FINAL REPORT

PROJECT TITLE: **Climate Change Impacts on Minnesota Corn Production and Environmental Consequences**
PROJECT NUMBER: MN CORN RES & PROMO COUNCIL 4118-15SP
PRINCIPAL INVESTIGATOR AND CO-INVESTIGATOR(S):

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ABSTRACT

The University of Minnesota Mesocosm Facility was developed to improve our understanding of the impacts of climate change on crop production in Minnesota and to improve our management practices to help reduce negative environmental impacts. Our experiments have provided important knowledge to corn growers with respect to climate change adaptation. Understanding how current cultivars respond to changing climate helps with developing an integrated climate change adaptation plan and can guide future research efforts. This research project has provided insights regarding the optimization of corn production while limiting the negative environmental consequences such as nitrogen leaching, nitrous oxide, and ammonia emissions. The products and deliverables from this project included: 1. A research facility dedicated to understanding the impacts of climate and management on productivity and the environment; 2. Insights regarding how corn growth, yield, and N use efficiency are likely to change, and how these changes affect environmental consequences; 3. Infrastructure and framework for permitting the identification of research needs for adapting to warmer/wetter/higher CO_2 corn growing conditions. <u>A main conclusion from our research is that increasing precipitation during spring is having a negative impact on reactive nitrogen losses from agricultural systems. We have shown, based on 4 different simulations, that current trends in precipitation are significantly enhancing nitrous oxide emissions and leaching of nitrogen. Thus, nitrogen use efficiency is likely to decrease in a wetter and warmer world.</u>

INTRODUCTION

The three primary climate effects that will impact corn production in Minnesota include changes in air temperature, precipitation, and ambient carbon dioxide concentration. The trends in all three of these variables in Minnesota are strong. The average minimum annual air temperature has increased by nearly 2^{o}C over the past century [Seeley, 2015], while precipitation has increased by about 1 mm per year over the last 50 years [Baker et al., 2012]. Carbon dioxide concentration has increased by nearly 80 ppm over the last 50 years. These trends are expected to continue or accelerate over the next 50 years [IPCC, 2013] with important implications for global food production. Schlenker and Roberts [2009] have shown that corn yields generally increase with air temperature up to an optimum of about 29^{o}C, while strong reductions in corn yield were observed above that temperature optimum. Based on the projected ensemble of climate scenarios proposed by the Intergovernmental Panel for Climate Change (IPCC, 2007), they argue that weighted-average corn yields will decrease by 30-46% before the end of the century under the slowest (B1) warming scenario and will decrease by 63-82% under the most rapid warming scenario (A1FI). Lobell et al., [2011; 2013] also argue that warming is likely to exert a negative impact on yield of the world's major commodity crops. The Mesocosm Facility will allow us to investigate a broad range of climate scenarios, using repeated measures, to establish probability distributions associated with the impacts of climate on corn yields and other environmental factors.

The production of corn requires significant synthetic nitrogen (N) inputs. One of the potent side effects associated with these high N inputs is the emission of nitrous oxide. Nitrous oxide has recently become the most significant stratospheric ozone depleting substance [Ravishankara et al., 2009] and is one of the three most important long-lived greenhouse gases [Hartman et al., 2013] contributing to the warming that, ironically, could reduce future corn yields. Recently, our work demonstrated very high nitrous oxide emissions from drainage ditches and streams within our region [Turner et al., 2015; Chen et al., 2015; Griffis et al., 2013]. These studies indicate that direct and indirect nitrous oxide emissions will increase with rising air temperature and increasing precipitation. Our preliminary mesocosm experiments show that higher precipitation rates in spring amplified nitrous oxide emissions (Fig. 2).

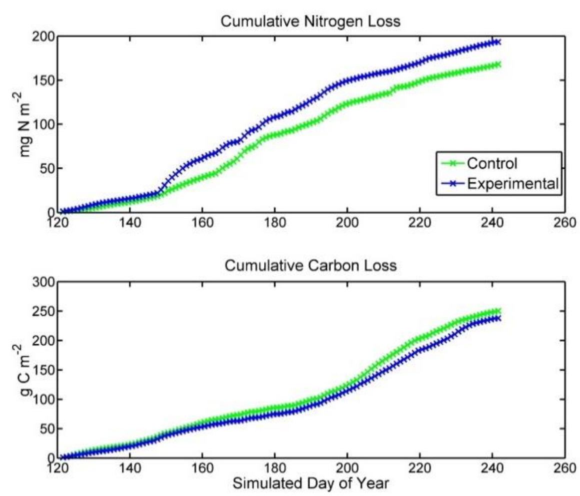

Figure 1. The impact of +20% increased precipitation (experimental) on nitrous oxide and carbon dioxide emissions.

Understanding how soils and crops respond to climate change is critical towards adapting farm-level management, and identifying possible traits for breeding programs to target to maintain or improve future productivity. A key challenge in this regard is being able to compare present with future conditions under controlled conditions. The Mesocosm Facility will allow us to address these key questions related to climate change impacts on production because we have a high level of control over important environmental and management variables, as well as the capacity to measure all aspects of the soil-water-plant-atmosphere continuum.

OBJECTIVE AND GOAL STATEMENTS

Our proposed research focused on finding realistic ways to reduce N losses, associated with drainage or gas emissions, to the environment.

MATERIALS AND METHODS

Climate Simulations: Here we are examined a +20% precipitation in the experimental mesocosms, while the control mesocosms were run using baseline ("current") climate conditions. Although the above studies [Schlenker and Roberts, 2009; Lobell et al., 2011; 2013] have suggested a decline in corn yield with warmer temperatures, we hypothesized that in Minnesota corn growth and yield will increase for the warmer/wetter treatment. Higher temperatures and more precipitation should promote faster decomposition of crop residue, and thus more timely release of residue N. If we can predict this with reasonable accuracy, and also take advantage of our improved forecasting of precipitation and ET (http://www.biometeorology.umn.edu/research/etool), it should be possible to schedule N applications to better match crop needs.

Environmental Impacts: Whether N_2O emissions and nitrate leaching increase will depend on how efficiently corn absorbs inorganic N. Our preliminary experiments indicate that nitrous oxide emissions to the atmosphere are likely to increase under projected future climate conditions. We now want to explore to what extent these emissions and leaching could be reduced if we had the technology to deliver N as a function of crop nutrient demand (Fig. 3). Producers have recognized contemporary challenges with respect to water management, and as a result the irrigated acreage in Minnesota has been increasing in recent years. While this management decision was based on water quantity needs, there are synergies with respect to improving the timing of N-application to coincide with crop demand through fertigation. Questions remain regarding the benefits in terms of productivity, fertility management and soil nutrient cycling. Here, we will use a subset of the 12 mesocosms to evaluate if we can optimize N application rates and timing to match crop demand to maintain crop productivity, while substantially reducing N leakage under a range of climate scenarios. If we can demonstrate these benefits, we may be able to help shape future technological developments regarding the real-time on-demand application of N.

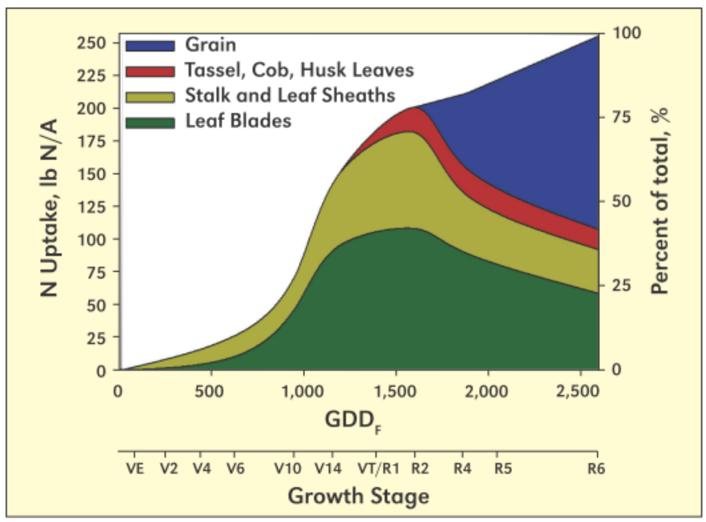

Figure 2. Plant nitrogen demand/uptake and allocation of nitrogen as a function of growing season accumulated growing degree days (from Bender et al. 2013; Better Crops vol. 97, No. 1, pp 8-10).

RESULTS AND DISCUSSION

Control Treatments (Normal Precipitation)

Season N_2O-N loss for each simulation totaled 1.21, 2.45, 2.65, and 2.04 kg/ha for simulations 1 through 4; respectively. Mean N_2O emission rates were 0.61, 1.24, 1.22, 0.92 nmol/m2/s for simulations 1 through 4; respectively. Cumulative nitrogen loss over all four simulations totaled 8.36 N_2O-N/ha.

Median water-filled pore space (WFPS) was well correlated with N_2O loss and peak observed fluxes. Observed WFPS values were 50.93 %, 48.97 %, 52.1 %, 49.2 % for simulations 1 through 4; respectively. Average WFPS values during DOY 120-151 were 3.49% less than the experimental treatments. Average WFPS values during DOY 152-210 were 0.59% greater than the experimental treatments, consistent with applied precipitation treatments.

The soil nitrogen value differences do not completely reflect the N_2O loss differences for simulations. Mean soil NH_4 values were 31.6, 15.4, 7.34 ppm for simulations 1, 3, and 4; respectively. Mean soil NO_3 values were 52.7, 48.2, 42.6 ppm for simulations 1, 3, and 4; respectively.

Experimental Treatments (Enhanced Spring Precipitation)

Season N_2O-N loss for each simulation totaled 2.85, 3.44, 2.53, and 2.01 kg/ha for simulations 1 through 4; respectively. These values are greater than the control for simulations 1 and 2 and slightly less than for simulations 3 and 4. Mean emission rates were 1.44, 1.73, 1.16, and 0.91 nmol/m2/s for simulations 1 through 4; respectively. Cumulative nitrogen loss over all four simulations with enhanced early season precipitation totaled 10.8 kg N_2O-N/ha; a treatment difference of 2.44 kg N_2O-N/ha and 29.7% greater relative to the historical normal treatment.

Median water-filled pore space (WFPS) were well correlated with N_2O loss differences and peak observed fluxes between treatments. Observed WFPS values were 54.4%, 50.98%, 48.92%, 49.08%, 55.2% for simulations 1 through 4; respectively. Median WFPS values are consistent with maximum observed fluxes and cumulative nitrogen loss for all four simulations 1 through 4. Average WFPS values during DOY 120-151 were 3.49% greater than control treatments. Average WFPS were 0.59% less during DOY 152-210, reflecting declining mid-season precipitation and consistent with the applied treatments.

Soil nitrogen value differences do not completely reflect N_2O loss differences for all four simulations. Mean soil NH_4 values were 21.3, 11.8, 12.8, ppm for simulations 1, 3, and 4; respectively. Mean soil NO_3 values were 50.9, 41.4, and 33.7 ppm for simulations 1, 3, and 4; respectively.

Emission Factors

The emission factors for the control versus experimental treatments for each simulation were as follows:

Year	**Control**	**Experimental**
1	0.54	1.27
2	1.09	1.53
3	1.18	1.13
4	0.91	0.90
Mean	0.93	1.21

The above results show that increasing precipitation enhances the emission factor for N_2O losses associated with synthetic fertilizer application.

Corn Yield

Reaching adequate yields is a challenge in the indoor environment due to limited PAR and higher heat indexes relative to outdoor field conditions. Yields were close to the MN state average during simulation 3 when PAR and heat indexes were adequately controlled. Yields were 174.4 and 166.6 bu/acre for the control versus experimental treatments, respectively. Yields during the most productive season suggest that yield losses will be experienced under future precipitation scenarios.

Long-term Baseline Measurements and Split Nitrogen Application

The above experiments have provided an excellent baseline for determining if applying nitrogen fertilizer in a timely (on-demand) manner can reduce reactive nitrogen losses.

Mesocosm experiments were conducted to quantify the effects of split fertilizer application on soil NH_3 and N_2O emissions. Three "control" mesocosms were set up to receive urea at a rate of 103 kg N/ha immediately prior to corn planting at the beginning of a three-month study period. The same amount of urea N was divided into four individual applications and sequentially applied to three "experimental" mesocosms within the same study period. Soil NH_3 fluxes in the control and experimental mesocosms were continuously measured using two automated chambers and calculated on an hourly basis.

The results show that soil NH_3 flux was highly sensitive to fertilization events in both treatments. In the control treatment, urea application triggered a pulse of NH_3 emission, which lasted for about 4 weeks, with peak emission rate, up to 43 nmol/m2/s, being observed one week after the application. While pulsed NH_3 emissions were also triggered by individual applications in the experimental treatment, the magnitude and duration of these pulsed emissions were lower (<10 nmol/m2/s) and shorter (< 6 days) compared to those measured in the control treatment. Integrated over the entire study period, NH_3 emission accounted for 2.8% and 0.9% of the applied urea N in the control and experimental treatments, respectively. These results suggest that split fertilizer application designed to better match plant N demand is an effective measure to reduce NH_3 emission from urea-fertilized agricultural soils.

Cumulative nitrogen loss in the form of N_2O was 0.352 and 0.176 kg-N/ha for the control and experimental treatments; respectively. Peak N_2O flux was 0.644 and 0.2878 nmol/m^2/s control and experimental; respectively. The control single application also lost more nitrogen as nitrate in drainage water relative to the experimental split application treatment. Total NO_3-N lost was 163.97 and 150.54 kg-N/ha for the control and experimental treatments; respectively.

Higher soil nitrogen concentrations and higher gaseous and aqueous nitrogen losses paired with lower total N uptake indicates that the single application treatment provided nitrogen less efficiently and at a time that did not correspond with plant demand. This analysis indicates that split application treatments during periods of highest crop demand can reduce total nitrogen loss and increase total crop N uptake.

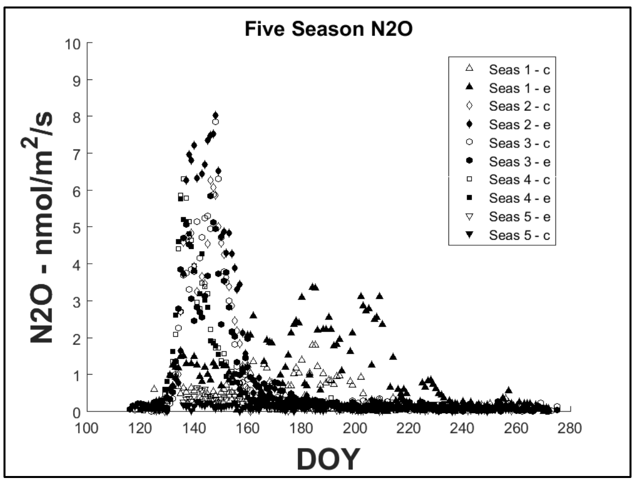

Figure 4. Season emission response for all five growing season simulations

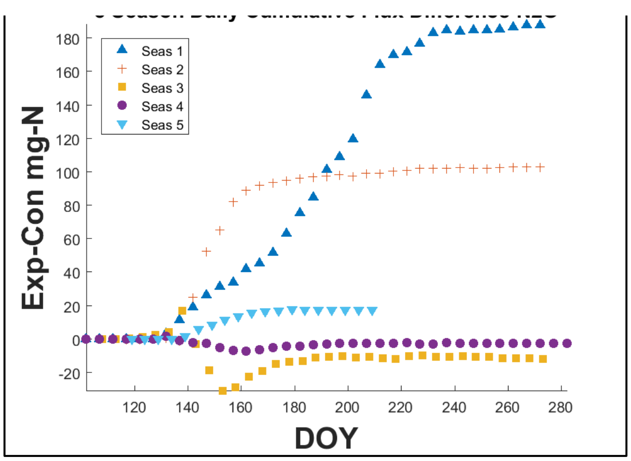

Figure 5 . Daily emission treatment difference. Units on the y-axis are calculated as hypothesized high emission response treatment minus hypothesized low emission.

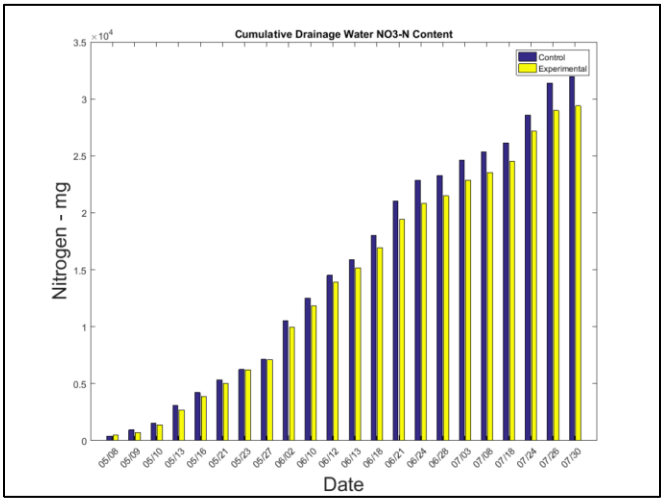

Figure 6. Drainage water nitrogen values for simulation 5

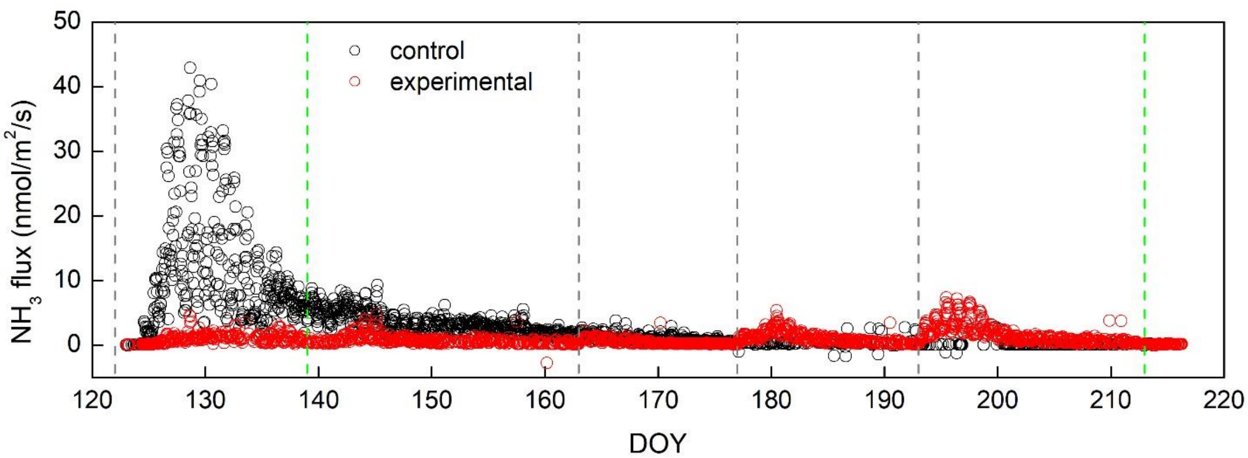

Figure 7. NH_3 fluxes (nmol/m2/s) in the control (black) and experimental (red) plots. Grey dashed vertical lines denote fertilizer applications. Green dashed and dotted vertical lines denote plant emergence and plant harvest, respectively.

CONCLUSIONS

Over the last several years our regional atmospheric measurements and mesocosm experiments have revealed that reactive nitrogen losses associated with corn production are likely to increase as our climate continues to get warmer and wetter. Our mesocosm experiments also indicate that alternative nitrogen management techniques have significant potential to reduce reactive nitrogen losses. Based on these experiments we can make the following conclusions:

1. Over the four years the enhanced precipitation treatments lost 30% more nitrogen relative to the historical normal.
2. Nitrous oxide emission factors for synthetic nitrogen were enhanced for the future precipitation scenario.
3. Corn yield was found to decline slightly for the future precipitation scenario.
4. Split application of nitrogen (targeting plant demand for nitrogen) reduced N_2O and NH_3 emissions and reduced nitrogen as runoff.
5. Overall, timely application of nitrogen fertilizer can improve nitrogen use efficiency and can act to mitigate the effects of increasing spring precipitation on reactive nitrogen losses.

EDUCATION, OUTREACH, AND PUBLICATIONS

These research activities have provided education and training opportunities for numerous post docs (Dr. Zhongjie Yu, Dr. Jeff Wood, Dr. Zichong Chen) and 1 graduate student (Lee Miller) and 1 research scientist (Matt Erickson).

The mesocosm facility has provided educational opportunities for ESPM students taking Biometeorology graduate classes at the University of Minnesota.

Our students provided a tour of the facility to “Destination Discovery” participants and to over 100 visiting high school students from Denmark.

Presentations related to this research were presented at the following:

“The imprint of agricultural ecosystems on trace gas emissions in the US Midwest”, **T.J. Griffis**, J.M. Baker, D.B. Millet, Z. Chen, J.D. Wood, C. Hu, and Z. Yu, American Geophysical Union (AGU), December 10-14, 2019, San Francisco, USA

“Sensitivity of Nitrous Oxide Emissions to Changes in Precipitation”, L. Miller, **T.J. Griffis**, R.T. Venterea, P. Turner, M.D. Deventer, M. Erickson, and J.M. Baker, American Geophysical Union (AGU), December 10-14, 2019, San Francisco, USA

“Top-down constrains on regional scale reactive nitrogen emissions” **T.J. Griffis**, Institute of Geography and Limnology Chinese Academy of Sciences, October 25, Invited, Jiangsu, Nanjing, China

“Top-down constrains on regional scale reactive nitrogen emissions” **T.J. Griffis**, Symposium on Terrestrial Ecosystems and Agricultural and Forest Meteorology, October 26-28, Key Note Speaker,Jiangsu, Nanjing, China

“Tall tower observations of ammonia and emission estimation for the US Midwest Corn Belt” C. Hu, **T. J. Griffis**, J. M. Baker, Z. Chen, D. B. Millet, J.D. Wood, and M. Erickson, American Meteorological Society, 4th Conference on Atmospheric Biogeosciences, May 14-18, 2018, Boise, ID, USA

This research has helped to support the following publications:

Griffis, T. J., Z. Chen, J. M. Baker, J. D. Wood, D. B. Millet, X. Lee, R. T. Venterea, and P. A. Turner (2017), Nitrous oxide emissions are enhanced in a warmer and wetter world, *Proc. Natl. Acad. Sci. U. S. A., 114, 12081-12085*.

Lee, M. Griffis T.J., Yu, Z., Baker, J.M. Turner, P. et al., (2019), A mesocosm investigation of interacting environmental and management controls on nitrogen loss pathways in an agricultural soil, *Journal of Environmental Quality* (To be submitted fall 2019)

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