Urea Volatilization and Enhanced Efficiency Nitrogen Fertilizers for Small Grains
Crop Pest Management School
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Objectives

• Present urea volatilization study results
• Present fertilizer management options to decrease volatilization
• Explain pros and cons of enhanced efficiency fertilizers (EEFs)
• Show research results for EEFs
The N Cycle

- Nitrogen Fixation
- Foliar Uptake
- Volatilization
- Denitrification
- Plant Uptake
- Organic Nitrogen
- Urea
- Urease
- Hydrolysis
- Mineralization
- Immobilization
- Leaching
- Exchange
- Clay or O.M.
- The N Cycle
- NH₃(g)
- NH₃(aq)
Factors Increasing Volatilization

1. High Soil pH and Temperature
2. Windy
3. Low Cation Exchange Capacity (CEC). WHY?
4. Low buffering capacity (resistance to pH change)
5. High soil moisture/humidity
6. Little Rainfall/Irrigation following fertilization
7. High Ground cover/vegetation/residue. WHY?
8. Low Soluble and Exchangeable Calcium

Bottom line: Large number of factors make volatilization amounts VARIABLE and difficult to predict.
A first look at ammonia volatilization losses from surface-applied urea

Richard Engel, Clain Jones, Jeff Whitmus
Montana State University
Project Objectives

- How much N as ammonia are we losing from applications of surface urea (fall, winter, and early spring)?
- Is this a significant economic loss to Montana producer?
- If losses are significant, then how do we mitigate losses?
Research approach

- conduct on-farm trials – no till systems
- focus on north central Montana
- diversity of soils (texture, pH)
- ammonia emissions quantified over 8-wk gas sampling campaign following fertilization (urea, NBPT-coated urea)
Integrated horizontal flux method

- preferred approach for quantifying gas loss
- moderate size plots (~0.3 acre)
- continuous measurement of NH$_3$(g) loss over time

mast and shuttles
Circular plots (22 yard radius)

- urea (90 lbs N/acre)
- urea + NBPT (Agrotain @ 4 quarts/ton)
- large unfertilized buffer areas around plots
Shuttles

- traps for collecting ammonia

*stainless steel spiral coated with oxalic acid*

rotate on pivot & face into wind
Two examples of field trial results from west Havre field site (Kaercher farm)

- Hill County
- Phillips-Elloam silt loam
- pH 6.0
- no till winter wheat
- Campaigns 2 and 5 - conducted in the identical field

Campaign 2: October 9, 2008.  
Air temp = 45 F, Soil temp = 43 F

Campaign 5: March 26, 2009.  
Air temp = 21 F, Soil temp = 34 F
Campaign #2 – low NH$_3$ losses observed

- October 9, 2008 application, air-temp. 45 °F, dry soil surface
- No rain for 24 days and then Nov. 2-5 field site received 0.98”ppt.

1 wk post-fertilization prills not dissolved
Campaign #2 - Kaercher farm

- Urea (3.1%)
- Urea + NBPT (1.4%)

Mean Air Temp ~ 42 F
Mean Soil Temp ~ 41 F
Campaign #5 - high NH₃ losses observed

Fertilizer applied on Mar 26, 2009
light snow on soil surface and air temp = 21 F

soil surface with fertilizer prills beginning to dissolve
Campaign #5 - Kaercher farm

Precipitation
- no rain 0-2 wks
- 1.54” 2-8 wks

Mean temperature
- Soil = 38 °F
- Air = 39 °F

Conclusion: High losses observed even though temperatures were cold!
Campaign 9 & 10 – Willow Creek
Brocko silt loam

- calcareous soils, pH 8.3
Campaign 9 – Willow Creek – Jan. 27

5.3 inches of snow
Campaign 9 – Willow Creek – Feb. 17

- no runoff

- urea (total = 24.3%)
- urea + NBPT (total = 9.3%)

% of applied N lost

Weeks post-fertilization
Campaign 9 – Willow Creek – Feb. 17

- no runoff
- NBPT < urea (10 wks activity)

% of applied N lost

- urea (total = 24.3%)
- urea + NBPT (total = 9.3%)

Weeks post-fertilization
Soil temperature (0.4 inch) at Willow Creek, Campaign 9
## Campaign Summary (% N loss)

<table>
<thead>
<tr>
<th>Campaign</th>
<th>Fertilization date</th>
<th>Urea</th>
<th>Agrotain</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>April 3, 2008</td>
<td>8.4</td>
<td>4.4</td>
</tr>
<tr>
<td>2</td>
<td>Oct 8, 2008</td>
<td>3.1</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>Nov 14, 2008</td>
<td>31.5</td>
<td>4.0</td>
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<tr>
<td>4</td>
<td>March 25, 2009</td>
<td>35.6</td>
<td>18.0</td>
</tr>
<tr>
<td>5</td>
<td>March 26, 2009</td>
<td>39.9</td>
<td>18.1</td>
</tr>
<tr>
<td>6</td>
<td>Oct 6, 2009</td>
<td>10.7</td>
<td>3.3</td>
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<td>7</td>
<td>Oct 13, 2009</td>
<td>10.4</td>
<td>4.8</td>
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<td>8</td>
<td>Oct 19, 2009</td>
<td>15.7</td>
<td>3.4</td>
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<td>9</td>
<td>Jan 27, 2010</td>
<td>24.3</td>
<td>9.3</td>
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<tr>
<td>10</td>
<td>Feb 26, 2010</td>
<td>44.1</td>
<td>11.9</td>
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<tr>
<td>11</td>
<td>March 29, 2010</td>
<td>6.3</td>
<td>1.7</td>
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<tr>
<td>12</td>
<td>April 20, 2010</td>
<td>14.7</td>
<td>1.4</td>
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<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>20.4</strong></td>
<td><strong>6.8</strong></td>
</tr>
</tbody>
</table>

*wide range in N loss amounts*
Ammonia volatilization and urea fertilizer

A micrometeorological study to quantify volatilization losses of ammonia from surface urea applications to no-till wheat

In Montana, farmers often fertilize wheat by applying urea to the soil surface during the fall, winter, or early spring. The question of how much nitrogen is lost from this application strategy seems to be raised by growers and fertilizer dealers every season. Surface urea applications are known to be susceptible to nitrogen losses as a result of ammonia volatilization (lost to the air). However, the importance of this process in cold soils is not known and is the focus of an investigation I am currently leading. To answer this question, I am using a micrometeorological system referred to as the integrated horizontal flux (picture in photograph below) method to quantify ammonia losses from the soil. Micrometeorological and greenhouse measures of gas losses from soils. This method is not disruptive of the soil environment and provides for continuous collection of ammonia gas over time. This is a first of its kind study in Montana. Field studies are presently being conducted at two farms in northern Montana, with a third farm site to be added in the fall 2009. I have constructed this website to keep people up-to-date on the progress of this study.

Recent presentations
August 6, 2009 - CCA and Dealer Training, Huntley, Montana

Updated: 08/29/2009
Summary – take home messages

• Significant ammonia losses (30-40% of applied N) from surface-applied urea can occur even though soil temperatures are near freezing!

• Soil moisture conditions at surface that dissolve urea granules (i.e. prolonged damp) without rain promote high ammonia losses (*more common to find these conditions in MT during late fall or early spring*)

• NBPT (Agrotain) reduced losses 62% over untreated urea
If ~20% of broadcast urea is lost, why didn’t MT research from the 1990s show large yield/protein losses compared to ammonium nitrate and/or subsurface banding? (Jones et al. 2007)

1. Adequate precipitation may have occurred after application.
2. Urea takes 2 - 5 weeks to become available whereas AN is immediately available for plants and for other losses-urea’s ‘slow release’ property may increase its efficiency, making up for loss.
3. About 50% of N uptake comes from fertilizer (rest from soil). So 20% of 50% is 10% difference in N availability-might not make a statistically SIGNIFICANT difference (though still a bottom line difference).
4. With longer term no-till could ‘urease’ enzyme concentrations have increased? It is known that residue contains more urease than soil.
5. With longer term no-till, some calcium has likely leached out of surface soil. Calcium is known to decrease volatilization and most source studies were conducted last decade.
Effect of Urea Placement on Hays Annual Forage Yield
Effect of Urea Placement on Hays Barley (Annual Forage) Yield

Angvick et al. unpub data

Froid, MT

Forage yield (tons/acre)

subsurface band

broadcast

a

b

2009

2010

0.0

0.5

1.0

1.5

2.0

2.5

3.0
Urea broadcast

2009 (apparent low volatilization)

1.8 inches

0.5 inches

2010 (apparent high volatilization)
Effect of irrigation rate on urea volatilization (Horneck, unpub data)

\[ y = 62.655e^{-3.9586x} \]

\[ R^2 = 0.9193 \]

Echo, Oregon

Soil Temp = 46°F
Does ½ inch of rain also stop volatilization? (Horneck unpub data)

Not if spread out over 3 days
What should you do to minimize volatilization?

1. Do not apply urea on moist ground UNLESS a snow or rainstorm is forecast to drop at least ½ inch of rain in a day. Preferably more (unlikely unfortunately!).

2. If you irrigate, apply ½ inch of irrigation after urea application.

3. Apply urea below the surface – either in a midrow band, 2 inches from the seed or with the seed with a ‘protected’ product or a wide opener.

4. Consider seeding right after urea application to cover some urea; wider openers will help with this. (We’re currently testing effectiveness of this practice)

5. Consider using Agrotain or ammonium nitrate (if available) if can’t apply during a low risk time.
Enhanced Efficiency Fertilizers

EEFs

• Any fertilizer designed to:
  – Increase fertilizer availability
  – Decrease fertilizer losses

• 3 major methods of action
  – Stabilized - alter soil microbial or enzymatic reactions
  – Slow release - have additives which require chemical or biological decomposition to release nutrients
  – Controlled release - a semipermeable coating, usually a polymer, regulates release
Stabilized Urease Inhibitors

- Volatilization
- Plant Uptake
- Denitrification
- Leaching

NH₃

N₂ and N₂O

slow urea hydrolysis here, most common is NBPT

Urea

UAN

NO₃⁻

NO₂⁻
Stabilized Nitrification Inhibitors

\[ \text{NH}_4^+ + \text{NH}_3 \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \rightarrow \text{N}_2 \text{ and N}_2\text{O} \]

- Volatilization
- Plant Uptake
- Denitrification
- Leaching
- Slow conversion to nitrate here

Urea
UAN
Slow and Controlled Release

- NH$_4$$^+$
- NO$_2^-$
- NO$_3^-$
- N$_2$ and N$_2$O

Volatilization

Plant Uptake

Leaching

N$_2$ and N$_2$O

Dentritification

NH$_3$

Urea control release here

UAN slow release here

Nitrification

Plant Uptake
Questions?
Under what growing conditions would you expect EEFs to work better?

- High potential volatilization loss
  - coarse soils
  - moist surface
  - warm temps
  - long time between application and incorporation

- High potential leaching
  - coarse soils
  - high moisture content/irrigation/rainfall
Effect of irrigation and NBPT on volatilization

Cumulative N loss (% of applied N)

Days after N fertilization

0.8 inch irrigation on days 2 and 8

Rawluk 2000
Manitoba

Urea

Urea + irrigation

NBPT-urea

NBPT-urea + irrigation
NBPT uses

- Can minimize urea volatilization for several weeks
- ‘Buys’ time for rainfall, irrigation or mechanical incorporation to protect urea
- Warm weather top-dressing
- Cool weather broadcast
N release by polymer-coated (controlled release) fertilizers

- Water moves in through coating
- Urea dissolves in prill
- N moves out through coating into soil solution
- Collapsed prill biodegrades

Schematic adaptation and photo courtesy of Agrium, U.S. All rights reserved.
Effects of over-winter moisture conditions on effectiveness of PCU

Yield change with spring-banded PCU over conventional urea (%)

- Barley
- Canola
- Wheat

Grant & Downbenko 2008

Low moisture
High moisture

WHY?
What type of crops would you expect slow release to work better?

- Irrigated
- Warm season

What about dryland cool season crops?
Timing of N uptake by wheat
Timing of N uptake by wheat and ESN® N release

Options for wheat?

Approx % N released by typical ESN seed placed in mid May
How does PCU work for small grains?

• Fall/winter pre-plant works well. PCU is in soil long enough to dissolve in time for plant need.
• Late winter/spring broadcast PCU does not - may dry out, release is too slow.
• Incorporation is important, especially late winter/spring.
• Blending is recommended with late winter/spring surface applied PCU.
Effect of EEF source and application method on winter wheat yield

Location: Beiseker, Alberta
Soil: silt loam, 4.5% organic matter
Precipitation: 13.5 in. seeding to harvest
5 N sources:
• AN – ammonium nitrate
• Urea
• Agrotain® treated urea – urease inhibitor
• Super Urea® – urease and nitrification inhibitor
• ESN® – polymer coated urea
Rate: 80 lb N/ac
Subsurface side-banded (1.2” below and 1” side of seed) at seeding or broadcast in spring
Yield with N fall subsurface side-banded

Why did urea outcompete AN?

NITROGEN SOURCE

- AN
- Urea
- Agrotain
- Super Urea
- ESN (side)
- ESN (seed-row)

Fall subsurface banded at 80 lb N/acre

Jensen 2010
Stabilized Urease Inhibitors

Volatilization

NH$_3$

Plant Uptake

Plant Uptake

NO$_3^-$

N$_2$ and N$_2$O

Dentritication

Leaching

Urea

(NH$_4^+$ + NO$_3^-$)

AN

Urea

(NH$_4^+$ + NO$_3^-$)
Yield with N spring broadcast

Why equal AN, Urea and Agrotain yields?

Spring broadcast 80 lb N/acre

Winter Wheat Yield (bu/acre)

Jensen 2010

- AN
- Urea
- Agrotain
- Super Urea
- ESN

Nitrogen Source
Alberta Study Summary

Each form of N is suitable – if used properly

- Urea and Agrotain®-urea best used in spring
- Super Urea® best fall banded
- ESN® best side- or seed-row banded in fall – advantage likely less in MT. Why?
- Blend urea with ESN® to ensure early N availability (50/50?)
Winter wheat with Nutrisphere-N® (NSN) side-banded at seeding

Location: North of Conrad (WTARC)

2 N sources:

- Urea
- Nutrisphere-N® – urease and nitrification inhibitor

Rate: 40 and 80 lb N/ac

Subsurface side-banded (1” above and to side of seed) at seeding
Yield with NSN treated urea side banded

<table>
<thead>
<tr>
<th>Nitrogen Rate and Source</th>
<th>Winter Wheat Yield (bu/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>check</td>
<td>b</td>
</tr>
<tr>
<td>40 lb N urea</td>
<td>a</td>
</tr>
<tr>
<td>40 lb N urea+NSN</td>
<td>a</td>
</tr>
<tr>
<td>80 lb N urea</td>
<td>a</td>
</tr>
<tr>
<td>80 lb N urea+NSN</td>
<td>a</td>
</tr>
</tbody>
</table>

Jackson 2008 unpubl.

banded 1" to side and above seed
Seed placing EEFs

- Can apply ~ 2 – 4x as much slow release product as urea directly with small grain seeds
- Saves on field passes – fuel, labor, soil disturbance
Effect of N source applied with the seed on dryland spring wheat yield

Saskatchewan
Malhi et al. 2003

Grain yield (bu/acre)

Polymer-coated
Urease inhibitor
Urea

Application rate (lb N/acre)
Conclusions

• Urea volatilization rates are highest when applied to moist soil surface w/o rain for at least 2 weeks following application.
• The best way to prevent volatilization is to place urea below the soil surface (> 1.5 inches is optimum)
• Agrotain decreases volatilization.
Conclusions

• Enhanced efficiency fertilizers can decrease N losses.
• Blending EEFs with conventional fertilizer may provide a good match between crop uptake and fertilizer availability.
• More EEF can be placed with the seed than conventional fertilizer, possibly saving a fertilizer pass and fuel costs.

Additional info in:
Enhanced Efficiency Fertilizers (EB0188)
http://landresources.montana.edu/soilfertility
Go to Fertilizer Information