Environmental and Agronomic Benefits of Enhanced Efficiency Nitrogen Fertilizers

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Why Nitrogen?

After water, N is the most limiting factor in crop production in Prairie Canada
- therefore, it is the nutrient applied in the greatest amount

Crop use of applied N is generally <100%
- in western Canada, NUE is ca. 50% for cereal crops
- for oilseed crops, NUE is generally considered to be “poor” (ca. 30–40%)

NUE tends to decrease as the amount of N applied increases
Why Nitrogen?

• Sustainability is now part of the marketing landscape
  • driven by consumer demand for “green” products

• Carbon (C) footprinting is an important component of any sustainability initiative
  • demand for carbon emissions labeling
  • requires emissions accounting throughout the supply chain

• For field crops (and agri-food products in general) nitrous oxide (N$_2$O) is an important component of the C footprint
Why Nitrogen?

Agriculturally important greenhouse gases

- carbon dioxide (CO₂); GWP* = 1 (t_r = 5-200 yr)
- methane (CH₄); GWP = 25 (t_r = ca. 12 yr)
- nitrous oxide (N₂O); GWP = 298 (t_r = ca. 114 yr)

*Global Warming Potential: a measure of the ability of each greenhouse gas to trap heat in the atmosphere relative to an equivalent mass of CO₂ (over a specified time period).

How do we manage N to achieve N₂O emission reductions?

Are agronomic and environmental goals at odds?
**N response curves**

(conceptual model)

![Graph showing N response curves](image)

- **Yield (bu ac⁻¹)**
- **N₂O emissions (g N ha⁻¹)**
- **N fertilizer applied (kg N ha⁻¹)**

Adapted from Luo et al. 2016

Environmental optimum

OEY

Max yield
What do we do?

Goal is to improve both the agronomic and environmental performance of cropping systems by increasing NUE

Synchronize N availability to crop demand

• nutrient requirements lower in early plant stages
• sufficient N required ca. 2-3 weeks after emergence

Research has shown that the adoption of BMPs can improve NUE by 10 to 20%

• apply 4R nutrient stewardship principles
4R Nutrient Stewardship

4Rs OF NUTRIENT STEWARDSHIP
Economically, Environmentally & Socially Sustainable Crop Nutrition

The 4Rs promote best management practices (BMPs) to achieve cropping system goals while minimizing field nutrient loss and maximizing crop uptake.

RIGHT SOURCE
Matches fertilizer type to crop needs.

RIGHT RATE
Matches amount of fertilizer to crop needs.

RIGHT TIME
Makes nutrients available when crops need them.

RIGHT PLACE
Keeps nutrients where crops can use them.

http://www.nutrientstewardship.com/4rs

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Enhanced Efficiency Fertilizers

- **Enhanced efficiency fertilizers (EEF)** are products that control the release of N, or alter reactions in the soil that lead to the formation of nitrate (NO$_3^-$)

  - physically slow the dissolution and release of urea by encasing the granule in a polymer or sulfur coating

  - alter the chemical formulation of the N source to decrease its solubility and slow entry into the N cycle (e.g., methylene urea, urea formaldehyde, isobutylidene diurea)

  - temporarily block microbial or enzymatic processes involved in the conversion of urea to ammonium (NH$_4^+$) or NH$_4^+$ to nitrate (NO$_3^-$)
Enhanced Efficiency Fertilizers

• **Slow- and controlled release fertilizers**
  - granular fertilizers encased in a coating (sulfur or polymer) that reduces the diffusion rate of the fertilizer from the granule
    - *sulfur-coated urea (SCU)*: the sulfur coating breaks down allowing the granule to slowly dissolve and diffuse out into the soil
    - *polymer-coated urea (PCU)*: a permeable coating that allows water to diffuse into the granule, creating a urea solution that diffuses through the membrane at a rate controlled by the polymer chemistry, thickness of the coating, and soil temperature

• **Stabilized fertilizers**
  - *urease inhibitors*: prevent or delay the hydrolysis of urea to ammoniacal N by inhibiting the activity of the urease enzyme
  - *nitrification inhibitors*: inhibit the activity of ammonia-oxidizing bacteria (*Nitrosomonas*) thereby delaying the oxidation of \( \text{NH}_4^+ \) to \( \text{NO}_3^- \)
How do they work?

Modes of action

1) polymer (or sulfur) coating to control (slow) release rate of urea;
2) urease inhibitors (UI) to block urea hydrolysis;
3) nitrification inhibitors (NI) to delay the sequential oxidation of ammonium ($\text{NH}_4^+$) to nitrate ($\text{NO}_3^-$).
Use of enhanced efficiency nitrogen fertilizers to reduce $\text{N}_2\text{O}$ emissions during wheat production

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Canada-Saskatchewan Irrigation Diversification Centre
## EENF Products

<table>
<thead>
<tr>
<th>N source</th>
<th>Mode of Action</th>
<th>ai†</th>
<th>ID</th>
<th>EENF</th>
<th>Manufacturer</th>
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<tbody>
<tr>
<td>Urea</td>
<td>Controlled release</td>
<td>PCU</td>
<td>ESN*</td>
<td></td>
<td>Nutrien‡</td>
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<tr>
<td>Urea</td>
<td>Dual-action urease inhibitors</td>
<td>NBPT &amp; NPPT</td>
<td>DUI</td>
<td>Limus*</td>
<td>BASF</td>
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<tr>
<td>Urea</td>
<td>Nitrification inhibitor</td>
<td>Nitrapyrin</td>
<td>NI</td>
<td>eNtrench™</td>
<td>Corteva Agriscience§</td>
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<tr>
<td>Urea</td>
<td>Urease + nitrification inhibitor</td>
<td>NBPT &amp; DCD</td>
<td>UNI</td>
<td>SuperU™</td>
<td>Koch Agronomic Services</td>
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<tr>
<td>AA</td>
<td>Nitrification inhibitor</td>
<td>Nitrapyrin</td>
<td>NI</td>
<td>N-Serve™</td>
<td>Corteva Agriscience</td>
</tr>
</tbody>
</table>

† Active ingredient: NBPT = N-(butyl) thiophosphoric acid triamide; NPPT = N-(propyl) thiophosphoric triamide; DCD = dicyandiamide.

‡ Formed when Agrium Inc. merged with PotashCorp of Saskatchewan (formerly Agrium).

§ Formed when Dow Chemical merged with DuPont Chemical (formerly Dow AgroSciences).
Climate data (Fall 2015 – Spring 2018)
Urea-derived $N_2O$
EEF-derived $\text{N}_2\text{O}$

- PCU
- U+NI
- NI
- UI

Date (mm-dd-yy)

N$_2$O flux (g N ha$^{-1}$ d$^{-1}$)
Fall applied N
(rainfed cropping)

2015/2016

Cumulative $N_2O$ emissions (g N ha$^{-1}$)

Fall N

Spring thaw

Growing season

DOY

DOY

DOY

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Fall applied N

(irrigated cropping)

2015/2016

Cumulative N₂O emissions (g N ha⁻¹)

- Fall N
- Spring thaw
- Growing season

DOY

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Spring applied N

( rainfed cropping )

2016/2017

Cumulative N$_2$O emissions (g N ha$^{-1}$)

- Check
- Urea
- PCU
- UI
- NI
- U+NI

Growing season

Spring thaw
Spring applied N

(irrigated cropping)

2016/2017

Cumulative N$_2$O emissions (g N ha$^{-1}$)

Growing season

Spring thaw

DOY

DOY

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Wheat yield (2016)

- Fall fertilizer application
- Spring fertilizer application

Seed Yield (Mg ha⁻¹)
# Emissions summary

<table>
<thead>
<tr>
<th>N source</th>
<th>EEF product</th>
<th>t-N₂O&lt;sup&gt;a b&lt;/sup&gt; (kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>FIE&lt;sup&gt;c&lt;/sup&gt; (kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>EF&lt;sup&gt;c&lt;/sup&gt; (%)</th>
<th>YSE&lt;sup&gt;c&lt;/sup&gt; (kg N Mg&lt;sup&gt;-1&lt;/sup&gt; grain)</th>
<th>t-N₂O&lt;sup&gt;a b&lt;/sup&gt; (kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>FIE&lt;sup&gt;c&lt;/sup&gt; (kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>EF&lt;sup&gt;c&lt;/sup&gt; (%)</th>
<th>YSE&lt;sup&gt;c&lt;/sup&gt; (kg N Mg&lt;sup&gt;-1&lt;/sup&gt; grain)</th>
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<tr>
<td><strong>Fall-applied fertilizer products</strong></td>
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<tr>
<td>Check (ON)</td>
<td>---</td>
<td>1.03 c</td>
<td>---</td>
<td>---</td>
<td>0.31 c</td>
<td>0.53 b</td>
<td>---</td>
<td>---</td>
<td>0.12 c</td>
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<tr>
<td>Urea</td>
<td>---</td>
<td>3.01 a</td>
<td>1.98 ab</td>
<td>1.60 ab</td>
<td>0.72 ab</td>
<td>1.95 a</td>
<td>1.42 a</td>
<td>1.44 a</td>
<td>0.33 b</td>
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<tr>
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<td>2.67 ab</td>
<td>1.64 ab</td>
<td>1.32 ab</td>
<td>0.64 abc</td>
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<td>Urea</td>
<td>UI</td>
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<td>Urea</td>
<td>U+NI</td>
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<td>0.99 b</td>
<td>0.82 b</td>
<td>0.52 bc</td>
<td>0.73 b</td>
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<td>0.20 b</td>
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<td><strong>2016-17</strong></td>
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<tr>
<td>Check (ON)</td>
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<td>---</td>
<td>---</td>
<td>0.11 c</td>
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<td>3.26 a</td>
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<td>2.38 a</td>
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<td>0.51 b</td>
<td>2.35 a</td>
<td>1.45 a</td>
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<td>UI</td>
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<td>0.38 c</td>
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<td>1.14 b</td>
<td>0.24 b</td>
<td>0.25 b</td>
<td>0.19 c</td>
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<tr>
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<td>NI</td>
<td>0.75 c</td>
<td>0.40 c</td>
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<td>1.01 b</td>
<td>0.12 b</td>
<td>0.12 b</td>
<td>0.19 c</td>
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<tr>
<td>Urea</td>
<td>U+NI</td>
<td>0.58 c</td>
<td>0.22 c</td>
<td>0.18 c</td>
<td>0.15 c</td>
<td>0.91 b</td>
<td>0.02 b</td>
<td>0.02 b</td>
<td>0.15 c</td>
</tr>
</tbody>
</table>

**Spring-applied fertilizer products**

| **2016-17** | | | | | | | | | |
| Check (ON) | --- | 0.35 c | --- | --- | 0.11 c | 0.90 b | --- | --- | 0.20 c |
| Urea | --- | 3.26 a | 2.91 a | 2.38 a | 0.81 a | 1.98 a | 1.08 a | 1.11 a | 0.33 b |
| Urea | PCU | 2.02 b | 1.66 b | 1.35 b | 0.51 b | 2.35 a | 1.45 a | 1.48 a | 0.44 a |
| Urea | UI | 0.84 c | 0.49 c | 0.38 c | 0.20 c | 1.14 b | 0.24 b | 0.25 b | 0.19 c |
| Urea | NI | 0.75 c | 0.40 c | 0.32 c | 0.19 c | 1.01 b | 0.12 b | 0.12 b | 0.19 c |
| Urea | U+NI | 0.58 c | 0.22 c | 0.18 c | 0.15 c | 0.91 b | 0.02 b | 0.02 b | 0.15 c |

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Lessons learned

• Significant N₂O emissions reductions can be achieved in both rainfed (non-irrigated) and irrigated cropping systems by using a urea-based EENF

• largest, and most consistent, emissions reductions were achieved using stabilized N products that employ a nitrification inhibitor

• product that employed a urease inhibitor alone yielded significant emissions reductions, but only when applied in the spring

• polymer-coated urea was the least effective at reducing N₂O emissions, though significant emissions reductions were observed with ESN following the spring application in 2016
  • emissions reductions at both the rainfed and irrigated sites, which suggests that this was not a “random” effect
Lessons learned

• Regardless of absolute magnitude, N$_2$O emissions reductions were greatest when the EENFs were applied in the spring

• Despite clear environmental benefits of using the EENFs, we were unable to detect any significant agronomic (i.e., yield) benefits
  • likely due to the fact that the N rates applied to the plots were based on soil test recommendations and were chosen to approximate crop demand
  • a small increase in N supply to the crop as a result of a decrease in N loss is unlikely to produce a significant increase in yield, and may only result in “luxury uptake” of N by the crop
Conclusions

• Fall application should not be recommended in the prairies provinces for agronomic and environmental reasons

• Enhanced efficiency fertilizers can be used to reduce N$_2$O emissions from cropland while maintaining or improving crop productivity

• Including N-serve did not show any benefit over anhydrous ammonia alone on agronomy or reduction of N$_2$O emissions
  • suggesting a limited benefit to using inhibitors with AA to reduce N$_2$O emissions

• Environmental and agronomic outcomes are aligned
  • farmers may benefit from voluntarily implementing 4R practices to reduce N$_2$O emissions through a carbon offset marker
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