Nitrogen Fertilizer Management to Mitigate N₂O Emissions in Alberta

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Acknowledgements


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The Nitrogen Cycle

Atmospheric Nitrogen Fixation

Animal Manures and Biosolids

Biological Fixation By Legume Plants

Organic and Microbial Nitrogen

Ammonium $\text{NH}_4^+$

Nitrate $\text{NO}_3^-$

Crop Harvest

Volatilization $\text{NH}_3$

Industrial Fixation (Commercial Fertilizers)

Crop Harvest

Plant Residues

Plant Uptake

Ammonium $\text{NH}_4^+$

Nitrate $\text{NO}_3^-$

Leaching

Denitrification

Runoff and Erosion

Input

Loss

Component

Adapted from IPNI
Nitrogen Losses

- N-Cycle is open ended with many pathways for inputs and losses; control is difficult
- Large amounts of surplus reactive N (NH₃, NH₄⁺, NOₓ, HNO₃, NO₃, N₂O and organic N forms)
- Volatilization, leaching, runoff, denitification

Source: Manitoba Agriculture, Food and Rural Initiatives
N$_2$O Concerns

- A significant greenhouse gas
  - GWP - 296 – 310 times greater than CO$_2$
  - Ozone depleting agent

- Indicator of inefficiencies in N recovery from soil and fertilizer.

- Limiting N$_2$O emissions from farming operations can be beneficial from both an environmental as well as an agronomic standpoint.

- IPCC established values to calculate direct N$_2$O emissions from fertilizer N use in various parts of the world - 1.25%.
Synchronizing Available N and Crop Uptake

- Low N recoveries by crops, i.e., low NUEs,
  - Quick nutrient release characteristics of common fertilizers
  - Nonresponsive to changes in soil water and temperature (factors regulating plant growth)
  - Not coinciding with crop growth peak demands

- The gradual release of ammonium from controlled release N fertilizers provides a slow stream of nitrogen for plant uptake, and minimize N losses.
Nitrogen Fertilizer Use

Fertilizer Nitrogen Sales for Alberta 1946 - 2005
Management Options to Improve Nitrogen Use Efficiency

- Crop selection
  - Legumes vs non-legumes

- Crop breeding
  - Improve NUE

- Fertilizer management
  - Implement N BMPs, “4R Nutrient Stewardship”
    - Timing, placement, rates and sources

- Use enhanced efficiency fertilizers (EEF) with improved characteristics:
  - Single application for the entire growing season
  - High percentage uptake into the target crop
  - Minimum detrimental effects on environment
ESN is a polymer-coated urea (PCU) fertilizer

Moisture and Temperature Controlled

Adapted from "Olson-Rutz et al., 2009. Enhanced Efficiency Fertilizers (EB0188), Montana State Univ. Extension" Schematic adapted from Agrium U.S., Inc. (Photos courtesy of Agrium U.S., Inc. All rights reserved.)
Collaborative 5 year study 2008-2012:

- AARD
  - ESD (Land Use)
  - RAID (Food & Bio-Industrial Crops)
- AAFC – Lacombe, Beaverlodge
- Agrium
- ACIDF
Project Objectives

- Evaluate agronomic performance of urea, ESN and blend, for crop growth, yield and quality, based on 4R nutrient management system “Right Product @ Right Rate, Right Time, Right Place™”
- Identify appropriate use of ESN, urea or blend (spring versus fall application, soil moisture conditions, agro-climatic regions and crop).
- Identify agronomic rate limits of ESN, urea and blend application to reduce seedling damage.
- Determine economic optimum rates, placement and timing of ESN, urea and blend application.
- Evaluate N fertilizer management to mitigate N₂O emissions
- Update provincial N fertilizer management recommendations and the AFFIRM software.
Study crop productivity, crop quality, maximum safe fertilizer rates, and N use efficiency:

- Compare effectiveness of N fertilizer sources - urea, ESN and blend (25% urea-75% ESN).
- Compare N fertilizer application time/placement - Fall Banded (FB), Spring Banded (SB), Spring Seed-Placed (SP) of urea and ESN - Spring Seed-Placed (SP) blend
- Crop response to increasing N fertilizer application rates (0, 30, 60, 90, 120 kg/ha).
- 3 Crops (HRS Wheat, 2R Barley and RR Canola)
Agronomic Research Locations

- 9 sites across Alberta
  - 8 dryland & 1 irrigated

- Range of agro-ecological regions with various soil types and climatic regimes

- Continuously cropped or stubble fields
- Determine $N_2O$ emissions reduction from timing, rates and nitrogen fertilizer products (urea and ESN).

- 3 sites for $N_2O$ monitoring
  - 2 dryland & 1 irrigated
  - Dark Gray Luvisol
  - Black Chernozem
  - Dark Brown Chernozem
Evaluate N fertilizer management options to mitigate N$_2$O emissions:

- Compare effectiveness of N fertilizer sources - urea, ESN.
- Compare N fertilizer application time - Fall Banded (FB), Spring Banded (SB),
- Compare N fertilizer application rates - 0, 60, 120 kg/ha
- 1 Crop - 2R Barley
Sampling Equipment & Protocol

- **Gas Sampling**
  - Plexiglas vented chambers (0.1 m² soil surface area and 10-L headspace volume); 20 ml syringes and # 20 needles; 10 ml evacuated exetainers (stored in a Cooler)
  - Sampling using a time step method - samples taken 15, 30 and 45 minutes after placing the cover on the chamber; ambient air samples are considered as samples at time 0

- **Lab Analysis**
  - Gas Chromatograph (Varian 3800 with ECD)

- **Sampling Schedule**
  - Fall to fall (October – October) – fall fertilizer application
  - Spring to spring (May – May) – spring fertilizer application

- **Sampling Frequency**
  - Weekly
  - High moisture events

- **Data Processing**
  - Excel spreadsheet calculator - Dr Richard Farrell (U of S)
  - Calculator tests both linear and quadratic models for fit of the time step concentration data.
## Meteorological Summary

### Total Growing Season (May-September) Precipitation/Irrigation (mm)

<table>
<thead>
<tr>
<th>Year</th>
<th>Dark Gray Luvisol</th>
<th>Black Chernozem</th>
<th>Irrigated Dark Brown Chernozem*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>220.4</td>
<td>297.2</td>
<td>524.8</td>
</tr>
<tr>
<td>2009</td>
<td>157.7</td>
<td>208.3</td>
<td>423.8</td>
</tr>
<tr>
<td>2010</td>
<td>293.1</td>
<td>457.6</td>
<td>456.2</td>
</tr>
<tr>
<td>2011</td>
<td>265.2</td>
<td>387.5</td>
<td>328.3</td>
</tr>
<tr>
<td>2012</td>
<td>257.3</td>
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<td></td>
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</tbody>
</table>

* Precipitation + Irrigation
N$_2$O Monitoring Results
Irrigated Dark Brown, 2010
N₂O Monitoring Results
Dark Gray Luvisol, 2009

Fall Banded Treatments
- F-C-0
- F-E-120
- F-E-60
- F-U-120
- F-U-60

Spring Banded Treatments
- S-C-0
- S-E-120
- S-E-60
- S-U-120
- S-U-60

Chambers installed just after fall banding
No sampling over winter

Chambers installed just after spring banding and seeding

Cumulative N₂O Emissions (g N ha⁻¹)
N$_2$O Monitoring Results
Dark Gray Luvisol, 2010
Cumulative N$_2$O Emissions: Dark Gray Luvisol

- **Fall Urea**
  - Equation: $y = 0.0057x + 0.5102$
  - $R^2 = 0.98$
- **Fall ESN**
  - Equation: $y = 0.0047x + 0.5281$
  - $R^2 = 0.99$
- **Spring Urea**
  - Equation: $y = 0.0035x + 0.5092$
  - $R^2 = 0.93$
- **Spring ESN**
  - Equation: $y = 0.0033x + 0.5269$
  - $R^2 = 0.98$
Cumulative $\text{N}_2\text{O}$ Emissions: Black Chernozem

Cumulative $\text{N}_2\text{O}$ Emissions (kg ha$^{-1}$) vs. N Fertilizer Rate (kg ha$^{-1}$)

- **Fall Urea**
  - $y = 0.0074x + 0.7077$
  - $R^2 = 0.79$

- **Fall ESN**
  - $y = 0.005x + 0.8121$
  - $R^2 = 0.98$

- **Spring Urea**
  - $y = 0.0028x + 0.866$
  - $R^2 = 0.41$

- **Spring ESN**
  - $y = 0.0026x + 0.8504$
  - $R^2 = 0.44$
Cumulative $N_2O$ Emissions: Irrigated Dark Brown Chernozem

- **Fall Urea**
  - Equation: $y = 0.0086x + 0.739$
  - $R^2 = 0.84$

- **Fall ESN**
  - Equation: $y = 0.0072x + 0.7158$
  - $R^2 = 0.72$

- **Spring Urea**
  - Equation: $y = 0.0047x + 0.7099$
  - $R^2 = 0.92$

- **Spring ESN**
  - Equation: $y = 0.0022x + 0.7497$
  - $R^2 = 0.99$
## Fertilizer Induced Emission Factor $\text{EF}_{\text{annual}}$ (%)

<table>
<thead>
<tr>
<th>Appl'n Time</th>
<th>N Source</th>
<th>N Rate kg ha$^{-1}$</th>
<th>Dark Gray Luvisol</th>
<th>Black Chernozem</th>
<th>Irrigated Dark Brown Chernozem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>std err</td>
<td>ave</td>
</tr>
<tr>
<td>Fall</td>
<td>Urea</td>
<td>60</td>
<td>0.42</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>Fall</td>
<td>Urea</td>
<td>120</td>
<td>0.57</td>
<td>0.11</td>
<td>0.74</td>
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<tr>
<td>Fall</td>
<td>ESN</td>
<td>60</td>
<td>0.40</td>
<td>0.15</td>
<td>0.41</td>
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<tr>
<td>Fall</td>
<td>ESN</td>
<td>120</td>
<td>0.48</td>
<td>0.09</td>
<td>0.53</td>
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<tr>
<td>Spring</td>
<td>Urea</td>
<td>60</td>
<td>0.35</td>
<td>0.08</td>
<td>0.26</td>
</tr>
<tr>
<td>Spring</td>
<td>Urea</td>
<td>120</td>
<td>0.27</td>
<td>0.05</td>
<td>0.44</td>
</tr>
<tr>
<td>Spring</td>
<td>ESN</td>
<td>60</td>
<td>0.26</td>
<td>0.04</td>
<td>0.30</td>
</tr>
<tr>
<td>Spring</td>
<td>ESN</td>
<td>120</td>
<td>0.34</td>
<td>0.07</td>
<td>0.43</td>
</tr>
</tbody>
</table>
## N₂O Emission Mitigation Summary

### Impact of N fertilizer management change (%) on mitigation of N₂O emissions (2008 – 2012)

<table>
<thead>
<tr>
<th>Management Change</th>
<th>120 kg N ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave</td>
</tr>
<tr>
<td>Fall Urea → Fall ESN</td>
<td>-6.1</td>
</tr>
<tr>
<td>Fall Urea → Spring Urea</td>
<td>-18.0</td>
</tr>
<tr>
<td>Fall Urea → Spring ESN</td>
<td>-24.9</td>
</tr>
<tr>
<td>Fall ESN → Spring ESN</td>
<td>-16.6</td>
</tr>
<tr>
<td>Spring Urea → Fall ESN</td>
<td>39.4</td>
</tr>
<tr>
<td>Spring Urea → Spring ESN</td>
<td>-4.9</td>
</tr>
</tbody>
</table>

Positive average values indicate increased emissions; Negative average values indicate reduced emissions.
Summary

- Measured emission factor coefficients much lower than the 1.25% IPCC coefficient.
- Emissions are episodic with high spatial (regional) and temporal variability closely related to spring thaw, precipitation and irrigation events.
- Spring application of nitrogen fertilizer was the most effective means of reducing total emissions.
- Switching from fall applied nitrogen fertilizer to spring application results in 17% to 25% N\textsubscript{2}O emission reduction.
- Switching from fall applied urea to fall applied ESN results in 6% reduction.
- Changing from spring applied urea to spring applied ESN would result in a 5% reduction.
High rates of N fertilizer caused more nitrous oxide emissions compared to the low N rates.

Reduction in emissions was greater for high N treatments compared to the low N.

In general, the ESN product resulted in lower emissions than uncoated urea.

ESN could provide higher N use efficiency than uncoated urea, under similar conditions.

If economically viable, producers could use ESN as a potential alternative to urea for improved crop production and reducing $\text{N}_2\text{O}$ emissions.

Any disruption or reduction in crop N uptake during the growing season could result in higher emissions from the ESN or similar products.
Future Work

Current Data Set
- Soil mineral N
- Soil N mineralization from SOM
- Crop N uptake and NUE
- Yield response modeling
- AFFIRM update

Research Needs
- Fertilizer blends
- Split applications
- Variable rate
- Manure fertilizer blends
- Inhibitors
- Combining genetic, technological and management opportunities