RESEARCH FUND

Impacts of 4R Nutrient Stewardship

META ANALYSES

A "MANAGE"ED APPROACH FOR 4R NUTRIENT STEWARDSHIP ON DRAINED LAND

PRINCIPAL INVESTIGATOR: Laura Christianson, The Conservation Fund, Freshwater Institute, Sherpardstown, WV; l.christianson@freshwaterinstitute.org

IPNI Research Database:
http://research.ipni.net/project/IPNI-2014-USA-4RM04

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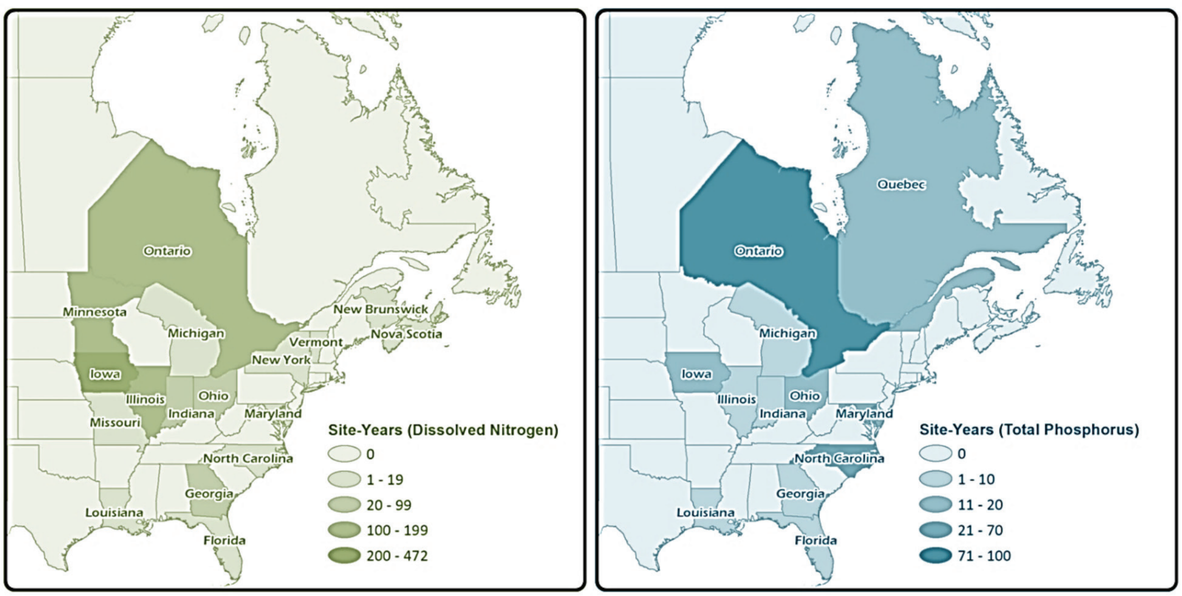
What we did:

Approximately 400 drainage water quality studies were reviewed to create a publically accessible database containing site, climate, cropping and agronomic management information from 50+ years of drainage research. From these studies, data from 91 journal publications, representing 1,279 site-years spanning 1961 to 2012, were compiled. The data were then used to investigate the impact of controllable factors (cropping management such as the 4R practices: right source, rate, time, and place of nutrient application) and uncontrollable factors (wet and dry years) on nitrogen (N) and phosphorus (P) loads. This new "Drain Load" table in the USDA-ARS "Measured Annual Nutrient loads from AGricultural Environments" (MANAGE) database allowed numerous water quality and crop yield comparisons based on this pooled dataset.



Distribution of drainage dissolved nitrogen (left) and total phosphorus (right) site-year records from the MANAGE Drain Load table.

What we learned:

- Wetter years predictably resulted in more drainage and greater N and P loads in drainage waters.
- Nutrient loads increased at greater N and P application rates. However, increased N and P application rates also improved crop yield across this large dataset, which indicates that new approaches and trade-offs may be required to balance agronomic and environmental goals.

(continued)

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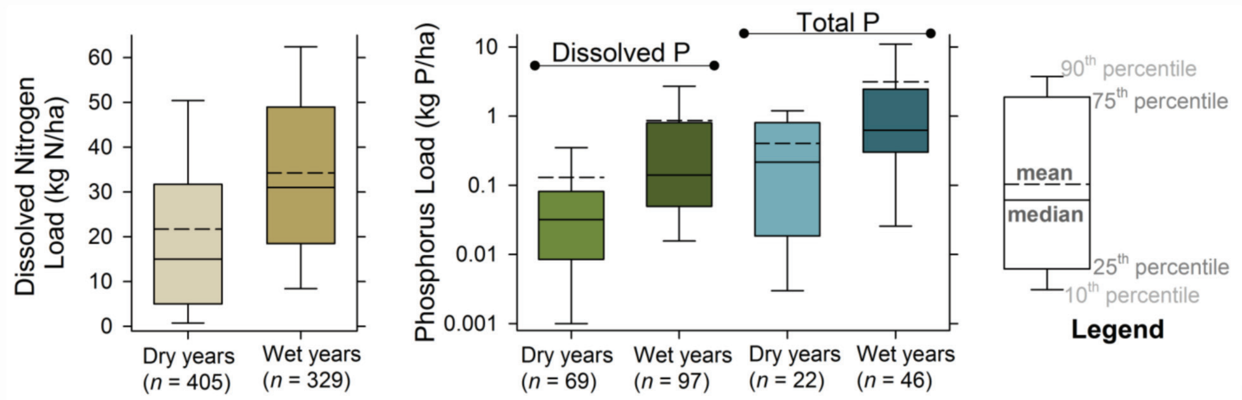
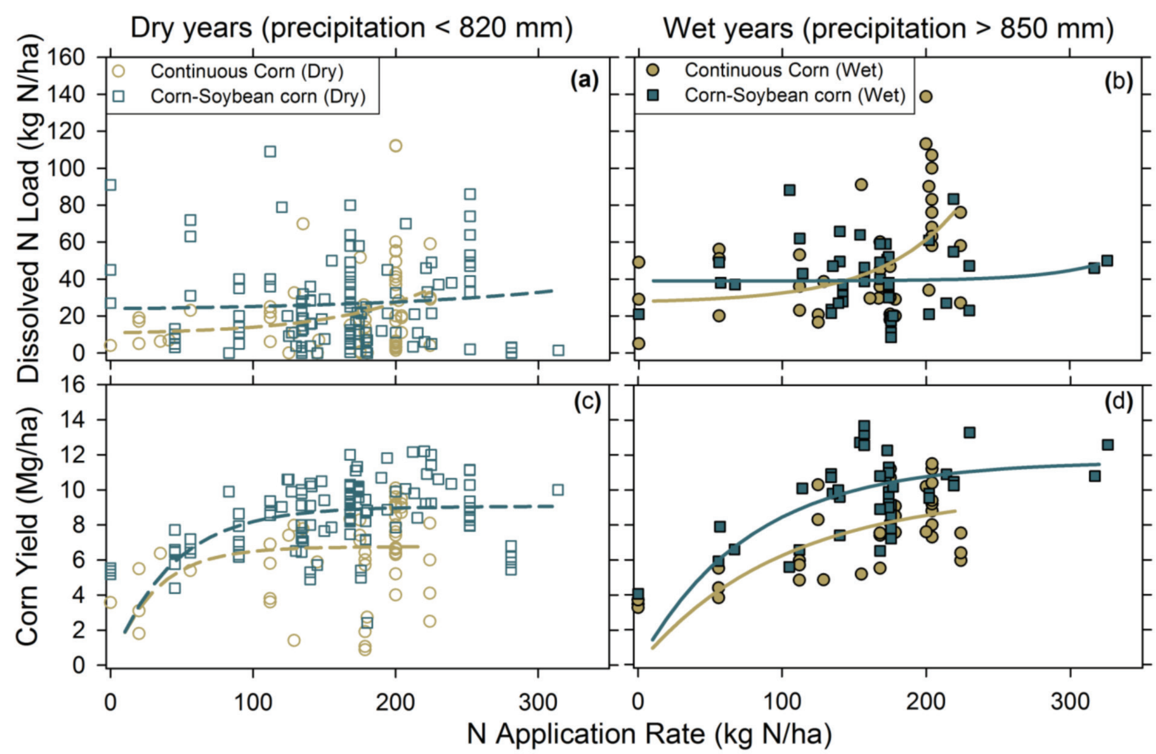
- Optimal nutrient application timing and placement are generally known to be important strategies for improving agronomic performance and water quality, but these two approaches showed no significant impact on dissolved N or total/dissolved P loads. This may have been complicated by a lack of drainage P studies.



Ranges of dissolved N and dissolved/total P drainage loads across the Drain Load table. Wetter years (darker colors) resulted in significantly greater nutrient loads.



Corn yield and dissolved nitrogen loads increased at increasing N application rates.

How to move forward:

- This review and meta-analysis clearly indicated the need for more long-term studies with coordinated controls across multiple sites and years. Specifically, information is needed on: 1) newly drained areas, 2) ditch-drained areas, and 3) factors affecting P in drainage water.

- The MANAGE database primarily focuses on North America; however, suggested future directions for related work include the addition of international drainage studies as well as creation of a "Drain Concentration" table to complement this new "Drain Load" table.

Impacts of 4R Nutrient Stewardship

META ANALYSES

RESEARCH FUND

META-ANALYSIS OF ENHANCED EFFICIENCY FERTILIZERS IN CORN SYSTEMS IN THE MIDWEST

PRINCIPAL INVESTIGATOR: Rachel Cook, Southern Illinois University, Department of Plant, Soil and Ag Systems Carbondale, IL; rachel.cook@siu.edu

IPNI Research Database:
http://research.ipni.net/project/IPNI-2014-USA-4RM06

Enhanced efficiency fertilizers (EEFs) can be an effective means to improve crop yields and protect natural resources. Their relative success, however, can be highly dependent on a range of environmental and management factors. This meta-analysis will help growers, industry, and academics by compiling the most up-to-date information on enhanced efficiency fertilizers in the Midwest and move the concept of 4R Nutrient Stewardship and sustainable agriculture forward.

EEFs such as nitrification inhibitors, urease inhibitors, and polymer-coated fertilizers may provide environmental and agronomic benefits in N fertilization of corn. Their effectiveness, however, can be influenced by fertilizer source, rate, application time, and placement and can vary by location due to climate and soil characteristics. In this study we performed a systematic review on published data from the Midwest region to address the effectiveness of enhanced efficiency fertilizers on corn yield, nitrous oxide emissions, and nitrate leaching.

After selecting for papers referring to EEFs published in the last 20 years, we identified 45 papers with 1,248 observations to describe corn yield response; 5 papers and 135 observations in relation to nitrate leaching; and 12 papers and 162 observations for nitrous oxide (N_2O) emissions. We collected information on 87 variables pertaining to study design, location, site management, fertilizer source, timing, rate, and placement, soil characteristics, and weather information.

Corn yield data are being modeled by fertilizer sources (anhydrous ammonia, urea ammonium nitrate, and urea). Most rotations, tillage treatments, and 4Rs are represented by the dataset. Preliminary analysis shows that EEFs can positively affect yield, the 4Rs are typically significant factors, and climate and soil characteristics are significant. Final models vary based on the fertilizer source. By taking site characteristics into account, we are more likely to detect differences between conventional fertilizers and EEFs. The gaps, such as few continuous corn observations in the anhydrous ammonia model, will give direction as to where more studies are required. Final modeling, sensitivity, and gap analysis are currently underway.

Nitrous oxide emissions and nitrate leaching data at this point will require better representation in the literature to determine the effects of EEFs. Consistency in reporting as area and yield basis would allow for greater comparisons across studies. Our database will serve as a valuable baseline and our corn yield models as a methodology for future meta-analyses as more literature is published.

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Table 1. Variables collected in database for all observations.

Study	Fertilizer	Soils	Climate	Yield	Leaching	N_2O
Author	place	pH	tempmax	yld	leach	N_2O-days
Year	place2	pHmeth	tempmin	yld source	leach source	N_2O
Journal	dateplant	SOM	precipann	yld-n	leach-n	N2O source
Source	dateharvest	SOC	preciprep	yld-sd	leach-sd	N_2O-n
Inhibitor	rot	bulkdensity	precipest	yld-sd source	leach-sd source	N_2O-sd
Name	till	WFPS	irrig	yld-se	leach-se	N_2O-sd source
state	apptime	slope	irrigapp	yld-se source	leach-se source	N_2O-se
country	split	sseries	MAP worldclim (mm)	NUE	leach-yldsc	N_2O-se source
county	dateN	sclass	MAT	plotsize-m2	leach-yldsc-se	N_2O-per
LRR	datesplit	sorder			reps	N_2O-yldsc
MLRA	datesplit2	stext				N_2O-yldsc source
lat	fallorspring	stextgrp				N_2O-yldsc-se
lon	ratetot	sand				N_2O-yldsc-se source
	ratetot source	clay				
	ratefall					
	ratepreplantspring					
	rateatplantoremerg					
	ratesidedresspostemerg					

Major Conclusions and Knowledge Gaps

- There is potential for EEFs to positively affect yield in certain circumstances.
- Environmental and management interactions need to be included in models to distinguish differences.
- The data summarized provide a rich baseline from which to project future study needs and for posing hypotheses regarding improved effectiveness of nitrogen utilization.

GAP: Need greater consistency in reporting means and variation, site characteristics, and weather information.

GAP: Results indicate a great need for more experiments with EEFs and water quality, both in tile-drained and non-tile-drained fields.

GAP: N_2O emissions and nitrate leaching are reported as either area- or yield-based results, often without information to calculate the other.

GAP: Consistent reporting of summary statistics full factorial supplemental tables would allow more information to be extracted for meta-analysis.

nutrient stewardship

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META ANALYSES

ASSESSING THE EFFECTS OF CONSERVATION PRACTICES AND FERTILIZER APPLICATION METHODS ON NITROGEN AND PHOSPHORUS LOSS FROM FARM FIELDS – A META ANALYSIS

PRINCIPAL INVESTIGATOR: Song Qian, The University of Toledo, Department of Environmental Sciences, Toledo, OH; song.qian@utoledo.edu

IPNI Research Database:

http://research.ipni.net/project/IPNI-2014-USA-4RM07

This project aims to use two tools of meta-analysis--propensity score and multilevel modeling—to quantify nutrient loss reductions arising from soil and water conservation practices. It uses the MANAGE database, which provides field scale information on nutrient loss from agricultural land. Applied to the 2007 version of the MANAGE database, the two analytical tools each found that conservation practices (one or more of waterways, contour farming, terraces, and buffers) reduced total phosphorus (P) loss by approximately 70%. In addition, they found that the conservation practices reduced the incremental increase in total P loss per unit increase in fertilizer application. These preliminary results have been summarized in a manuscript—essentially, a methods paper—submitted to the Journal of American Water Resources Association (Qian and Hamel, 2015).

Next steps include analysis of the 2014 version of the MANAGE database, which includes 65 peer-reviewed publications (ten more than the 2007 version) covering 1,980 watershed years. More than half of the observations in the database come from three states: Oklahoma, Texas and Ohio, with the remainder primarily from midwestern and southern states, California and Canada.

A graduate student is reviewing the 65 publications for further background information of specific importance to elucidating the effect of source, rate, time, and placement of fertilizer application.

The final analysis, likely to be available by mid-2015, aims to determine the influence of crop type, region, season, soil, and precipitation on conservation and fertilizer application practice effectiveness in reducing losses of total nitrogen (N) and P.

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META-ANALYSIS OF PHOSPHORUS FERTILIZER PLACEMENT AND TILLAGE INTERACTION FOR CORN AND SOYBEAN IN THE US

PRINCIPAL INVESTIGATOR: Dorivar Ruiz Diaz, Kansas State University, Department of Agronomy Manhattan, KS; ruizdiaz@ksu.edu

IPNI RESEARCH DATABASE:

http://research.ipni.net/project/IPNI-2014-USA-4RM09

Meta-analysis uses statistical methods for combining results from multiple studies on a specific topic with the aim of identifying patterns among study results, sources of disagreement among results, or other relationships that may exist among study results. Simply put, meta-analysis can be thought of as "conducting research about previous research" (after Wikipedia, 2015).

Phosphorus (P) fertilizer placement and interactions with tillage have been studied extensively in corn-soybean systems in the US. Results generally suggest that placement of P fertilizer can play an important role in plant uptake of P and crop yield, as well as potential P loss to surface water. Although there have been many studies evaluating this topic from both agronomic and environmental perspectives, there are no quantitative summaries of the available data. Thus a meta-analysis has the potential to advance the understanding of this subject, and help address questions about P placement that are common to both the production agriculture and environmental communities.

The basic objectives of this study were to: 1) find, analyze, and summarize published and unpublished field-based data on corn and soybean response to P fertilizer placement and interaction with tillage, 2) complete a data review on yield response and P loss with surface runoff as affected by P fertilizer placement and tillage interactions, and 3) include data reviews of estimated P use efficiency and economic return. The methodology involved a systematic review of published and unpublished research on P fertilizer placement under different tillage systems and diverse soils in the US, with emphasis on the Midwest and Great Plains regions. Data collection went back at least 30 years. The two main response variables evaluated included crop yield and P runoff loss.

A thorough literature search was completed that included an original number of approximately 56,000 publications. This initial search included the main databases (Digital Library, ScienceDirect, WileyInterScience, SpringerLink, and Web of Science). Publications from "grey" literature were also included - primarily conference proceedings and research reports. Phosphorus source was only for commercial fertilizer and information on fertilizer type was provided.

After applying specific selection criteria, approximately 250 papers for both corn and soybean were selected and entered in a database for analysis. Papers were primarily from Colorado, Idaho, Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. Papers found for this meta-analysis provided a strong dataset for the evaluation of yield response and early plant P uptake as affected by P placement and tillage.

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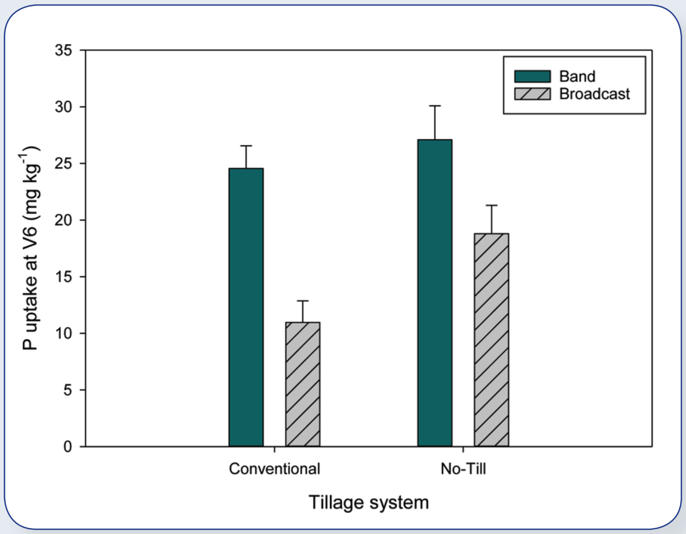

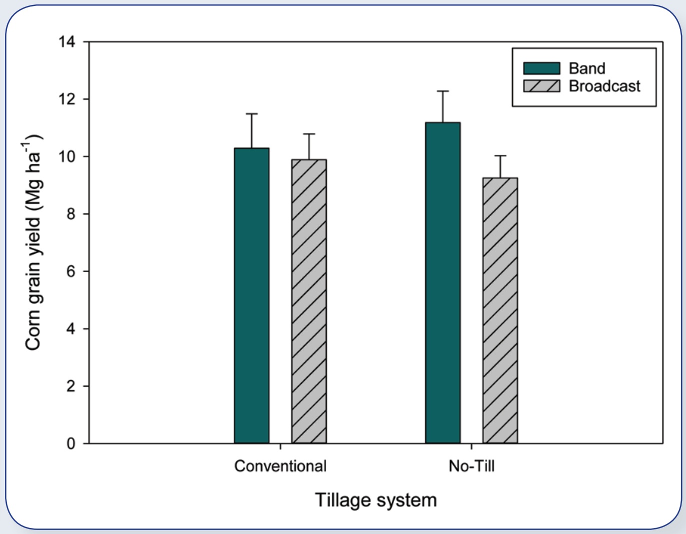

Figure 1. Tillage system by P fertilizer placement interaction for corn P uptake (top) and grain yield (bottom).

Major Conclusions and Knowledge Gaps

- Results show a clear interaction between tillage system and P fertilizer placement for early P uptake and grain yield in corn (**Figure 1**). Band placement of fertilizer P generally increases early P uptake and grain yield, particularly under no-till systems.
- Greater yield and P uptake with band application is consistent across a range of soil test levels; however, with low soil test levels broadcast fertilizer application seems to provide additional plant response for plant uptake and grain yield.
- Work focusing on the evaluation of P loss with different tillage and P placement interactions is relatively limited, especially compared to work evaluating agronomic aspects. The majority of the previous work on P loss focuses on P from manure sources, and a large amount of work was completed in the east and northeastern US leaving a limited number of papers meeting our selection criteria. Furthermore, most of the previous work focused primarily on the short-term effects of treatment application.
- The literature search shows that some databases (i.e., The Digital Library) are better suited for an effective meta-analysis. Future improvements in data stewardship are clearly needed to increase access and improve the use of published data on this topic.

GAP: Research that includes information on total plant P uptake and P removal in the grain is limited, particularly as affected by soil test P, tillage and fertilizer placement.

GAP: A very limited amount of work is available on the long-term effect of specific management systems used by producers for tillage and/or placement on potential P losses to surface water. Furthermore, work on the environmental effect of tillage by P placement interaction focus primarily on manure P source.

GAP: During the literature search, many issues were identified related to data presentation/availability in peer-reviewed papers, including differences and inconsistences among journals and papers within journals (e.g., background soil information, soil sampling methods and limited detail on fertilizer sources used).

GAP: Research on the overall topic of tillage by P placement interaction for both agronomic and environmental implications is very limited in some specific states in the Midwest and Great Plains region.

GAP: Published work on the interaction effect of tillage by P fertilizer placement on P loss to surface water is limited for the Midwest and Great Plains region, particularly as related to crop yield. This limitation is being addressed with current 4R Research and Demonstration projects focusing on P loss as affected by P fertilizer placement and the interactions with other common management practices.

Impacts of 4R Nutrient Stewardship

META ANALYSES

RESEARCH FUND

NITROGEN LOSSES: A META-ANALYSIS OF 4R NUTRIENT MANAGEMENT IN U.S. CORN-BASED SYSTEMS

PRINCIPAL INVESTIGATORS: Lydia Olander, Ecosystem Services Program Director, (lydia.olander@duke.edu) and Alison Eagle (alison.eagle@duke.edu), Policy Associate, Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC.

IPNI RESEARCH DATABASE:
http://research.ipni.net/project/IPNI-2014-USA-4RM10

Nitrogen (N) fertilizer has enabled modern agriculture to produce sufficient food for a growing population. However, environmental damages from the loss of nitrous oxide (N_2O) – a potent greenhouse gas – and nitrate (NO_3) – a water quality pollutant – increase the need for improved management that minimizes losses and improves efficiency. We collected data of N_2O and NO_3 losses from corn-based field experiments throughout North America and published by July 2014. The goal of this project was to determine the impact of 4R fertilizer N management (right rate, source, timing, and placement) on the unintended losses of fertilizer N as either N_2O or NO_3.

We identified 4,400 research papers that mention fertilizer, nitrogen, or nutrient management in agriculture, or fertilizer-associated N_2O or NO_3 losses. After reading titles and abstracts, most studies were discarded because they were not about cropland, corn, or field N losses, or were outside North America. A total of 237 studies were reviewed further. We assessed these papers to find measurements of N fertilization rate, crop yield and either N_2O or NO_3 losses. In the end, 27 studies contained N_2O emissions data and 22 contained NO_3 loss data together with crop yield and N fertilization rate (one study reported both losses). The final database built from these 48 individual studies included 408 observations of N_2O emissions and 396 observations of NO_3 leaching losses. Each observation reports growing season or annual loss in a single year at a specific location for a given treatment.

Locations across studies for the N_2O and NO_3 data rarely overlap, only one study reported losses of both N_2O and NO_3, and management practices for both types of field studies are diverse. For example, 60% of NO_3 observations and only 1.4% (reportedly) of the N_2O data were from tile-drained fields, plus 40% of N_2O observations and only 8% of NO_3 data points were in no-till systems. Thus we were unable to identify possible trade-offs between air and water quality N pollutant losses (i.e., N_2O vs. NO_3 losses).

Fertilizer N rate comparisons were frequent. Crop yield increases with N rate up until a saturation point, N_2O emissions respond in an exponential fashion, and NO_3 losses tend to show a linear relationship. Fertilizer source comparisons were conducted in about half of the N_2O observations, and statistical analysis indicates that N_2O losses decrease in the following order: Anhydrous ammonia > urea = coated urea = UAN = UAN & AgrotainPlus > Super U. However, only one NO_3 study examined different sources. Placement was compared in 15% of N_2O and 9% of NO_3 observations, with no significant effects on losses. There were also no differences detected between timing treatments, compared in 2% of N_2O and 13% of NO_3 observations.

Multi-level regression models were developed for both N_2O and NO_3 to compare 4R treatments between studies and correct for climate, soil, and other characteristics. This broadened results

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beyond the specific side-by-side comparisons. With many different fertilizer N rates used in the component observations, rate proved to be a key factor for both N_2O and NO_3 losses. Nitrous oxide emissions increased with average July temperature, but decreased with the use of nitrification inhibitors and when delaying fertilizer application by side-dressing when the crop was growing (**Figure 1**). Nitrate losses increased with precipitation, were lower with higher levels of soil C, and were reduced with UAN or urea fertilizer compared to anhydrous ammonia and other ammonium-based fertilizers (**Figure 2**).

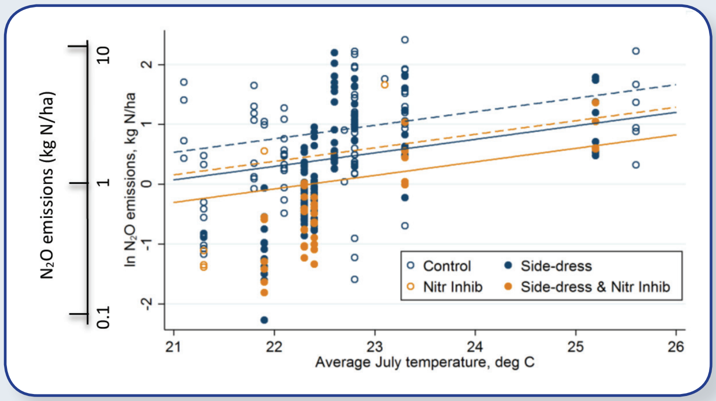

Figure 1. Nitrous oxide emissions from corn receiving 150-250 kg fertilizer N/ha as affected by July temperature, nitrification inhibitors, and side-dress fertilizer. Solid lines are model of solid circles, dotted lines model open circles.

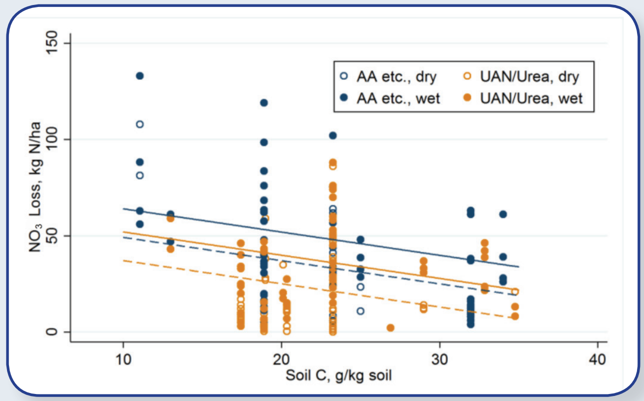

Figure 2. Nitrate losses from non-irrigated corn receiving 110-280 kg fertilizer N/ha as affected by soil carbon, wet or dry climate (<800 mm vs. >800 mm), and UAN/urea vs. anhydrous ammonia etc.

With poor regional coverage, minimal overlap between N_2O and NO_3, and limited data on placement and timing impacts, we lack knowledge about important management practices. Thus, the best-available process-based models, which only have these existing studies for calibration, may be the only somewhat reliable way to test loss responses to 4R fertilizer management in the foreseeable future.

Major Conclusions and Knowledge Gaps

- Project team assembled database with ~400 observations each of nitrous oxide (N_2O) emissions and nitrate (NO_3) leaching losses from fertilizer nitrogen (N) experiments across North America. Each entry includes loss measurements, fertilizer details, corn crop yield, as well as climate and soil information.
- Fertilizer source affects N_2O emissions as follows: Anhydrous ammonia > urea = coated urea = UAN = UAN & AgrotainPlus > Super U
- Nitrification inhibitors reduce N_2O losses by an average of 37%.
- UAN and Urea may reduce NO_3 losses by 8-12 kg N/ha (7-11 lb/A) when compared to anhydrous ammonia and other ammonia-based fertilizers.
- Delaying fertilizer application until crop is growing reduces N_2O losses by an average of 50%.
- Regional data gaps mean conclusions cannot be applied to many corn-growing places in North America.
- Difficult to determine relationship between N_2O and NO_3 because studies for each loss pathway did not overlap in place, time, or management practices.
- Research needs identified: 1) field studies to test the effects of fertilizer sources (NO_3), timing (NO_3), and placement (N_2O and NO_3), 2) field studies on all 4Rs in regions with no current data and 3) studies that measure both N_2O and NO_3 losses at the same time.

PROJECT ASSOCIATES:

Research Assistants: Katie Locklier & Tibor Vegh, Nicholas Institute

Student Assistants: Erin Vining, Jocelyn Tsai

Research Collaborators: Jim Heffernan, Assistant Professor, Nicholas School of the Environment, Duke University; & Emily Bernhardt, Associate Professor, Department of Biology, Duke University

nutrient stewardship

ENHANCED EFFICIENCY FERTILIZER TECHNOLOGIES TO REDUCE NITROUS OXIDE EMISSIONS FROM CROPPED SOILS IN PRAIRIE CANADA

PRINCIPAL INVESTIGATOR: Mario Tenuta, University of Manitoba, Department of Soil Sciences, Winnipeg, MB; tenutam@cc.umanitoba.ca

IPNI Research Database:
http://research.ipni/net/project/IPNI-2014-CAN-4RC08

Activities in 2014 included the development of a plot-scale anhydrous ammonia (NH_3) applicator to be used in the project. An old anhydrous ammonia applicator tank was re-fitted and a plot seeder was modified to pull the applicator cart and accept hosing and mounting of the flow controller. The whole system was safety checked and approved for use by Transport Canada was obtained. Personnel completed NH_3 safety training and obtained applicator certification. All this was completed by October 2014.

The operation of the applicator was tested to deliver ammonia at required depths with good band closure, calibration of delivery rates, and ability to meter and mix nitrification inhibitors into the ammonia injection stream. In October 2014, the applicator was repeatedly tested for safe operation and calibration of flow meters and proper mixing of nitrification inhibitors. Closure and depth placement were perfected.

***Dr. Tenuta** at N_2O emissions research site, Glenlea, MB.*

Proper delivery of nitrification inhibitors to the anhydrous ammonia stream was verified. The anhydrous ammonia system was used to put in fall treatments for the project at two sites in Manitoba the first week of November. Each site had treatments of various formulations of urea and anhydrous ammonia with and without nitrification inhibitors in a random complete block design.

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More at: http://nutrientstewardship.com/funding or http://info.ipni.net/4R-ResearchFund seed-placed and banded treatments, followed by broadcast and incorporated (**Figure 2**). The yields of all the broadcast treatments, including the higher rates, were similar to the control or no P treatment.

These results indicate that sub-soil placement of P is more effective in promoting soybean yield than broadcast application. No significant response of soybean yield to P rate or placement was observed in the upper slope site, which may be explained by the eroded nature of the soil and high variability. Enhanced extractable P concentrations were observed near the soil surface with broadcast applications.

Simulated snowmelt runoff, *on intact soil slabs collected from field site.*

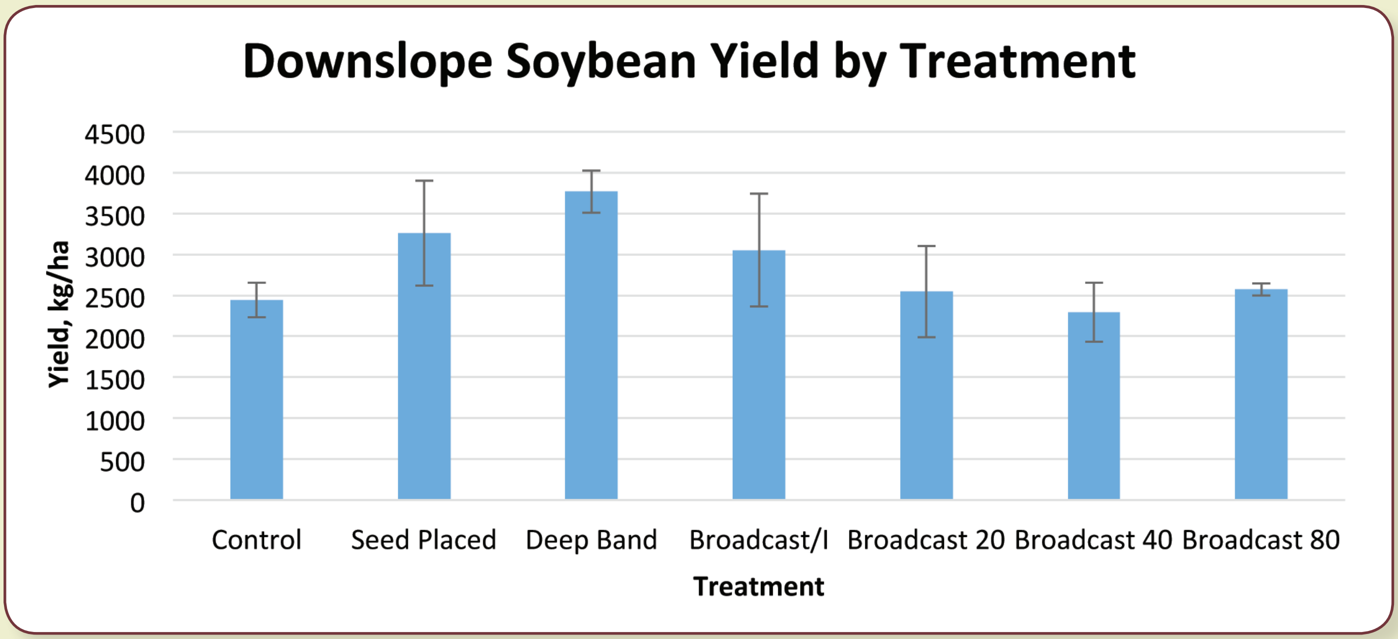

Figure 2. Downslope soybean grain yield by treatment. Error bars represent the standard error of the four field replicates of each treatment.

EFFECT OF BROADCAST VERSUS BANDED PHOSPHORUS APPLICATION ON FATE OF APPLIED PHOSPHORUS IN SOIL AND IN SNOWMELT WATER FLOW

PRINCIPAL INVESTIGATOR: Jeff Schoenau, University of Saskatchewan, Department of Soil Science, Saskatoon, SK; jeff.schoenau@usask.ca

IPNI Research Database:
http://research.ipni/net/project/IPNI-2014-CAN-4RC07

There is interest in the impact of phosphorus (P) fertilizer placement on crop recovery, and fate of the applied P in the soil, and in run-off water. This research will evaluate the influence of methods of placement of mono-ammonium phosphate (MAP) fertilizer on the yield and recovery of phosphorus by soybean, in a typical Western Canadian soil.

A farm field (wheat stubble) was selected in the spring of 2014 in the Dark Brown soil zone near Central Butte, SK. Two sites representing contrasting slope positions in the same field were chosen: an upper slope and lower slope. A soybean variety (Moosomin) was selected for the study. Treatments evaluated were no P fertilizer, and P fertilizer added at the recommended rate (20 kg P_2O_5/ha) applied in the seed-row, banded beneath the seed, broadcast with incorporation, and broadcast without incorporation, as well as broadcast without incorporation treatments at rates of 40 and 80 kg P_2O_5/ha. Each treatment was replicated four times at each slope position. Background soil information was obtained from pre-plant, and pre-fertilizer application soil samples. Both sites were considered marginal to deficient in available P with < 10 mg P/kg soil test extractable P.

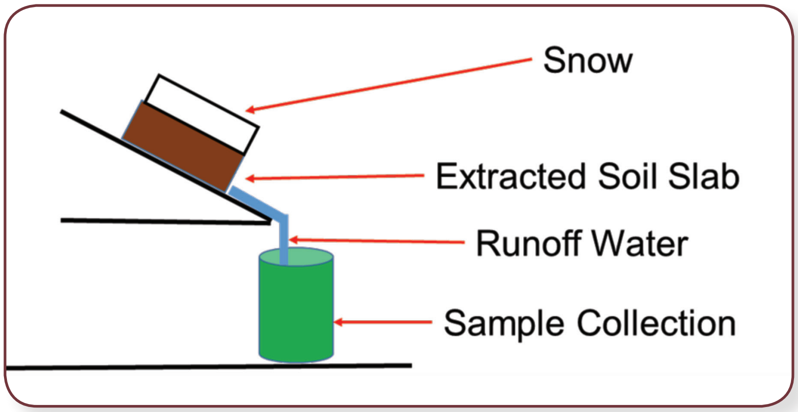

Figure 1. Schematic of simulated runoff experiment.

The soybean crop grew well over the 2014 season, and was harvested in the week following the first hard frost (September 11, 2014). Soil cores to a 60 cm depth were obtained from each plot in October 2014, and will be analyzed for plant available P content. Intact surface soil slabs were collected in October and were used in a simulated snowmelt run-off experiment in January 2015 to assess the impact of treatments on soluble P in the run-off (**Figure 1**).

Soybean yield responses observed in the 2014 season at the site showed a grain yield response to P placement at the lower slope position, with the highest yields (~3,000 kg/ha) found in the

(continued)

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More at: http://nutrientstewardship.com/funding or http://info.ipni.net/4R-ResearchFund rotation. The hay phase of the WOBHH rotation consists of an alfalfa-brome mixture, which contributes a significant amount of biologically-fixed N to all treatments due to the presence of alfalfa in the sward. This biologically-fixed N contributes to N_2O emissions in other rotation phases. There was, however, a consistent ranking of fertility treatment emissions within each rotation – Manure > NPK < PKS/NPKS < Control. The long-term fertility treatments have influenced soil properties such as total C, total S and pH. Total C in the top 15 cm was significant correlated to N_2O emissions over both growing seasons ($r = 0.71$; $P<0.01$), also total S ($r = 0.59$; $P<0.01$) and pH ($r = -0.49$; $P<0.01$).

Field research, *NPKS balanced fertility plot, Breton, AB.*

Long-term management practices that result in high production and increase soil nutrient stocks are also associated with higher growing season N_2O emissions likely because of increased nitrification, but these emissions are offset by greater crop yields – yield-normalized N_2O emissions were lowest in the NPKS treatment of both rotations.

COORDINATED NITROGEN AND SULFUR MANAGEMENT IN SULFUR DEFICIENT SOILS

PRINCIPAL INVESTIGATOR: Miles Dyck, University of Alberta, Renewable Resources, Edmonton, AB; miles.dyck@ualberta.ca

IPNI RESEARCH DATABASE:
http://research.ipni/net/project/IPNI-2014-CAN-4RC06

Long-term soil experiments have shown management practices such as rotation, tillage and fertilization affect soil nutrient cycling and crop response to fertilizer. The majority of soil fertility research has quantified the benefit of fertilizers in the growing season they are applied, but there is a need for research quantifying the effects of long-term fertilizer applications on soil quality, nutrient use efficiency and nitrous oxide (N_2O) fluxes. Further, there is a need for research focusing on nitrogen (N) and sulfur (S) interactions because many prairie soils are potentially S deficient, and S deficiency may be increasing because of increased crop removal by high yielding, S-demanding crop species (i.e., canola), increased cropping intensity, and decreased industrial S emissions into the atmosphere. The objective of this research is to quantify and compare N_2O emissions in treatments with different long-term N and S fertilization regimes at the University of Alberta - Breton Plots long-term research site near Breton, AB.

In the 2014 growing season, weekly N_2O fluxes were measured on the wheat phase of the control, NPKS, NPK, PKS, and manure treatments of the wheat-oats-barley-hay-hay (WOBHH) rotations, and wheat-fallow (WF) rotations. Growing season precipitation was 286 mm, about 100 mm below normal (393 mm), but growing degree days (1,269) were slightly greater than normal (1,230). Based on the calculated cumulative evapotranspiration of 497 mm, a significant water deficit was experienced. The N_2O flux and grain yield data from the 2014 growing season showed greater differences in cumulative N_2O emissions from the long-term fertility treatments in the WF rotation compared to the WOBHH rotation (**Figure 1**). The manure and NPK treatments in the WF rotation, had significantly higher emissions than the control, but there were no differences between fertility treatments in the WOBHH

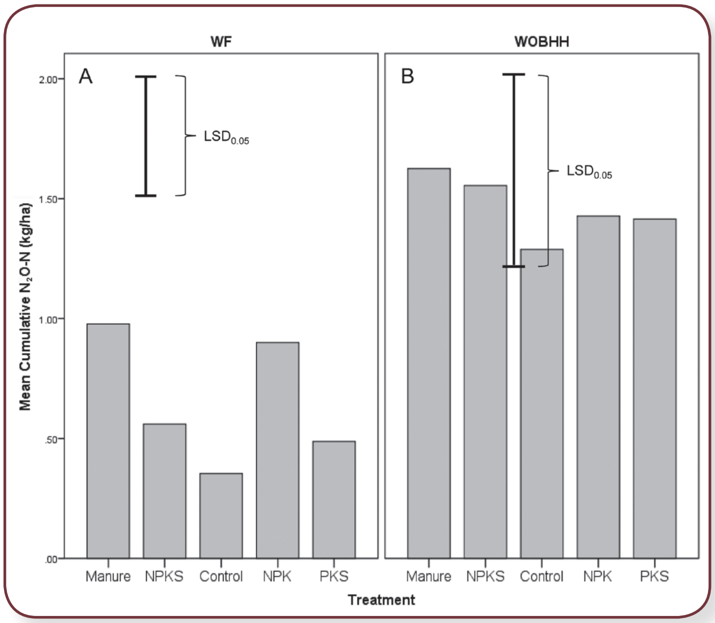

Figure 1. Comparison of cumulative N_2O-N fluxes between the fertility treatments of the (A) WF rotation and (B) WOBHH rotation.

(continued)

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RESEARCH FUND

Impacts of 4R Nutrient Stewardship

RESEARCH AND DEMONSTRATIONS

NITROGEN STABILIZERS TO ENHANCE NITROGEN USE EFFICIENCY AND REDUCE GREENHOUSE GAS EMISSIONS

PRINCIPAL INVESTIGATOR: Linda Hall, University of Alberta, Agriculture & Forestry Centre, Edmonton, AB; linda.hall@ualberta.ca

IPNI RESEARCH DATABASE:
http://research.ipni/net/project/IPNI-2014-CAN-4RC05

Canadian annual use of nitrogen (N) fertilizer is 1.8 M t; however, due to natural soil and plant interactions with applied N fertilizers, efficiency of plant uptake and utilization is often around 50% of applied N in the year of application. Much of the applied N that is not taken up by the crop remains in the soil. However, there are some losses of applied N that can result in lower yields and grain quality, and are an environmental concern if N is leached into surface or ground water, or lost to the atmosphere as ammonia or nitrous oxide. Nitrogen stabilizers, including nitrification inhibitors (NI) and urease inhibitors (UI), and polymer coated – controlled release urea, may decrease greenhouse gas (GHG) emissions and increase N use efficiency (NUE).

***Nitrogen fertilizer** application, Fall 2013.*

In 2014, trials were conducted in spring at Lethbridge, AB, and in the fall and spring at Edmonton and Devon, AB. The study used eNtrench® treated urea, ESN® – polymer coated controlled release urea, SuperU® and urea with five N rates (0, 50, 75, 100 and 125% of soil test recommendations). Spring wheat was the crop grown at all sites. In this year, the data gathered included GHG emission using a steady state Photoacoustic gas monitor at the Edmonton site only. Soils samples were collected prior to application, two and four weeks after emergence, and post harvest to assess the nitrogen balance. NDVI was quantified at stem elongation and mid-anthesis, crop vigor ratings were taken. In addition to wheat yield, wheat stubble and grain nitrogen analysis, test weights and grain quality were measured.

***Research site** near Devon, AB, June 2014.*

During the 2014 crop year, September 2013 through to September 2014, the weather was slightly cooler and drier compared to 30-year average weather. For example at the Devon site, the average temperature was 0.3 C compared to the 30-year average of 1.9 C; and for precipitation, 353.8 mm of moisture fell in the crop year compared to the 30-year average of 404.9 mm.

***Harvesting** research plots, September 2014.*

All enhanced N fertilizer forms, whether fall or spring applied, resulted in greater levels of ammonium N (NH_4^+), and lower levels of nitrate N (NO_3^-) at two and four weeks after crop emergence, compared to using regular urea. Relative to urea, eNtrench had a N_2O emission reduction of 18% in the fall, but SuperU® and ESN® emissions were not reduced. In the spring eNtrench® reduced N_2O emission by 24%, and SuperU® by 30% compared to urea. ESN® N_2O emissions were not reduced compared to urea. Another year of field experiments and data measurements will be collected during the 2015 growing season.

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CAN FOLIAR UREA REDUCE NITROGEN LOSSES FROM POTATO PRODUCTION IN ATLANTIC CANADA?

PRINCIPAL INVESTIGATOR: David Burton, Dalhousie University, Department of Environmental Sciences, Truro, NS; dburton@dal.ca

IPNI Research Database:
http://research.ipni/net/project/IPNI-2014-CAN-4RC04

In recent years it has become increasingly popular for potato producers in Atlantic Canada to include urea in the foliar applications of fungicides. Producers believe this practice sustains their potato crop through periods of water stress and allows for more rapid recovery following a precipitation event. This urea application is not considered as part of their nitrogen (N) fertility program and is added in addition to the recommended rates of N fertilizer at planting. This project examines the potential to reduce the amount of N fertilizer added at planting in situations where foliar urea will be applied to the crop. We are evaluating whether in-season foliar urea (Right Product, Right Time and Right Place) in combination with reduced N fertilizer rates (Right Rate) at planting is an effective best management practice (BMP) for sustaining potato yields and reducing nitrous oxide emissions and nitrate leaching.

The experiment, established in 2013, was conducted for a second year in 2014 evaluating the use of foliar urea to increase N use efficiency in potato production in Atlantic Canada. The treatments included five rates of N fertilizer application at planting (0, 107, 134, 161, 214 lb N/A) as well as addition of 27 lb N/A of foliar applied urea on the 107 and 134 lb N/A treatments. Plant yield response, greenhouse gas emissions, soil nitrate concentration and nitrate flux (ion exchange membranes) were measured during the growing season.

In 2014, preliminary data suggest that rates of N fertilizer above 134 lb N/A did not result in an increased potato yield. The application of foliar urea did not increase potato yield. Increased rates of N fertilization did however result in higher soil nitrate concentration and flux. The application of foliar urea did not increase soil nitrate concentration or flux.

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Impacts of 4R Nutrient Stewardship

RESEARCH AND DEMONSTRATIONS

RESEARCH FUND

OPTIMIZATION OF 4R NITROGEN FERTILIZATION PRACTICES IN RESPONSE TO PRODUCTION SYSTEM UNCERTAINTIES

PRINCIPAL INVESTIGATOR: Nicolas Tremblay, Agriculture and Agri-food Canada, St-Jean, QC; nicolas.tremblay@agr.gc.ca

IPNI RESEARCH DATABASE:

http://research.ipni/net/project/IPNI-2014-CAN-4RC03

Nitrogen fertilization provides essential benefits for food production but its optimal management is subject to a high level of complexity. The fertilizer industry, agronomists, consultants and farmers recognize the 4Rs as the basis for optimum fertilization, but their implementation is knowledge-intensive and site-specific. For a full implementation of the 4R strategy in the specific context of N applications, it is necessary to address the risks and opportunities of N fertilization management at the field-scale with respect to weather, crop response and economics.

Our goal is to quantify the influence of soil and weather conditions (i.e., temperature, precipitation): 1) experienced prior to the growing season; 2) from sowing to topdressing application (if applicable); and 3) after the last N application on the potential for crop yield response and N losses. For this matter, it will be necessary to study the accuracy of site-specific weather forecasts and the opportunity for their inclusion in a probabilistic strategy to optimize N use efficiency while safeguarding crop yield potential, and to explore system sensitivity to possible interactions with other soil amendments, cultivar specification, tillage systems and different influential management-induced factors.

The project will utilize past and new datasets from researchers involved in the other activities supported by the 4R Fund, as well as those already available, to perform meta-analyses in order to identify crop yield responses to applied fertilizer N and N losses as influenced by soil properties, climatic conditions and 4R management practices. The first step is to create a unified database of past and new N fertilization experiments dealing with rates, sources, timing and placement on crop yield production, nitrous oxide and ammonia emissions and nitrate leaching, including relevant meta-data (weather dynamics, cropping practice, soil characteristics) explaining regional differences. This unified database of Canadian observations on corn, canola, wheat, and potato is currently being assembled as a part of this project.

Meta-analyses have recently emerged as a necessity in agriculture to review accumulated evidence and extract new, meaningful information from knowledge fragments that need to be consolidated. Combination of spatial analysis methods and modeling techniques like multifactorial analysis, state equation representation, and fuzzy inference systems will then be used to analyze the relationships between crop response to N fertilization and information on soil properties, crop growth status, meteorological conditions and market status (commodity and N prices). The outcome of this project is a framework model to manage the sources of uncertainties affecting 4R practice outcomes on a site-specific basis.

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Preliminary results are presented in **Table 1**. The highest yields (~160 bu/A) and N removal in grain (~100 lb/A) resulted from injecting UAN with either UI or UI+NI. The injected UAN+UI+NI produced 16% more grain and 21% more grain N than broadcast urea without inhibitors.

Broadcasting urea resulted in the greater ammonia volatilization losses, as compared to streaming or injection. Without inhibitors, broadcast urea resulted in ammonia volatilization loss amounting to 28% of the N applied, followed by streaming at 9%, and injection at 6%. The addition of urease inhibitors decreased ammonium volatilization losses by 76% with broadcast urea, 52% with streaming and by 97% with injection.

Cumulative growing season emissions of nitrous oxide increased when the urease inhibitor was used without the nitrification inhibitor. Injecting UAN produced higher nitrous oxide emissions than broadcasting urea or streaming UAN. While adding UI+NI to injected UAN reduced emissions to reasonable levels, streaming UAN+UI+NI produced the lowest emissions per bushel of yield.

Nitrogen sources and placements that reduced ammonia emissions generally increased crop yields and N recovery in grain. The same was not apparent for nitrous oxide emissions. Injection of UAN was shown to require a nitrification inhibitor to reduce potentially high emissions of nitrous oxide. However, these results are based upon only one year of field measurements. Additional research is required to see how these comparisons hold over varying soil and weather conditions.

Table 1. Corn grain yields, N in grain, and emissions of ammonia and nitrous oxide as a function of varying N sources and placements in 2014 (preliminary results; do not cite).

Placement	Nitrogen source	Grain yield, bu/A	Grain N, lb/A	NH_3-N emission, lb/A	N_2O-N emission, lb/A	N_2O-N emission, lb/1,000 bu
Control		73	42		0.2	3
Broadcast	Urea	139	79	33	0.6	4
	Urea + UI	145	83		1.0	7
	Urea + UI + NI	150	88	8	0.6	4
Streaming	UAN	145	83	11	0.7	5
	UAN + UI	144	87		0.9	6
	UAN + UI + NI	145	85	5	0.5	3
Injection	UAN	154	88	8	0.8	5
	UAN + UI	163	96		1.9	12
	UAN + UI + NI	161	100	1	0.8	5

IMPROVED NITROGEN APPLICATION METHODS AND SOURCES FOR CORN IN SOUTHWESTERN ONTARIO

PRINCIPAL INVESTIGATOR: Craig Drury, Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Centre; Harrow, ON; druryc@agr.gc.ca

IPNI RESEARCH DATABASE:
http://research.ipni/net/project/IPNI-2014-CAN-4RC02

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Increased farm sizes and greater urgency for timeliness have resulted in greater time constraints for producers to apply nitrogen (N) fertilizers to crops. Hence, some producers have now started applying their N by either streaming urea-ammonium nitrate (UAN) or broadcasting urea onto their soils. They are considering adding inhibitors with urea or UAN to reduce losses of applied N. The increased use of urea and UAN fertilizers compared to other N sources may also enhance N losses through ammonia volatilization and/or denitrification (nitrous oxide) and dinitrogen (N_2) emissions). The objectives of this study were to: 1) determine the amount of ammonia lost following side-dress N application; 2) determine the effectiveness of injecting or streaming N application in reducing ammonia volatilization losses compared to broadcast application; 3) evaluate the ability of urease and nitrification inhibitors to reduce ammonia volatilization and nitrous oxide emissions; and 4) determine the crop response to the various N sources and application methods. This study was started in April 2014 and this is the first year of the co-operative study. Corn was planted on 26 May and a starter fertilizer (20-20-10) at 127 lb/A was applied to all treatments including the control. The side-dress treatments investigated included three application methods (broadcasting, streaming and banding N fertilizers) and three different N sources—the regular N source (urea for broadcast and UAN for streaming and banding), the regular N source with a urease inhibitor (UI) and the regular N source with UI and a nitrification inhibitor (NI). These sources were applied at 116 lb N/A on 30 June when the corn was at the 6 to 8 leaf stage. A control N treatment (zero rate) was included for comparison.

***Wind tunnel and instrumentation** (flow meters and acid traps) used to monitor ammonia emission following side-dress application of N.*

Ammonia volatilization measurements were obtained daily using wind tunnels over the first 28 days after application. Weekly measurements of nitrous oxide emissions were obtained throughout the growing season from early May until the end of October. Every three weeks, soil samples and five plant samples were taken to examine the amount of inorganic N remaining in the soil and the plant biomass and plant N uptake.

(continued)

IMPROVING NITROGEN MANAGEMENT TOOLS FOR REDUCED ENVIRONMENTAL LOSSES FROM CORN PRODUCTION

PRINCIPAL INVESTIGATOR: Claudia Wagner-Riddle, University of Guelph, School of Environmental Sciences. Guelph, ON; cwagnerr@uoguelph.ca

IPNI RESEARCH DATABASE:
http://research.ipni/net/project/IPNI-2014-CAN-4RC01

Nitrogen is a key input for sustaining high crop yields, but the fertilizer N uptake efficiency in crops is relatively low with conventional production practices (<50%). Part of the applied N not taken up by crops is vulnerable to losses such as nitrate leaching and nitrous oxide emissions. To overcome this situation, several mitigation practices have been proposed as part of the 4R nutrient strategy. However, these mitigation measures are poorly described and understood in current models and decision support system tools. With this project we aim to contribute to the long-term sustainability of corn agro-ecosystems in Ontario through the improvement of a process-based N model (SPACSYS). This improved model will ultimately contribute to rankings of management practices that can result in the greatest reduction in N losses, over a wide range of soil and climate conditions common in the province.

SPACSYS is a multi-dimensional, field scale, weather-driven dynamic simulation model of C and N cycling between plants, soils and microbes, which operates with a daily time-step. It includes a plant growth component; an N and C cycling component; a water component, which incorporates representation of water flow to field drains as well as downward through the soil layers; and an energy component. To be implemented and applied to real scenarios and hypothesis-testing, the model needs to be calibrated and validated to ensure reliability. With that purpose, during 2014 we have compiled data obtained through previous field experiments involving 4R Nutrient Stewardship from Dr. C. Wagner-Riddle and Dr. C.F. Drury. A postdoctoral researcher (funded through OMAF-U of Guelph Partnership) has been analyzing and formatting the data to be used for SPACSYS calibration and validation. In order to characterize actual on-farm practices (e.g. rate, timing and method of application) used by corn producers, a co-op student has been hired for the January to April 2015 term. Simulations employing the calibrated and validated model will be carried out during 2015 providing the first regional-scale quantitative analysis of the 4Rs' effectiveness to reduce N losses.

Nitrogen deficient *corn leaf.*

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EVALUATING THE 4R NUTRIENT STEWARDSHIP CONCEPT AND CERTIFICATION PROGRAM IN THE WESTERN LAKE ERIE BASINE

PRINCIPAL INVESTIGATOR: Kevin King, USDA-ARS, Soil Drainage Research Unit, Columbus, OH; Kevin.King@ARS.USDA.GOV

IPNI RESEARCH DATABASE:
http://research.ipni/net/project/IPNI-2014-USA-4RN09

Since the mid 1990s, soluble phosphorus (P) entering Lake Erie has shown an increasing trend, as have the frequency and severity of nuisance and harmful algal blooms. Evidence indicates that a considerable proportion of this soluble P comes from cropland. The 4R principles of nutrient stewardship have been promoted in the western Lake Erie basin (WLEB) and adoption is "catching on." This multi-disciplinary research project, initiated in July 2014, aims to understand and quantify the water quality benefits of the 4R program.

Three WLEB sites are being instrumented for combined surface and subsurface edge-of-field monitoring from paired fields where management practices can be compared. A recent observation, from a paired site near the WLEB, showed a five-fold reduction in dissolved P loss in tile drain discharge resulting from incorporation of P fertilizer that was surface applied in early May. Available data from the Heidelberg University tributary program will be analyzed using a regression approach to assess impact of watershed practices. SWAT models for the Maumee, Sandusky, and Cedar-Portage watersheds are being set up to assess the watershed-scale impacts of 4R adoption. The Western Lake Erie Ecosystem Model was populated to evaluate the impact of proposed 4R activities in the Maumee watershed on 2011-14 *Microcystis* blooms.

Funding from the Mosaic Foundation and The Nature Conservancy is being leveraged for a triple bottom line assessment of the 4R program. To date, two undergraduate research assistants have been hired to develop timelines and summaries of key activities and to begin organizing data from a 2014 survey of Maumee farmers concerning cultivation and tillage practices conducted as part of an Ohio State University NSF project. Working with the Ohio Agri-Business Association, a survey of nutrient service providers participating in the 4R certification program has been developed. The project also helped survey, after a highly publicized drinking water advisory, Ohio residents' willingness to pay to reduce harmful algal blooms in Lake Erie.

(continued)

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The outreach component of the project has been accomplished through popular press and news releases and two websites (http://4rcertified.org/research/ and http://research.ipni.net/project/IPNI-2014-USA-4RN09) In addition, the 4R research project has been referenced and discussed in at least a dozen recent meetings and workshops.

Over the coming five years, it is anticipated that this project will lead producers to better understanding and adoption of practices that support their crop productivity goals while reducing loss of dissolved P, and enable the industry to communicate quantified benefits to those concerned about Lake Erie water quality.

PRINCIPAL INVESTIGATOR:

Kevin King

USDA-ARS
Columbus, OH

RESEARCH ASSOCIATES

Tom Bruulsema
International Plant Nutrition Institute, Guelph, ON

Rem Confessor
Heidelberg University
Tiffin, OH

Joe DePinto
LimnoTech
Ann Arbor, MI

Laura Johnson
Heidelberg University
Tiffin, OH

Greg LaBarge
Ohio State University Extension
Marion, OH

Todd Redder
LimnoTech
Ann Arbor, MI

Brian Roe
Ohio State University
Columbus, OH

Doug Smith
USDA-ARS
Temple, TX

Carrie Vollmer-Sanders
The Nature Conservancy
Angola, IN

Mark Williams
USDA-ARS
Columbus, OH

Robyn Wilson
Ohio State University
Columbus, OH

IMPACTS OF 4R NITROGEN MANAGEMENT ON CROP PRODUCTION AND NITRATE-NITROGEN LOSS IN TILE DRAINAGE

CO-PRINCIPAL INVESTIGATORS: Matthew Helmers (mhelmers@iastate.edu), and John Sawyer (jsawyer@iastate.edu), Iowa State University, Ames, IA.

IPNI Research Database:
http://research.ipni/net/project/IPNI-2014-USA-4RN16

In addition to local impacts on surface and groundwater quality, nitrogen (N) and phosphorus (P) loads from the U.S. Corn Belt are suspected as primary drivers of hypoxia in the Gulf of Mexico. Based on the need for nitrate-N reductions to meet water quality goals, new agricultural management practices are needed that have the potential to significantly reduce nitrate-N losses at minimal cost or even provide economic benefit to farm operations. This three year, field research and demonstration project is designed to evaluate various promising N management methods and technologies by documenting the nitrate-N in tile flow and crop yield from several practices and systems. The project is just getting under way, beginning on January 1, 2015 and running through December 31, 2017.

As part of this project we are evaluating various N management practices, including: 1) no N; 2) fall-applied anhydrous ammonia with nitrapyrin (135 lb N/A); 3) spring-applied anhydrous ammonia (135 lb N/A); and 4) sidedress N application with 40 lb N/A as urea ammonium nitrate (UAN) at planting plus an in-season adjusted rate. The treatments include a corn-soybean rotation with each phase of the rotation present each year. Each treatment is replicated four times. The objectives are to 1) determine the effects of N fertilizer application timing on nitrate-N leaching losses through tile flow in each crop phase; 2) determine the effects of N fertilizer application timing on crop yield; and 3) disseminate project findings through peer-reviewed journal articles, research farm reports, Extension and Outreach fact sheets and presentations, and other outlets as appropriate. Results will assist in the on-going review and adjustment of the Iowa Nutrient Reduction Strategy Science Assessment.

The study is located in northwest Iowa (O'Brien County). A tile drainage system was installed with funding from the Iowa State University Department of Agronomy Endowment in 2013 on a field area with no previous tile drainage (**Figure 1**). The site has 32 individual subsurface drained plots for drainage water quantity and quality evaluation.

(continued)

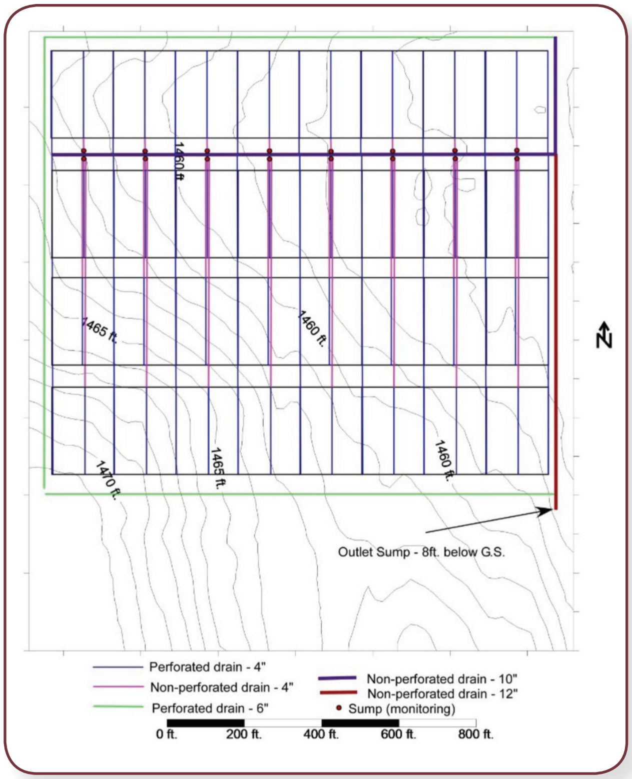

Figure 1. Subsurface drainage layout for study site.

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In 2014, the site was uniformly cropped in preparation for treatment implementation for the 2015 growing season. In 2014, all tile-flow monitoring equipment was installed on all plots and are ready for monitoring in the spring 2015.

Drainage lines from individual plots are directed to separate sumps within culverts (**Figure 2**). Drainage water is pumped through plastic plumbing fitted with a common plated sprayer orifice nozzle and a water meter (**Figure 3**). Back pressure created by the meter forces a small constant fraction of all drainage to be diverted to a sampling bottle so that a flow-proportional water sample is collected. The flow meters are connected to a data logger so flow volumes can be quantified. Subsamples from the sample bottle are collected to quantify nitrate-N and P concentrations. Based on the nutrient concentration of the water sample, and the volume of water during the period from when water was collected, a mass of nutrient in tile flow will be computed. In addition to sampling and quantifying nutrient loss we will also document crop yield for each treatment. Grain samples will be collected at harvest and will be analyzed for N to evaluate N export with the grain and to assess N use efficiency by N inputs, nitrate-N outputs, and N outputs with grain.

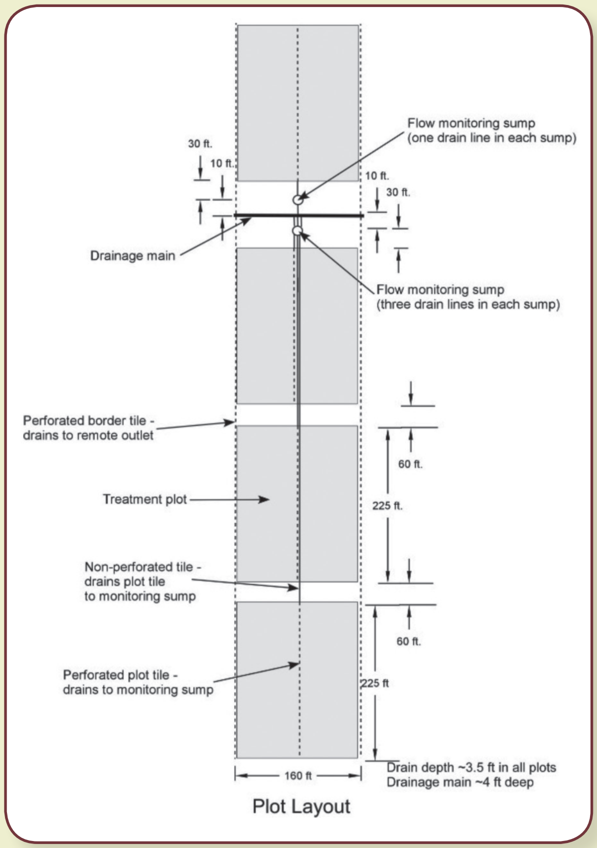

Figure 2. Subsurface drainage layout for four plots.

Figure 3. Example of flow monitoring system.

SUPPLEMENTAL LATE-VEGETATIVE NITROGEN APPLICATIONS FOR HIGH-YIELD CORN: AGRONOMIC, ECONOMIC AND ENVIRONMENTAL IMPLICATIONS WITH MODERN VERSUS OLDER HYBRIDS

PRINCIPAL INVESTIGATOR: Tony Vyn, Purdue University, Department of Agronomy, West Lafayette, IN; tvyn@purdue.edu

IPNI Research Database:

http://research.ipni/net/project/IPNI-2014-USA-4RN25

It has been proposed that modern hybrids continue to accumulate nitrogen (N) longer into the growing season, and for this reason it would be beneficial to ensure soil mineral N availability by way of intentional supplemental, late-season (e.g., V12 to V14) N application. In 2014 (the first year of this experiment), we began working toward answering the questions: (1) Are modern hybrids more likely to respond to intentionally very late-vegetative N applications than hybrids of 20 years ago? and (2) What are the physiological reasons for these differences if the modern hybrids are more responsive? To this end, we compared four hybrids across six N rate and timing combinations. The hybrids included two modern (P1360 and P1498) and two released in the early-mid 1990s (Pioneer hybrids 3335 and 3394). The N rates (0, 140, 180, and 220 lb N/A in addition to a starter N application of 25 lb N/A) were either applied only at V3 or split between V3 and a 40 lb/A application at the V13 stage.

The 2014 weather was characterized by cool temperatures and ample precipitation in Indiana. We had excellent population establishment and short anthesis-silking intervals during flowering. Additionally, the plants retained their leaf area index (LAI) long into their reproductive stages; both LAI and leaf chlorophyll (SPAD) for all hybrids persisted into R4, with the exception of the 0N plots. P1498 consistently had a significantly higher LAI throughout the reproductive stages. P1360 was significantly lower in SPAD readings. The modern hybrids had significantly higher total biomass accumulation at R1, and the leaf to stem ratio did not differ across the four hybrids.

As would be expected, average yields with the two modern hybrids were about 40 bu/A higher. P1498 was the only hybrid with a significant hybrid x N treatment interaction for final grain yield; the late-split N treatments (180L and 220L) were the highest yielding. For that hybrid, corn yields increased from 207 to 215 bu/A when the V3 sidedress N rate increased from 140 to 180 lb, but corn yields were even higher (233 bu/A) when the 140 sidedress was followed by a 40 lb N application at V13. We have yet to complete the R6 stage N analyses and N efficiency calculations.

MINIMIZING PHOSPHORUS LOSS WITH 4R NUTRIENT STEWARDSHIP AND COVER CROPS

PRINCIPAL INVESTIGATOR: Nathan Nelson, Kansas State University, Department of Agronomy, Manhattan, KS; nonelson@ksu.edu

IPNI Research Database:

http://research.ipni/net/project/IPNI-2014-USA-4RN26

The overall objective of this research is to determine how interactions between cover crops and phosphorus (P) fertilizer management impact P loss, P use efficiency, crop yield, and net return. A replicated small watershed study at the Kansas Agricultural Watershed Field Laboratory near Manhattan, Kansas has been established to achieve the objectives. The study consists of 18 small watersheds (1.2 to 1.5 A each) equipped with automated runoff monitoring equipment. The following treatments will be applied: 1) no P fertilizer, no cover crop, 2) no P fertilizer, with cover crop, 3) fall broadcast P, no cover crop, 4) fall broadcast P, with cover crop, 5) spring injected P, no cover crop, and 6) spring injected P, with cover crop. The site has a history of a conventionally tilled wheat-soybean rotation, but for this study a no-till corn-soybean rotation will be adopted, with first planting in the spring of 2015. There are no results to report to date since most efforts gone into site preparation, and there have not yet been runoff events.

The summer of 2014 was spent reconstructing terraces, re-grading channels, constructing waterways, and installing pipe outlets to segment the research site into the 18 small watersheds. During the summer and fall each watershed outlet was equipped with a 1.5 ft. H-flume permanently mounted on a concrete pad equipped with an automated water sampler, bubble-type pressure transducer, data logger, batteries, and solar panel for continuous measurement of runoff and automated collection of water samples. Fall soil sampling across the watersheds indicated that soil test P concentrations ranged from 15 to 19 ppm, all below the critical value of 20 ppm (Mehlich 3). Soil pH ranged from 5.9 to 6.2. Lime was applied and incorporated to adjust the soil pH to the 6.0 to 6.5 range.

After site construction and preparation was completed, a cover crop (hairy vetch, rapeseed and winter wheat) was planted in appropriate watersheds, after which broadcast P fertilizer was applied. Cover crop biomass and nutrient uptake will be measured at the time of termination. Corn will be planted following cover crop termination in April, at which time the remaining fertilizer treatments will be applied. This project is planned to run through the end of 2019.