4R NUTRIENT STEWARDSHIP:

2010-2013 Science Cluster Report

CANADIAN FERTILIZER INSTITUTE
INSTITUT CANADIEN DES ENGRAIS

4R nutrient stewardship

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The Canadian fertilizer industry supports funding under the Science Cluster program as part of their continuing efforts to help reduce Greenhouse Gas (GHG) emissions at their facilities and among their farmer customers. In 2010, Canadian Fertilizer Institute (CFI) funded research investigating and measuring the impact of Best Management Practices (BMPs) under 4R Nutrient Stewardship — Right Source @ Right Rate, Right Time, Right Place® — on nitrous oxide (N_2O) emissions in crop production. The 4Rs is a science-based framework that promotes economic, social, and environmental sustainability on the farm by considering collectively the source, rate, time, and place practices for fertilizer and other crop nutrients. These practices are supported by scientific principles and research. Comprised of four leading researchers across Canada, the Science Cluster aims to provide this scientific understanding to better inform growers of the BMPs they should consider when making nutrient management decisions on the farm and, in turn, use their fertilizer more efficiently. This work will also help inform the Nitrous Oxide Emissions Reduction Protocol (NERP). The NERP was approved in the fall of 2010 for use in the province of Alberta and work is underway to have it accepted in the Saskatchewan and Ontario offset systems.The protocol will allow farmers in Alberta, and eventually other provinces, to receive offset payments by adopting best management practices for the application of nitrogen fertilizers. Because the science on N_2O emissions is complex, the protocol has been conservative in estimating the potential GHG reductions.

The following is a short summary of work on each Science Cluster research project and findings. Full reports of the research projects are available in Appendix A.

Activity 1 — Nitrous oxide emissions from corn as affected by timing and rate of nitrogen fertilizer application

Principal Investigator: Claudia Wagner-Riddle, University of Guelph

Overall Objective: To provide Ontario-specific GHG reduction factors for BMP incentive development and adoption by Ontario farmers.

Background: N_2O emissions are estimated to comprise the most important source of GHG emissions associated with growing corn. Applying nitrogen fertilizer at a rate and time to match corn needs are considered management practices that can lead to significant reductions of on-farm GHG emissions. However, additional research is needed to quantify the magnitude of N_2O emission reduction associated with these practices. The research proposed here addresses this knowledge gap by providing measurements of N_2O emissions from corn in a comprehensive field trial designed to evaluate the long-term effects of timing and rate of fertilizer N on grain corn yield potential. This project complements on-going research on the environmental footprint of corn and life-cycle analysis of corn residue as feedstock for bioenergy.

Summary of work: Highest N_2O emissions induced by nitrogen fertilizer application typically occur in April or May when soil moisture is relatively high and corn N uptake low. This effect was observed in both study years. Difference between study years were also observed with the growing season of 2011 being significantly wetter than 2012, and soil water conditions significantly higher after planting compared to the eighth leaf stage in 2012. As a result, emissions were larger in 2011 compared to 2013 (Fig. 3). Delaying N application to V8 stage (4R) and applying the recommended rate (145 kg N ha-1; 4R) significantly reduced N_2O emissions in 2011, though no significant effect was observed in 2012 (Fig. 3). Overall, delaying the bulk of N fertilizer application until the V8 stage (4R) reduced N_2O emissions by 58 per cent in a typical wet spring. The highest N rate (218 kg N ha-1) increased grain yield by only six per cent but N_2O emissions by 64 per cent, revealing the importance of using appropriate N rate (4R) (Fig. 4). Corn grain yield was not significantly different between the side-dress timing of fertilizer application in both years (Fig. 4). Matching amount and timing of application to crop uptake, an integral part of the 4R Nutrient Stewardship program, has the potential to significantly reduce N_2O emissions under typical Ontario early growing season conditions.

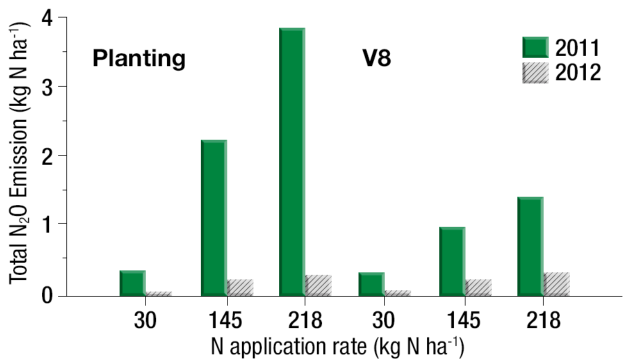

Fig. 3: Total nitrous oxide emissions over two growing seasons according to timing and rate of nitrogen fertilizer application. Values were averaged for the two history treatments as no significant effect was observed.

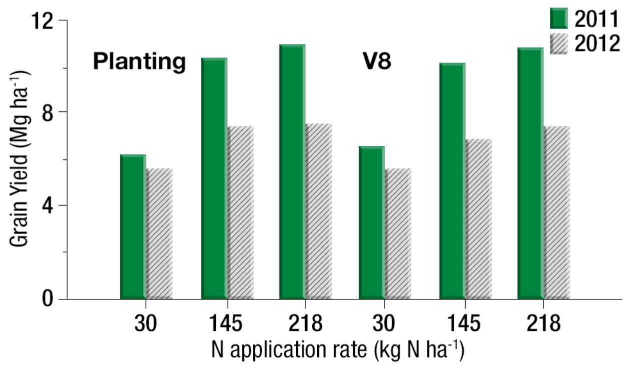

Fig. 4: Corn grain yield over two growing seasons according to timing and rate of nitrogen fertilizer application. Values were averaged for the two history treatments as no significant effect was observed.

Activity 2 — Determining Manitoba-based reduction modifiers for the Nitrous Oxide Emission Reduction Program (NERP)

Principal Investigator: Mario Tenuta, University of Manitoba

Overall Objective: To provide Manitoba-specific GHG reduction factors for BMP incentive development and adoption by Manitoba farmers.

Background: Dr. Tenuta's study comprised of three activities using Manitoba field trials to determine nitrous oxide emission reduction factors for the following beneficial management practices:

1. *Fall versus spring anhydrous ammonia application (Fall vs. Spring study)*

   The trial was located at the Trace Gas Manitoba Research Site (TGAS MAN) at the Glenlea Research Station, University of Manitoba, approximately 16 km south of Winnipeg. The research site was situated in the Red River Valley, a near-level, glaciolacustrine clay floodplain. The soils at the site were of the Red River association, consisting of a combination of Osborne and Red River series. The soils are classified as Gleyed Humic Vertisols (Canadian System).

   The work was conducted in conjunction with existing infrastructure of plots and the greenhouse gas measurement instrument at the site. Treatments consisted of fall versus spring application of anhydrous ammonia for spring wheat in 2011 and corn in 2012. The trial started in fall 2010 with anhydrous application. Application occurred to separate four ha plots for the fall and spring anhydrous treatment. 100 and 160 kg N ha^{-1} were applied for spring wheat and corn, respectively, using farm-scale equipment. Allocations of treatments were switched in the two years so the fall 2010 treatment became the spring 2012 treatment, whereas the spring 2011 treatment became the fall 2011 treatment.

2. *Soil test nitrogen and most economical rate of nitrogen application (N Rate study)*

   The trial was conducted at the Canada Manitoba Crop Diversification Centre near Carberry, Manitoba. This study was part of a three-year field study, from 2008 to 2010, that evaluated N dynamics in irrigated potato systems as influenced by cultivar and N fertilizer rate (Mohr et al. 2009). The study site was at the Canada-Manitoba Crop Diversification Centre (CMCDC) (49°54'N, 99°21W) in Carberry, Manitoba. The existing field experiments in 2009 and 2010 were used in the current study.

   Monitoring of N_2O emissions was conducted only in plots planted to the Russet Burbank cultivar, the most commonly grown cultivar in Manitoba for processing potato into French fries and patties. The soil at the experimental sites is a clay loam soil in the Wellwood series being classified as an Orthic Black Chernozem.

   Fertilizer N treatments included an unfertilized check (control) and application rates of 80, 160, and 240 kg N ha^{-1} as broadcast-incorporated urea, which was applied as a split application with 50 per cent just prior to planting and 50 per cent at hilling. Other agronomic management followed practices appropriate for the local area potato production.

3. *Banded versus broadcast-incorporation urea and enhanced efficiency fertilizer application (Placement study).*

   A study was conducted on two sites, Oak Bluff and Carman, comparing placement and source of urea on emissions from soil planted to hard spring wheat. The experiment was initiated in spring 2011. The treatments compare placement of urea as broadcast, side-band and mid-row bands. Also, treatments compared mid-row band placement of sources of urea (urea, SuperU and ESN).

Summary of work:

Summary of findings for the three studies regarding impact of 4R practices on N_2O emissions are found in the table below.

(Note: Some site years listed 'to be completed' because gas soil and plant samples were collected after project close in July 2012)

Ojective	Trial Name	Site Years	Results	Follow Up
Fall vs. Spring	TGAS MAN	2	36 per cent reduction in emissions with late fall than spring application	Examine if inhibitors can further reduce emissions from late fall application
N Rate	Potato N Rate	2	Emissions increased linearly with rate and not related to yield	none
Placement	Red River Placement	2(2)	Banding reduced emissions (side 24 per cent, mid 43 per cent) with ESN and SuperU mid-banded most reducing emissions (74 per cent) to broadcast incorporation	Complete analysis (>July 2012) for one site
Placement	Potato Placement	1(1)	Reductions: 24 per cent banding urea, 47 per cent banding ESN. ESN broadcast incorporated no effect	Complete analysis (>July 2012) for one site
Placement	Potato N Strategy	1(1)	Conventional split urea lower emissions than single or fertigation treatments	Complete analysis (>July 2012) for one site

Activity 3 — Magnitude and significance of the N_2O priming effect associated with long-term applications of manure

Principal Investigator: Richard Farrell, University of Saskatchewan

Overall Objective: To provide Saskatchewan-specific GHG reduction factors for BMP incentive development and adoption by Saskatchewan farmers.

Background: The present study was established to examine how long-term applications of manure affected the soil microbial community and whether this would lead to a potential "priming effect" that could result in increased N_2O emission after a more readily available N source (urea) is applied. The specific objectives of the study were to:

i. monitor N_2O emissions over the course of multiple growing seasons in order to quantify N_2O emissions from plots with a long-term history of manure application;

ii. examine how microbial community structure and abundance were impacted by long-term manure applications; and

iii. assess the link between soil microbial community abundance and/or activity and N_2O emissions.

Summary of findings

Data from the 2013-14 reporting period, together with those obtained during 2011 and 2012, demonstrate that soil environmental conditions and soil management practice can have a profound impact on the total N_2O emissions associated with crop production. Long-term applications of liquid swine manure and, to a lesser extent, solid cattle manure can, at high application rates, impact the soil microbial community and cause a "priming effect" that can exacerbate fertilizer-induced N_2O emissions from agricultural soils. The data also indicates that denitrification enzyme activity is a good predictor of the priming effect and the potential for enhanced N_2O emissions. N_2O flux measurements are seen in figures A1 and A2.

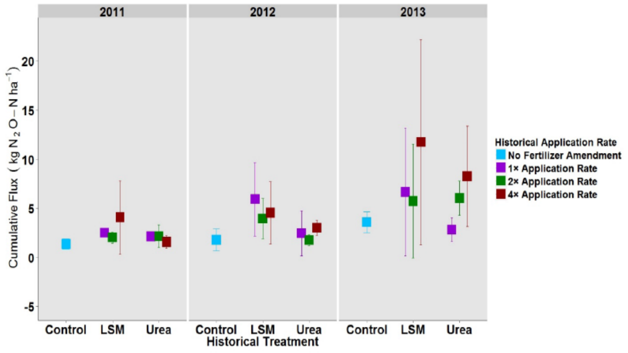

Fig. A1. Cumulative N_2O flux for the yearly historically applied liquid swine manure (LSM) plots for the 2011, 2012, and 2013 growing seasons.

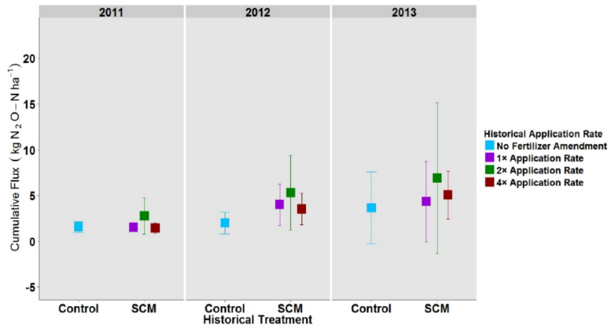

Fig. A2. Cumulative N_2O flux for the yearly historically applied solid cattle manure (SCM) plots for the 2011, 2012, and 2013 growing seasons.

Activity 4 — Nutrient Supply and GHG Emissions from a S-deficient Soil as a Function of Fertilization History

Principal Investigator: Miles Dyck, University of Alberta

Overall Objective: The objectives of Dr.Dyck's study were two-fold:

a. Quantify potential nutrient supply and GHGs production potential as a function of fertilization history and added fertilizer N and sulphur (S); and

b. Investigate and quantify N and S fertilizers interaction with respect to soil nutrient (plant available N and S) availability and GHG (N_2O) emission on sulfur-deficient soils collected at the University of Alberta Breton Plots with different long-term fertilization histories.

Background: This research investigates the interaction of both S and N fertilization with respect to fertilization history on an S-deficient soil on N_2O emission and nutrient supply (N and S) through field and laboratory experiments. Furthermore, a better understanding of the N and S fertilizer interactions with respect to nutrient supply/availability and N_2O emissions in sulfur deficient soils will help to contribute to knowledge needed to adopt the good fertilizer management practices that mitigate inefficient use of fertilizers, deleterious environmental effects, and mitigation of N_2O emission associated with fertilizers.

It was hypothesised the interaction between N and S transformation processes in the tested soils would decrease the N_2O emissions.

Summary of findings

4R/NERP Principle and application of results from this research:

Right Source

1. In soils where nitrifier denitrification is the main N_2O production process, the banding of elemental S with ammonium-based fertilizers may help to reduce nitrous

oxide emissions because S-oxidizing bacteria can use nitrite as an electron acceptor and the end result is N2 instead of N_2O. This process was not directly observed in this research, though it has been observed in other systems, such as wastewater treatment systems and estuarine environments, and is a hypothesis generated by the observations from this research that soils with long-term NPKS fertilization had 5–20% lower N_2O-N emissions than soils with long-term NPK or PKS fertilization. This result also demonstrates the importance of long-term balanced fertilization on residual soil nutrient levels. If this hypothesized N-S interaction is active, soil fertilizer N is still lost to the environment in a more benign form (i.e., N fertilization use efficiency is not likely to be increased).

2. This research observed that soils with low pH (acidic) had significantly greater N_2O emissions than soils with higher pH. At the Breton plots, cumulative growing season emissions increased by 5 kg N_2O-N/ha for every 1.0 decrease in pH. Liming is recommended to maintain soil pH above 6.0.

3. Ammonia-based fertilizers are recommended because they are less susceptible to leaching. However, this research showed that in soils where the dominant N_2O production process is nitrifier denitrification, ammonia-based fertilizers may not be the right product because oxidation of ammonium produces nitrite which is the precursor of nitrous oxide production in this process. The use of nitrification inhibitors might help to significantly N_2O emissions where nitrifier denitrification is the main N_2O production process.

Right Rate

This research showed that high levels of residual N from previous years can significantly increase nitrous oxide fluxes at Breton. This was shown by the observation that N_2O fluxes in wheat following two years of alfalfa-brome in the WOBHH rotation were up to three times greater than the wheat-fallow rotation despite a much lower N fertilizer application rate (50 kg N/ha for WOBHH; 90 kg N/ha for WF). Even though N fertilizer is not applied in the hay phase of this rotation, alfalfa contributes to increased N levels in the soil through N-fixation and through N-rich residues which are ploughed under prior to seeding annual crops. Coupled with applications of N fertilizer to subsequent annual crops, it would appear that this rotation has resulted in the accumulation of excess residual N over the long-term.

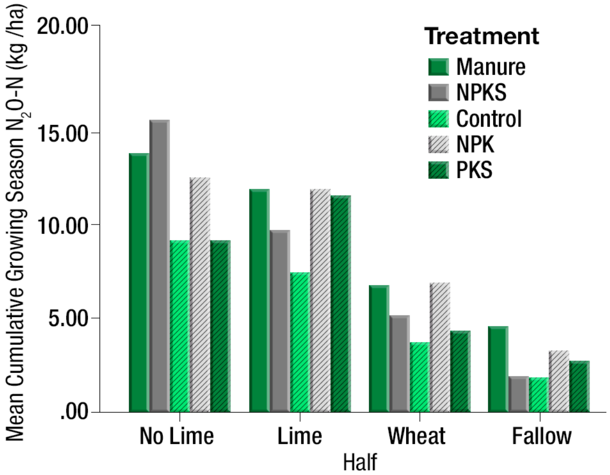

Figure 7: Summary of cumulative N_2O emissions in the 2013 growing season on selected treatments of the Breton Classical Plots.

In order to avoid excess residual N, fertilizer N recommendations appropriate for the crops in the rotation based soil tests are recommended.

Right Time and Right Place

This research observed that significant losses of N fertilizer to N_2O can occur following application if fertilizer is broadcast and incorporated especially in acidic soils. The method for fertilizer applications at the Breton Plots is to broadcast and incorporate with tillage prior to spring seeding. This application of N fertilizer to moist soil followed by tillage increases soil oxygen levels, soil temperature, and microbial activity. As a result, the urea N fertilizer is quickly transformed to ammonium which is then oxidized to nitrite which is susceptible to nitrifier denitrification. Nitrous oxide losses were greater in soils with low pH.

Banding N fertilizer in the spring or late fall slows down the transformation of N fertilizers because the soil is not disturbed to the same extent during banding compared to incorporation with tillage. Banding fertilizers decreased N_2O emissions.