Ammonia Volatilization: Process, Amounts, and Yield Effects

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Why Important?

- Ammonium nitrate (34-0-0) has been discontinued by both Simplot and Agrium, affecting N source options for many growers.
- Some producers have historically used ammonium nitrate partially due to concerns with volatilization of alternatives, such as urea (46-0-0), and now will need information from you on understanding the volatilization process, and managing for it.
Presentation Outline

• Volatilization
  - Mechanism
  - Factors that affect it
  - Amounts

• N Source Comparisons in Montana

• Management
  - Inhibitors
  - Placement
  - Timing
Ammonia Volatilization

READY FOR SOME CHEMISTRY??
Ammonia Volatilization

\[
\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 \text{ (gas)} + \text{H}_2\text{O}
\]

- Can occur with urea and all ammonia or ammonium based fertilizers
- Losses vary with environment and are difficult to predict. Most research done in Kansas and Texas where climate is more conducive to volatilization.

Looking at above equation, what is 1 factor that increases volatilization? **High pH**
N fertilizer can increase pH during ‘hydrolysis’

Ex: Urea

\[
\text{CO(NH}_2\text{)}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{NH}_4^+ + \text{CO}_3^{2-}
\]

\[
\text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{OH}^-
\]

Effect on pH? Increases \textit{temporarily. Why?}

Good or bad? Bad: \(\uparrow\text{pH}, \uparrow\text{volatilization}\)

\[
(\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3\text{ (gas)} + \text{H}_2\text{O})
\]
Ammonium Sulfate Volatilization—Calcareous Soils

\[(\text{NH}_4\text{)}_2\text{SO}_4 + 3\text{H}_2\text{O} + \text{CaCO}_3 \rightarrow 2\text{NH}_4^+ + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} + \text{HCO}_3^- + \text{OH}^-\]

(lime) \hspace{1cm} (gypsum)

**NOTE**: Generation of OH\(^-\), so pH rises.

In words: Sulfate dissolves some calcium carbonate releasing carbonate which increases pH. Increased pH increases volatilization.

Note: Ca-nitrate is generally too soluble to form so AN doesn’t dissolve CaCO\(_3\), and thus no pH increase.
QUESTIONS?
Factors Affecting Volatilization

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

Bottom line: Large number of factors make volatilization amounts VARIABLE and difficult to predict.
1. Soil pH and Temperature Effects on Relative Amount of Ammonia in Soil Solution

The graph illustrates the effect of pH and temperature on the relative amount of ammonia in soil solution. The data is represented by two curves, one for 77 degrees F (△) and the other for 35 degrees F (□). The x-axis represents pH levels ranging from 5 to 11, while the y-axis shows the ammonia concentration as a percentage of ammonia+ammonium.

At lower pH values (around 5-7), the ammonia concentration is low regardless of temperature. As pH increases, the concentration of ammonia increases significantly, especially at the higher temperature (77 deg. F). The 35 deg. F curve shows a more gradual increase in ammonia concentration with increasing pH.

This graph indicates that both pH and temperature significantly influence the amount of ammonia in soil solution, with higher pH levels promoting greater ammonia formation at both temperature settings.
2. Wind

- SO, don’t apply on windy day or with high winds in short term forecast.

Fillery et al., 1984
3. Cation Exchange Capacity

• As CEC increases, volatilization rates generally decrease (Fenn and Kissel, 1976). Why?
  1. Less NH$_4^+$ in solution to volatilize
  2. Increased pH buffering capacity (next slide)
4. Buffering Capacity

Figure 1. Soil surface pH and cumulative NH$_3$ loss as influenced by pH buffering capacity. (from Ferguson et al., 1984).
5. Effect of Soil Water Content

Bouwmeester et al., 1985
6. Rainfall/Irrigation

• 1/10 inch of rain/irrigation dissolves fertilizer, allowing volatilization.
• 1/2 inch of rain/irrigation pushes dissolved fertilizer about 2 in. into soil, essentially stopping volatilization if within about 2 days of fertilization (Meyer et al., 1961; Lloyd, 1992)
Effect of Incorporation Depth

Urea Rate = 100 lb N/ac
Texture = silt loam
Soil pH = 6.5
Temp. = 75° F
7. Effect of Grass Residue

![Urea volatilization rate (ppm/hr)]

- **Soil**: Low rate
- **Turfgrass Clippings**: Moderate rate
- **Thatch**: High rate
Effect of Residue, Cont’d

• Volatilization was found to be approximately 2 times higher in the upper 1.5 inches under no-till than under conventional tilled systems (Dick, 1984).
8. Exchangeable Ca$^{2+}$ Decreases Volatilization (Fenn and Kissel, 1976)

\[ \text{CO(NH}_2\text{)}_2 + 2\text{H}_2\text{O} + \text{Ca}^{2+}\text{-soil} \rightarrow 2\text{NH}_4^+\text{-soil} + \text{CaCO}_3 \]

In words: Calcium can tie up a carbonate ion, preventing pH rise AND opening up 2 exchange sites for ammonium.

**NOTE:** No generation of OH$^-$, so no pH rise.

**Implication:** Less concern with volatilization on soils with high exchangeable Ca levels (generally indicated by high CEC). Good news for MT. Doesn’t matter though if urea doesn’t reach soil.
QUESTIONS?
## Demonstration

<table>
<thead>
<tr>
<th>Urea Treatment</th>
<th>Ammonia odor</th>
<th>Ammonia test in air (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(500 lb N/ac)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorporated-Loam</td>
<td>no</td>
<td>.25</td>
</tr>
<tr>
<td>Surface-Loam</td>
<td>slight</td>
<td>3.0</td>
</tr>
<tr>
<td>Surface-Sand</td>
<td>low</td>
<td>5.0</td>
</tr>
<tr>
<td>Surface-Grass residue</td>
<td>med</td>
<td>&gt;6.0</td>
</tr>
<tr>
<td>Surface-Grass residue (100 lb N/ac)</td>
<td>slight</td>
<td>6</td>
</tr>
</tbody>
</table>
N Management

- Source
- Urease Inhibitors
- Placement
- Timing
Ammonia Volatilization Losses from a Calcareous Soil

Temp. = 75° F
Straw residue = 2 t/ac
Moisture ≥ Field capacity

Ammonium Nitrate
Ammonium Sulfate
Urea
UAN

Meyer et al., 1961
Why differences in volatilization?

• Urea, UAN, and AS cause larger pH increases than AN.
• \( \frac{1}{2} \) of N in AN is nitrate which can’t volatilize
Volatilization of Urea vs UAN

Mixed results (out of state studies):

1. In 3 of 5 studies located, UAN volatilized slightly more than urea
2. In 2 of 5 studies, urea volatilized approximately twice as much as UAN

Bottom line: Both urea and UAN can volatilize - selection should likely be based on equipment and price.
Effect of Granular N Source on Yield

Montana Research Results

Note: No journal-published data in Montana on effect of N source on volatilization and only one known published study on yield
Effect of N Rate and Source
70% Orchardgrass/30% Alfalfa, W. Montana

Averages of 2 sites

Christiansen, unpub. data
Effect of N Source on Irrigated W. Wheatgrass Yield
Averaged over 4 N Rates, Blaine County

Still, need to apply when cool, calm or some ammonia will volatilize, especially from UR and AS.

Christiansen, unpub. data
Effect of N Source on Winter Wheat Grain Yield
North Central MT

No significant N source effects
How could UR produce similar yields as AN if UR volatilizes more?

1. AN leaches more readily
2. Takes less energy for plant to convert ammonium-N than nitrate-N to protein.
3. Not much urea volatilized

Summary: Urea volatilization can happen, but in Montana studies it generally did not have a significant effect on yield compared to other granular N fertilizers. STILL need good management!
QUESTIONS?
Urease Inhibitors

• Agrotain (NBPT) is main product. Delays hydrolysis by up to 14 days
  - advantage: allows more chance for rain or irrigation to push N into ground
  - disadvantage: will delay time to become available, volatilization can still occur, and cost (adds ~$50/t-urea).
Research Results on Urease Inhibitors

**Spring wheat**
1st study: NBPT had a 1.3 bu/ac increase. Cost breakeven would need 2 bu/ac increase. (Ontario, MAFRA website)
2nd study: Seed-placed, approximately doubled grain yield due to higher emergence (Malhi et al., 2003)

**Forages**
1st study-NBPT significantly reduced ammonia volatilization (Watson, C.J. et al., 1994) on grassland.
2nd study-Kentucky bluegrass yield increased 15% with NBPT (Joo et al., 1991).
Would you recommend their use?

Depends on:

1. Potential for volatilization (ex: temperature when apply)

2. Cost
Placement

• Granular:
  - Established forage-surface broadcast is essentially only option.
  - No-till small grains-can place with seed if have equipment, but urea can decrease germination (see Jacobsen et al., 2003 for recommended maximum amounts)

• Liquid (UAN; 32-0-0 or 28-0-0): Surface broadcast including fertilization, surface band, or knifed.

<table>
<thead>
<tr>
<th>Method</th>
<th>Forage Yield</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>2.9 t/ac</td>
<td>Likely due to limited urease concentration, slowing hydrolysis</td>
</tr>
<tr>
<td>Knife</td>
<td>2.8 t/ac</td>
<td></td>
</tr>
<tr>
<td>Surface Band</td>
<td>3.4 t/ac</td>
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N. Central Regional Extension Pub #326, KSU
Timing

• Because UR may take days to weeks to hydrolyze, UR should be applied earlier than AN historically was for fast green-up (AN simply dissolves, UR also requires hydrolysis reaction).
Timing, continued

• Fall vs Spring

Generally better to apply near peak uptake to avoid losses (volatilization, denitrification, leaching, immobilization). However, weather conditions (temp., precip.) in first few days after application combined with soil texture may be more important.

1. Ex: Shallow, coarse soil. Fall or Spring?  
   Spring

2. Ex: Cool Fall temps with ability to irrigate, or warmer spring temps before irrigation water delivered. Fall or Spring?  
   Fall
Conclusions

• Urea has become the primary N granular option, so crop advisers will likely be getting more questions on its use.
• Urea volatilization is affected by a large number of factors, making predictions of volatilization amounts difficult.
• Volatilization doesn’t appear to have large effects on crop yield in Montana.
• Volatilization potential can be reduced with well thought out placement and timing.
QUESTIONS?

For more information on urea volatilization and management, see:

For more information on N cycling, fertilizer sources, placement and timing see:
http://landresources.montana.edu/nm

MSU Soil Fertility webpage:
http://landresources.montana.edu/soilfertility