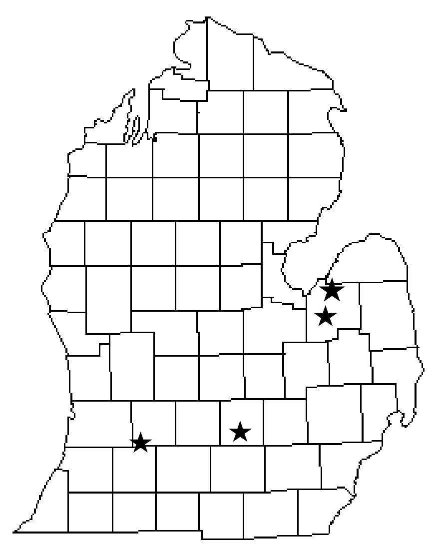


Figure 4-1
Solid stars denote approximate field locations in Michigan's Lower Peninsula where N_2O fluxes were measured in 2007 and 2008

We established fertilization plots 4.5 to 5.7 m (6 or 8 rows) wide and 15 m long, arranged in a randomized complete block design with 4 replications of six N treatments. Figure 4-2 shows a sample on farm site layout. Nitrogen treatments included 0, 45, 90, 135, 180, and 225 kg N ha^{-1}. Granular urea ($CO(NH_2)_2$; 46% N) was applied by surface broadcast within 3 days prior to planting and was incorporated immediately following application with a shallow cultivation pass (<6 cm).

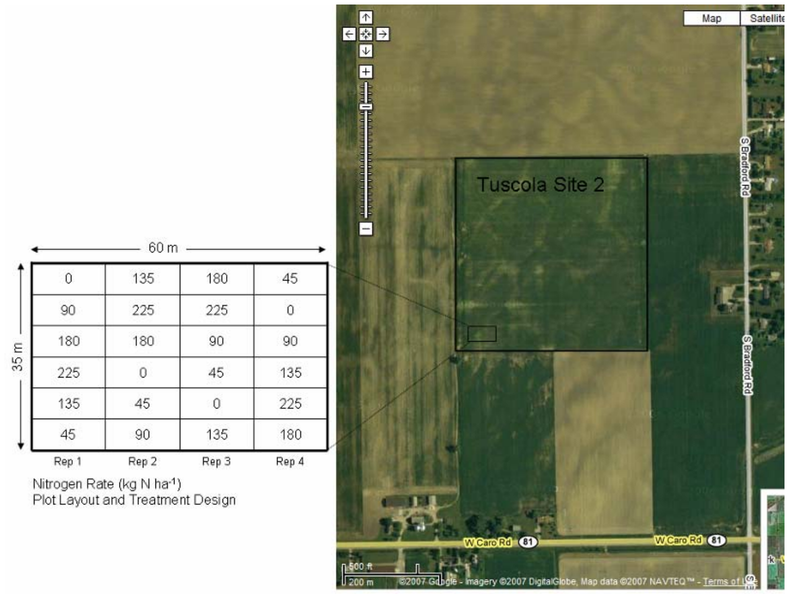


Figure 4-2
Sample on-farm site layout at the Tuscola Site 1

The project team measured N_2O fluxes in each plot at each site using the static chamber method as described by McSwiney and Robertson (2005). In this method chambers are placed on the soil surface and over the next hour, headspace samples are removed for gas analysis; N_2O flux is the rate at which N_2O accumulates inside the chamber headspace. Chamber bases were installed prior to fertilization for measurement of background N_2O flux, then were removed temporarily for fertilization and the final cultivation pass. Following this cultivation, bases were immediately reinstalled in the exact location they were removed to a depth of 9.5 cm, and were left in place for the entire growing seasons. With the removable lids, chambers measure 27.7-cm diameter by 27-cm height.

Lids are secured onto bases at the beginning of a flux determination and remain in place only for the measurement interval of up to 1.5 hrs. Four gas sample extractions are collected via a septum in the lid during the incubation period by transferring 10 mL headspace aliquots to 5 mL vials. Samples (0.5 mL) are analyzed for N_2O using a Hewlett Packard 5890 Series II gas chromatograph within 36 h of collection. Nitrous oxide flux was measured at each site prior to fertilization, within 2 days of fertilization, and every other day for 14 days following fertilization. After the 14 day interval, measurements were collected every 10-14 days until fluxes diminished (~October).

We collected a composite soil sample (0-15 cm, 10 cores) from each site prior to fertilization for determination of soil nutrient status (P, K, pH, Ca, Mg, organic matter, inorganic N). Additional soil samples are collected from each plot individually during each gas sampling event. We randomly collect ten 2.5-cm diameter cores (0-10 cm depth) that are then combined by plot to make a composite sample. Composite samples are then dried at 50˚C, ground to pass a 2-mm sieve, and analyzed for NO_3^- and NH_4^+ by flow injection analysis of 1 M KCl extracts (QuickChem methods, Lachat Instruments, Milwaukee, WI). Volumetric soil moisture status is determined within each plot at each gas sampling event using time domain reflectometry (TDR). A TRIME-EZ (Mesa Systems Co., Medfield, MA, USA) TDR probe was used for soil moisture determination by sampling to a depth of 10 cm.

Initial results of N_2O daily flux from the two Tuscola county sites in 2007 are shown in Figures 4-3 and 4-4. As shown, N_2O fluxes responded to N inputs 7 days post-fertilization at each site, and N_2O fluxes stayed relatively high for the next 7 weeks. The greatest N_2O fluxes tended to be in the plots receiving the greatest levels of N fertilizer. At these sites in 2007, the majority of daily N_2O flux occurred within a ~50 day critical zone from time of fertilizer application.

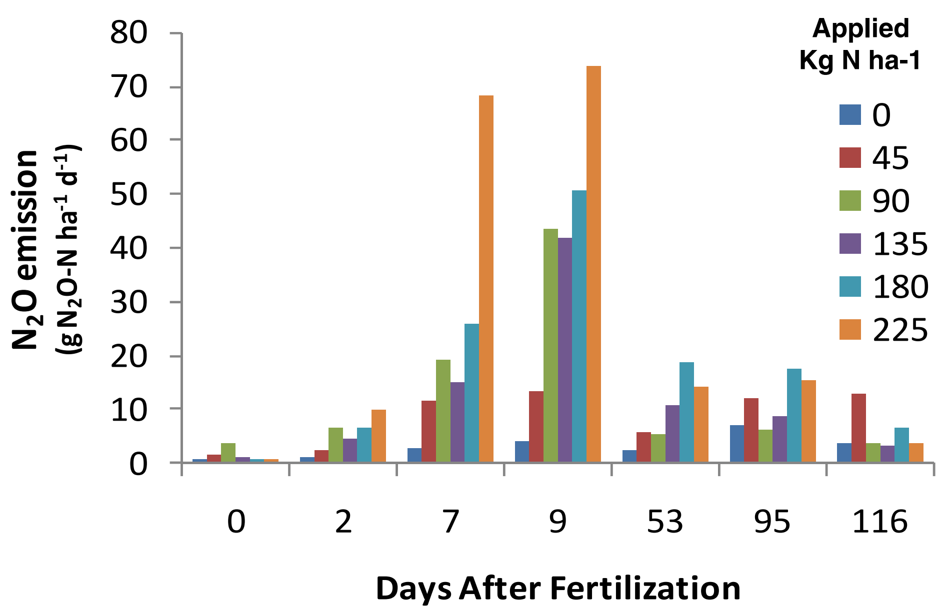


Figure 4-3
N_2O fluxes from Reese, MI (Tuscola County) during the 2007 growing season.
At each sample date (days after fertilization) fluxes are grouped by N fertilizer rate (kg N ha^{-1})

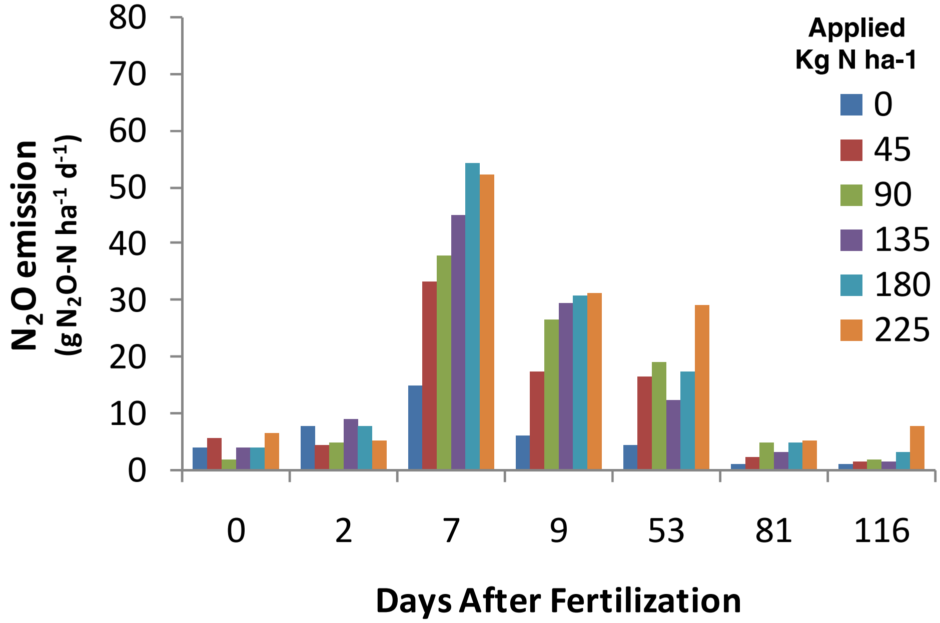


Figure 4-4
N_2O fluxes from Fairgrove, MI (Tuscola County) during the 2007 growing season.
At each sample date (days after fertilization) fluxes are grouped by N fertilizer rate (kg N ha^{-1})

Cumulative N_2O flux observed at the Fairgrove site also was closely related to N fertilizer rate. Figure 4-5 shows the importance of early season N_2O flux within the 170 day sampling period. The rate of increase in N_2O flux is highest within the 50 day critical period after which increases in N_2O flux are relatively small. Figure 4-5 also reveals the relationship between N fertilizer and N_2O. In agreement with our hypothesis, N_2O flux increased with increasing N rate at the Fairgrove site in 2007.

The relationship between cumulative N_2O flux and corn grain yield at Fairgrove (2007) is shown in Figure 4-6. These data support our hypothesis that an exponential relationship exists between N_2O flux and grain yield – increased flux is expected at N rates above that needed for maximum grain yield. This concept is further illustrated in Figure 4-7. The N rate for maximum yield at this site in 2007 was 138 kg N ha^{-1}, as shown by the quadratic-plateau line in the figure. Nitrogen applied in excess of 138 kg N ha^{-1} was not needed for grain production by the crop, and was thus more susceptible to gaseous loss. This excessive loss was measured through our field sampling efforts and is graphically shown by the bars in Figure 4-7. While similar data for the other sites has not yet been analyzed, we expect these trends will be consistent across sites and years. We will continue to explore the relationship of N rates beyond the demands of the crop and the excessive N_2O emissions these rates produce.

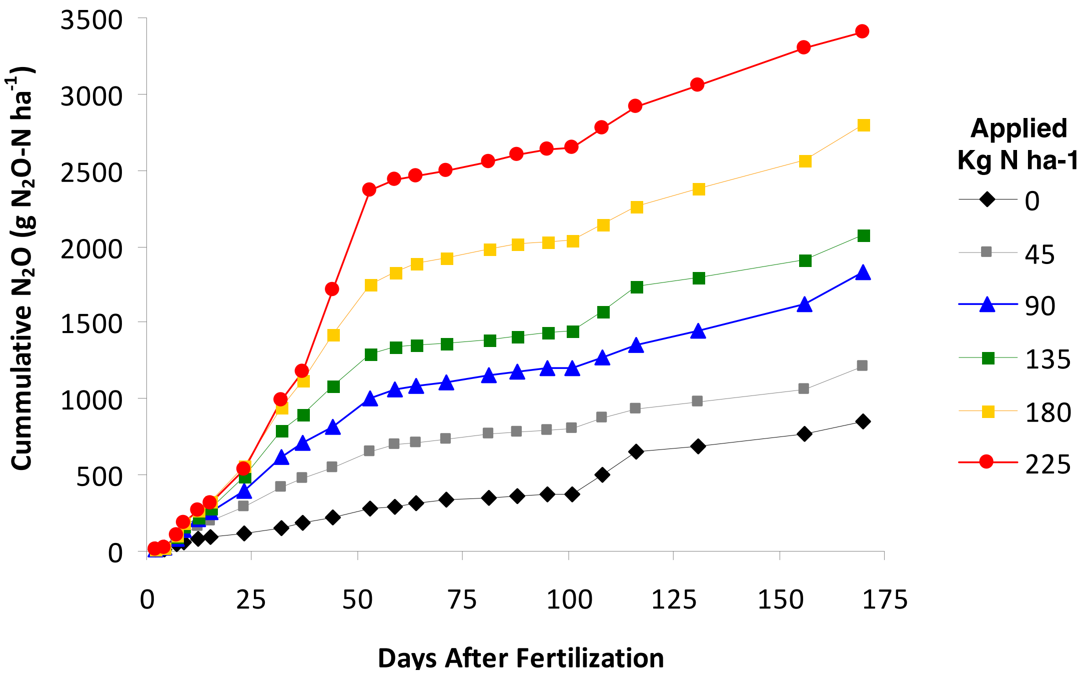


Figure 4-5
Cumulative N_2O flux in response to fertilizer N treatment (kg N ha^{-1}) after initial fertilizer application in 2007 at Fairgrove, MI (Tuscola County)

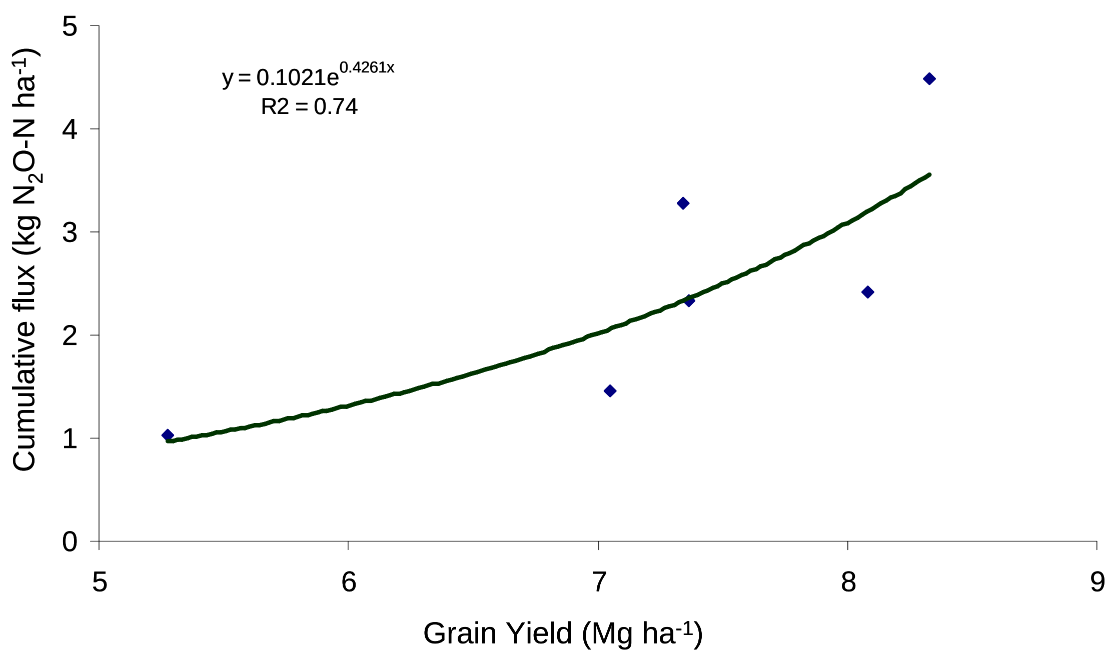


Figure 4-6
Graphical representation of the exponential fit between cumulative N_2O flux and grain yield at Fairgrove, MI (Tuscola County) in 2007

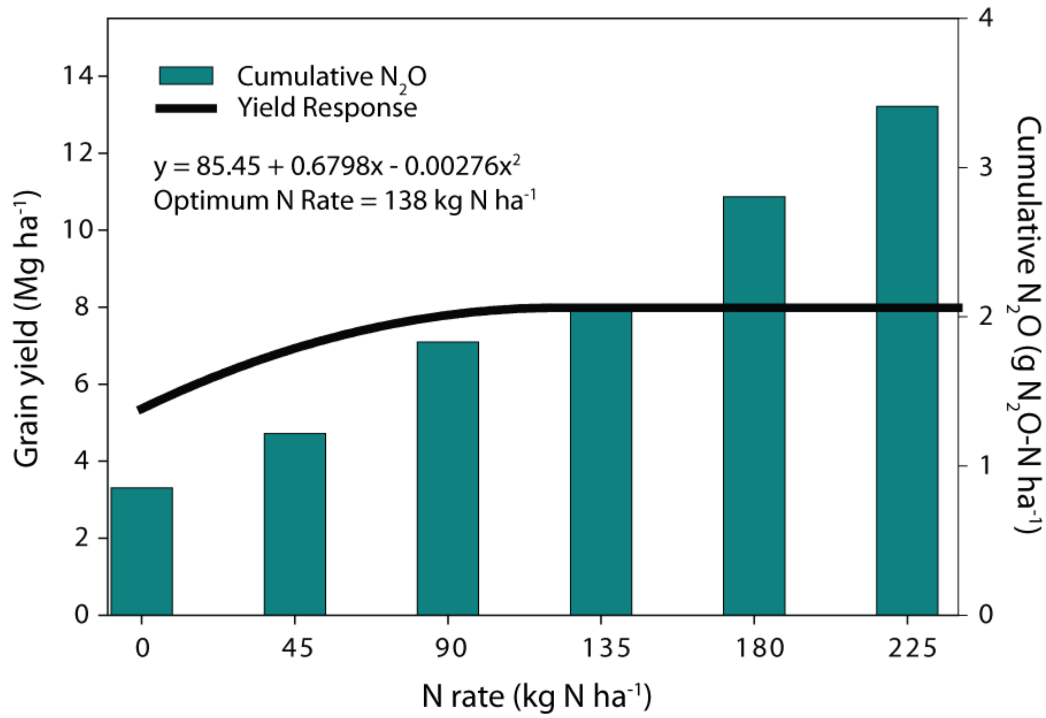


Figure 4-7
Effect of N fertilizer rate on corn grain yield and cumulative N_2O flux at Fairgrove, MI (Tuscola County) in 2007

5

TASK 3: FIELD-SCALE N_2O MODELING

We are continuing to further refine our quantitative N_2O model (used for Task 1 regional analyses) by testing model output against fluxes of N_2O. These N_2O fluxes are measured from our field plots at the KBS site, which are fertilized at varying levels of N. Corroboration between model output and field data will provide greater confidence for our regional estimates of N_2O emissions, allow for the development of a web-based N_2O abatement calculator, and provide insight into the soil-based mechanisms responsible for N_2O loss – which will help to elucidate additional management practices that could be use to abate soil N_2O flux in cropping systems.

Using EPRI project funds, the team at KBS has built and deployed a new automated gas flux chamber system. To our knowledge, this system is unique in Michigan and one of very few operational within the U.S. The new system has a capacity for 12 chambers and provides for the ability to measure year-round, near-continuous fluxes of N_2O, as well as CO_2 and CH_4. The chamber system was installed during March 2008 in 8 different N fertilizer level treatments, within one rain fed block, along the KBS N fertility gradient (Figure. 5-1). The gradient was planted to wheat in 2007 and corn in 2008. The automated chambers along with the mobile control center are shown in Figure 5-1 (right). Results from April – July 2008 (Figure 5-2) continue to show expected levels of temporal N_2O variability at all levels of fertilizer N input, with higher fluxes under higher fertilizer rates.

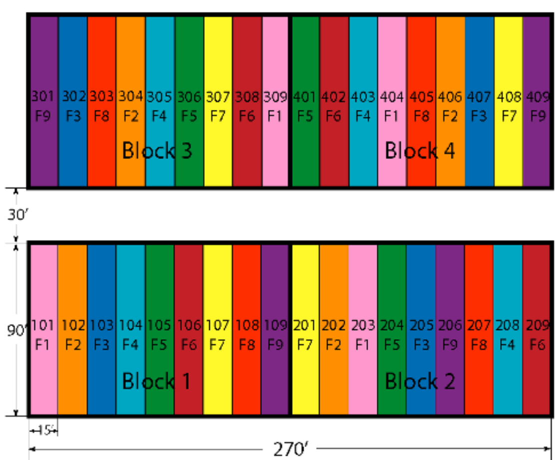


Figure 5-1
Nitrogen fertility gradient experimental layout at KBS (left). Nine different fertilizer levels (from 0 to 291 kg N/ha or 260 lb/ac) are represented in each of 4 rain fed randomized complete blocks. Automated N_2O chambers (right) are located in 8 different fertilizer levels in block 2

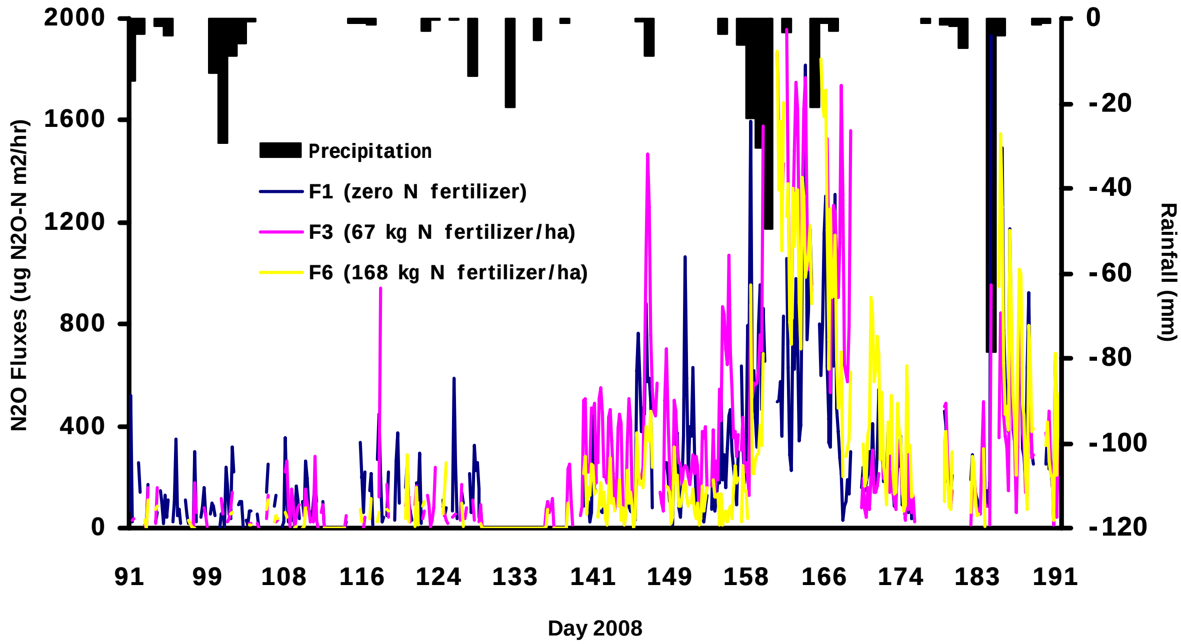


Figure 5-2
Measured N_2O fluxes at the KBS N fertility gradient during 2008. Solid color lines are the hourly N_2O fluxes for the noted fertilizer level. Black bars at top denote rainfall events

Typically, annual national inventories of N_2O emissions from agricultural soil are calculated by assuming a constant linear relationship between total N inputs, irrespective of magnitude, and subsequent N_2O emissions (e.g., IPCC Tier 1 methodologies). However, previous work at KBS has shown that N_2O emissions sharply increase in a non-linear fashion above the fertilizer N rate at which crop yields are optimized (McSwiney and Robertson, 2005, Millar and Robertson, in prep).

As of writing, corn crop yield data from 2008 are not available. Figures 5-3-5-5 present summary results from the 2007 wheat cropping season. Figure 5-3 shows the non-linear relationship between fertilizer N application and average daily N_2O flux as measured with the automated flux chambers. At the fertilizer N level at which the wheat crop yield was optimized (Figure 5-4), fluxes of N_2O show a concurrent rapid increase. This implies that a substantive decrease in N_2O flux can be achieved with moderate reductions in fertilizer N input and little or no yield impact. Figure 5-5 highlights the exponential tradeoff between crop yield and N_2O flux.

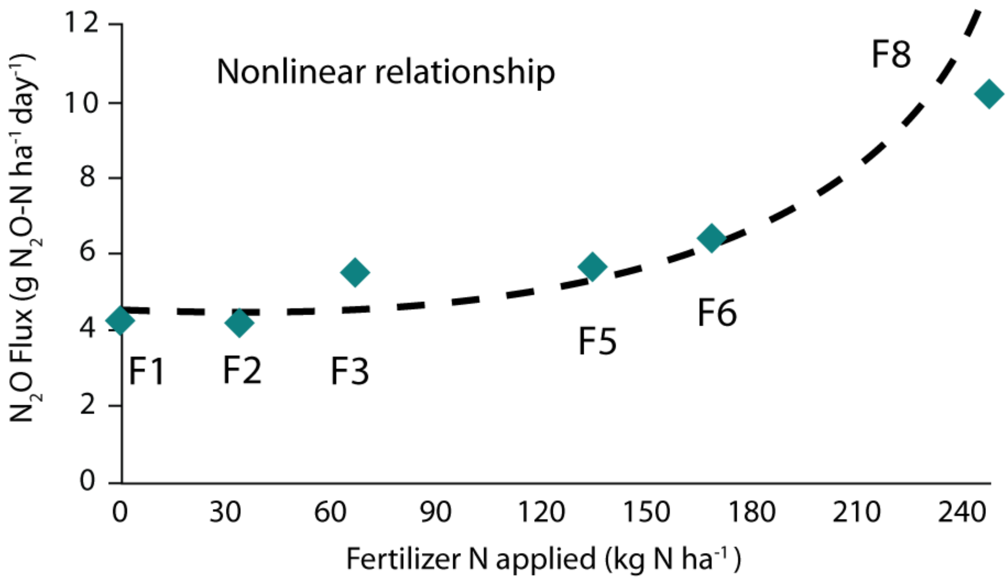


Figure 5-3
Relationship between N_2O flux and N fertilizer levels for 2007 winter wheat

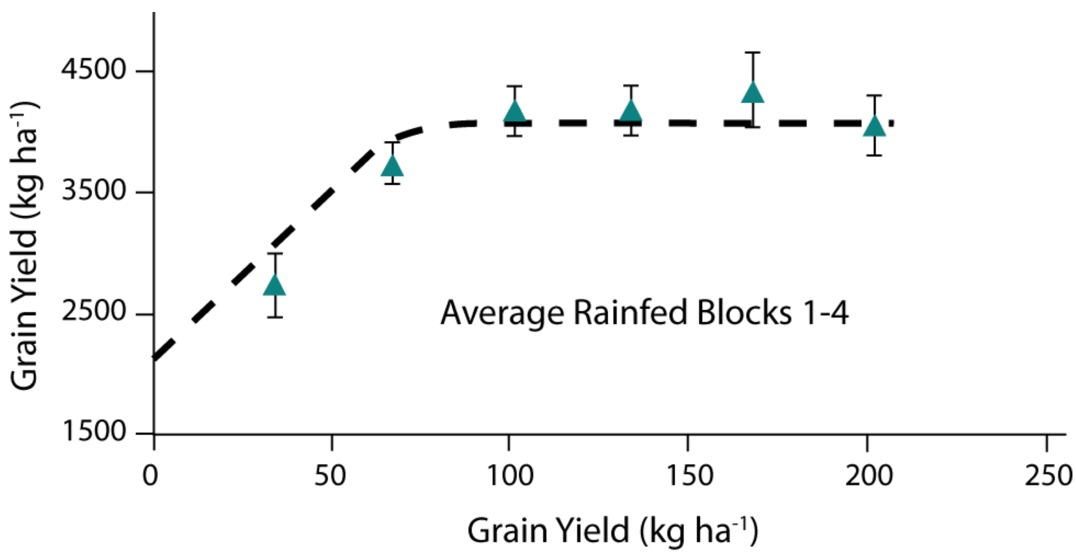


Figure 5-4
Fertilizer response curve for 2007 winter wheat

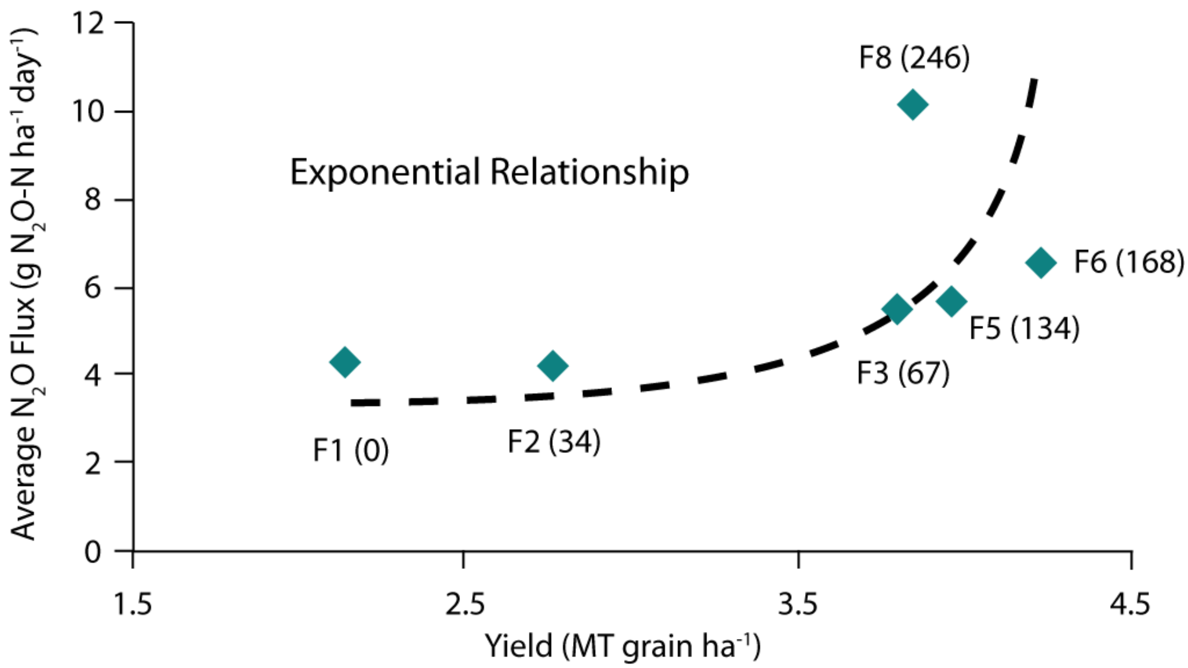


Figure 5-5
Yield-N_2O tradeoff curve for 2007 winter wheat

To estimate N_2O flux we are using the SOCRATES model (Soil Organic Carbon Rates and Transformation in agroEcosystems; Grace et al., 2006a, 2006b). The nitrogen portion of SOCRATES is being modified to include specific algorithms for N_2O evolution. These algorithms have been partially tested in the DNDC (denitrification-decomposition) model, a complex simulation framework to simulate carbon and nitrogen cycling processes in soils (Li et al. 1996). DNDC was specifically developed to predict daily N_2O fluxes through the nitrification and denitrification pathways. It includes CO_2 production from decomposition of soil organic matter and root respiration, as well as CH_4 oxidation and primary production across a wide variety of agro-ecosystems.

The DNDC model consists of two components. The first includes soil climate, crop growth, and decomposition submodels, and predicts soil temperature, water content, pH fluctuation, redox potential (Eh), and substrate concentration profiles based on ecological drivers (climate, soil properties, vegetation, and management activity). The second component, consisting of nitrification, denitrification and fermentation submodels, predicts NO, N_2O, N_2, CH_4 and NH_3 fluxes based on soil environmental variables. Classic laws of physics, chemistry, and biology or empirical equations derived from laboratory observations are used in the model to parameterize each specific reaction of C and N cycling.

The soil climate submodel of DNDC uses daily metrological data to predict soil temperature, water content, and Eh profiles. Soil water uptake by plants is simulated hourly by integrating air temperature, precipitation, soil thermal and hydraulic properties, and oxygen status. A plant growth submodel simulates the growth of various crops from sowing to harvest, and predicts the biomass as well as N content of grain, shoots, and roots by integrating crop characters, climate, soil properties, and agricultural practices. Crop growth is also limited by mineral N and water availability in the root zone. Crop transpiration is estimated from crop growth and a crop-specific parameter for water use efficiency.

The hourly-time-step denitrification submodel of DNDC is activated by three conditions: rain events (when soil water content increases and or soil oxygen availability decreases), flooding/irrigation, and cold temperatures. DNDC requires daily climatic variables (minimum and maximum air temperature, solar radiation and precipitation), soil properties, including bulk density, texture, organic C and pH), and agricultural practices (crop type and rotation, tillage, fertilizer N application, manure amendment, irrigation, flooding, grazing and weeding).

Testing and calibrating SOCRATES-N_2O with datasets from similar cropping systems in eastern Australia, where there is an automated gas flux chamber system identical to the one being installed at KBS, provides reasonable fits (Figure 5-6). The site is sub-humid, and offers a similar growing season in terms of temperature and moisture changes to what is seen in the U.S. Midwest during a typical spring/summer. The simulated N_2O emission output for this time period of 1.37 kg N ha^{-1} is not significantly different from the observed value of 1.42 kg N ha^{-1}.

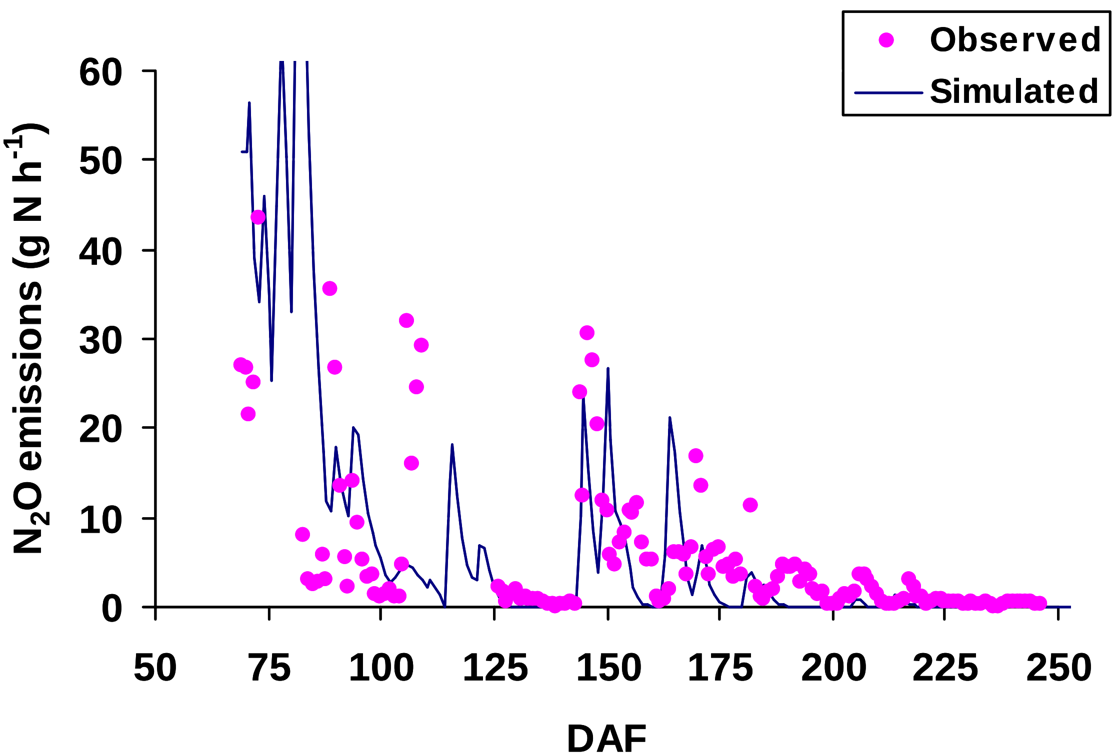


Figure 5-6
Simulated and observed N_2O emissions on a cropped field in Dalby, Australia, fertilized with a split application of 207 kg N (DAF = Days After Fertilizer applied)

The project team also is testing the Water and Nitrogen Management Model (WNMM) (Li, 2002; Chen et al., 2002) which is a spatially referenced biophysical model developed to simulate dynamic soil water movement and soil-crop carbon and nitrogen cycling under agricultural management. It is a decision support system used in the identification of optimal strategies for managing water and fertilizer N under intensive cropping systems. To date its usage has concentrated on the simulation of wheat and maize systems in China and Mexico, but the model has been developed for generic use by the University of Melbourne.

WNMM is similar to DNDC in its complexity and simulates the key processes of water and carbon and nitrogen dynamics in the surface and subsurface of soils. WNMM simulates the transformations of several N species in agricultural fields, including mineralisation of fresh crop residue N and soil organic N, immobilisation of N in the microbial biomass, nitrification, NH_3 volatilisation, denitrification, N_2O and N_2 emissions.

6

TASKS 4 & 5: SOCIOECONOMIC FACTORS AND INCENTIVES FOR FARMERS TO ADOPT MITIGATION PRACTICES

A range of factors may keep farmers from adopting N_2O abatement strategies even if the cost is low or nil: knowledge, cultural inertia, social acceptability, management complexity, economic risk, and others. The evaluation of socio-economic barriers to farmer adoption of mitigation strategies and the incentives that would encourage farmers to adopt low-N fertilizer application approaches is underway. Last year, as part of an NSF-funded study of farmer attitudes towards low-input farming, farmer focus groups identified ecosystem services and their value to themselves versus society at large. Climate stabilization through GHG emissions abatement was identified as a service valuable mainly to society (Figure 6-1), in contrast to soil carbon sequestration, which was identified as a service valuable to farming (related mainly to the fertility and water storage benefits associated with soil organic matter). These results have been used to define a large-scale survey of farmers attitudes towards low-input cropping methods, including nitrogen fertilizer use. This survey was administered in winter 2008 to several thousand Michigan farmers (Figure 6-2). These results will be used to inform additional focus groups scheduled for winter 2009.

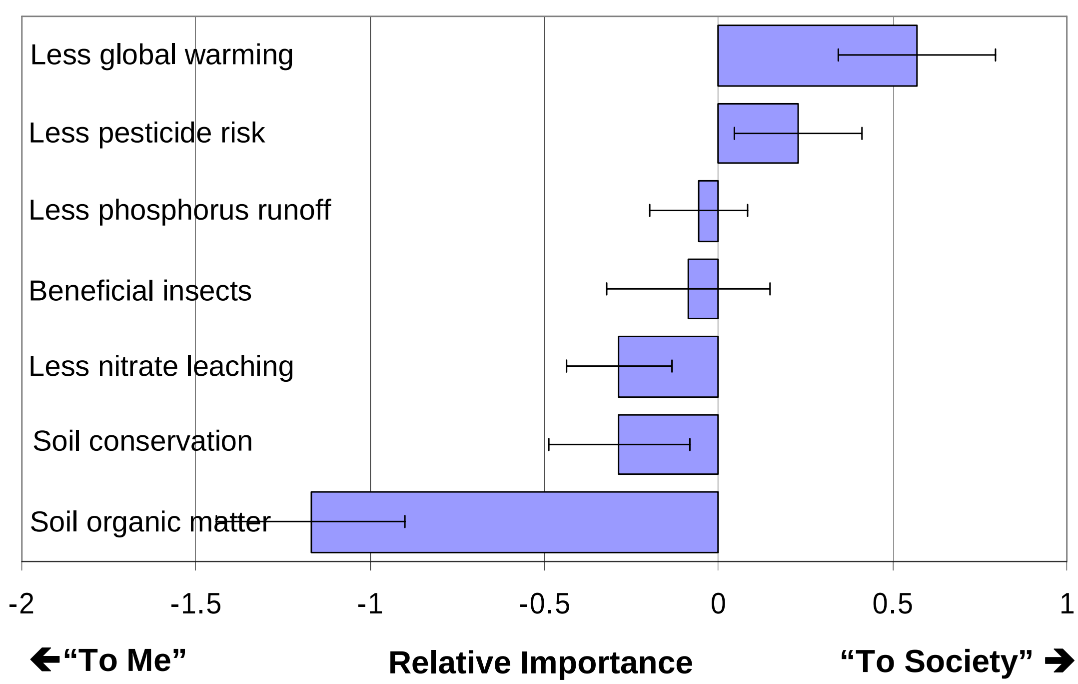
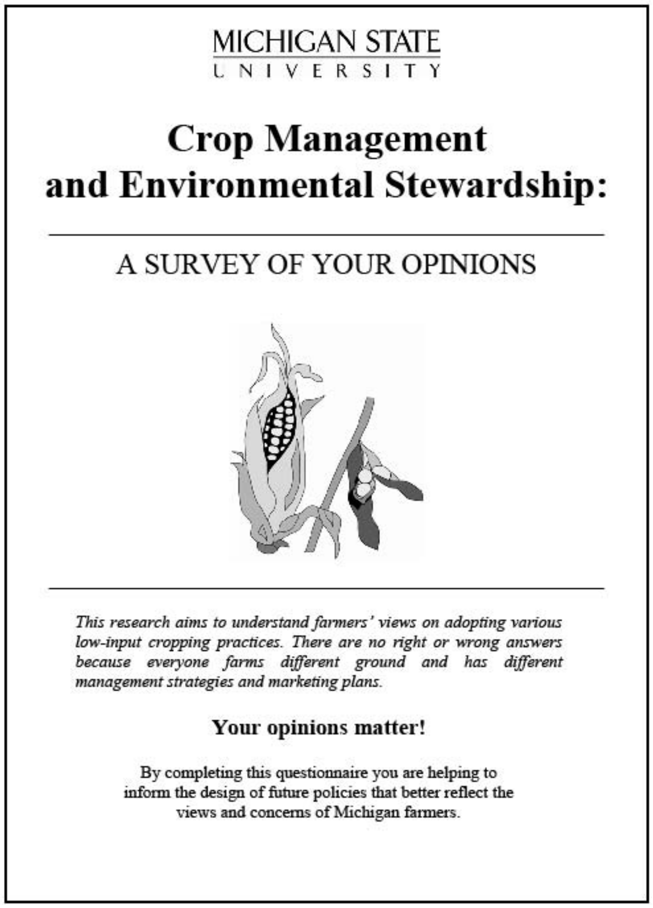


Figure 6-1
Michigan farmers' perceptions of the relative value of different ecosystem services. From Swinton et. al. 2007



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Crop Management
and Environmental Stewardship:

A SURVEY OF YOUR OPINIONS

This research aims to understand farmers' views on adopting various low-input cropping practices. There are no right or wrong answers because everyone farms different ground and has different management strategies and marketing plans.

Your opinions matter!

By completing this questionnaire you are helping to inform the design of future policies that better reflect the views and concerns of Michigan farmers.

Figure 6-2
Sixteen page survey sent to 3000 Michigan farmers to assess attitudes towards low-input cropping methods

Part of Tasks 2, 4, and 5 include development and deployment of a web-based farmer-level GHG abatement calculator. The MSU research team now is developing two interfaces for the calculator – one for the general public that includes few options for changing management variables; the other is designed to be used by farmers, GHG offsets project developers and others and provides wide latitude for changing fertilization, tillage, and crop rotation protocols. We are now linking the model with both interfaces. In early 2009, the public version of the N_2O abatement calculator will be added to a major Soils exhibit now open at the Smithsonian Museum of Natural History in Washington. The MSU team also is now working actively with curators to design an interface that is easy to understand and interesting to use (Figure 6-3), and this version will be accompanied by a K-12 teaching module that teachers can use in their classrooms for web-based inquiry lessons.

Figure 6-3
Sample screen shots for the museum interactive display being developed for the Smithsonian exhibit

7
NEXT STEPS

In 2009 the project team expects to continue to make progress on all fronts identified above.

In Task 1 the spatial databases will be assembled and model output generated and refined for the regions denoted in Figure 3-1.

In Task 2, 2008 yields will be measured for our extensive farm-field plots and combined with N_2O results to yield N_2O-yield curves for all sites in 2008. These two years of data will form a complete experiment.

The automated chamber system (Task 3) will continue to measure N_2O fluxes year-round from our N-fertility plots at KBS, and these data will be used to test our different N_2O models.

Farmer focus groups (Tasks 4 & 5) will be held in winter 2009, to pursue questions related to barriers and incentives for instituting N_2O-mitigation practices on farms and expand on survey results.

We will continue work on our web-based N_2O decision-support model (Tasks 2, 4, and 5), and the Smithsonian exhibit will be completed and installed.

Additionally, during 2009 we are planning to join EPRI in initiating a partnership with an organization specializing in the origination of GHG emissions offsets. The goal of this partnership will be to assist with the development of a project-based GHG offsets methodology that could be used by electric companies, offset developers and others around the world to quantify and verify GHG emissions reductions derived from reduced agricultural N_2O production as part of the UN's Clean Development Mechanism (CDM) offset program and other evolving offset programs.

8
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