Nitrogen Cycle (Intermediate)

Winter 2015 Webinar Series (3-12-15)
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Today’s Topics

• review N cycle & importance of optimal management
  – losses of N to the environment
  – basis of our knowledge

• deeper look at processes directly related to nutrient management plan development
  – mineralization (and immobilization)
  – nitrogen fixation
  – nitrogen credits
  – ammonium volatilization
The Nitrogen Cycle

Atmospheric nitrogen

Component
Input to soil
Loss from soil

Atmospheric fixation and deposition
Crop harvest
Industrial fixation (commercial fertilizers)

Animal manures and biosolids
Plant residues
Volatilization

Runoff and erosion

Biological fixation by legume plants
Plant uptake

Denitrification

Organic nitrogen
Mineralization
Immobilization

Nitrate (NO₃⁻)
Nitrification

Ammonium (NH₄⁺)
Leaching

Modified from the Potash & Phosphate Institute web site at www.ppi-ppic.org
Atmospheric nitrogen fixation and deposition

Animal manures and biosolids

Industrial fixation (commercial fertilizers)

Crop harvest

Volatilization

Runoff and erosion

Denitrification

Leaching

Organic nitrogen

Ammonium (NH₄⁺)

Nitrate (NO₃⁻)

Plant residues

Plant uptake

Immobilization

Nitrogen mineralization

Nitrification

Input to soil

Loss from soil

The Nitrogen Cycle

Modified from the Potash & Phosphate Institute web site at www.ppi-ppic.org
Reactive Nitrogen (Nr)

- vulnerable to loss
  - leaching
  - denitrification
  - volatilization

- biologically, radiatively or photo-chemically active N compounds

- “cascades through the environment external to the agroecosystem” (Cassman)
  - economic loss and environmental risk
Complications

• cycle is largely microbially driven
  – nitrogen fixation – *Rhizobia sp.*
  – nitrification – *Nitrosomonas* and *Nitrobacter*
  – mineralization and immobilization – many species
  – denitrification – many bacterial species

• dominant form of nitrogen in soil solution of most agricultural soils is an anion (nitrate or $\text{NO}_3^-$)
Fertilizer Rights

• right source
• right rate
• right time
• right method

IPNI (formerly PPI)
Soil-Hydro. Cycle, Lower Eastern Shore

Inches of water

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Ppt PET Soil Drainage

Meisinger
Fig. 4.7. Normal root depth of selected crops and nitrate leaching depth for 300 mm rainfall on various soil types. (Source: Cameron and Haynes, 1986; Addiscott et al., 1991.)
How do we know what we know?

- soil (over time, with depth, at various locations)
- plant biomass & nutrient content
- vadose zone water
- groundwater
- surface water
- ambient atmosphere near the soil surface
Mineralization-Immobilization

• mineralization
  – microbial transformation of organic forms of nutrients to inorganic forms
  – release of inorganic forms of nutrients

• immobilization
  – uptake of nutrients by soil organisms
Mineralization Factors ($f_{\text{min}}$)

• The proportion or percentage of the organic nitrogen that is converted to inorganic (mineral) nitrogen

• $N_{\text{organic}} \rightarrow$ ammonium –N (NH$_4$-N)

• ranges from -0.05% to 100%
Figure 5: Mineral-fertilizer equivalents (% MFE) for several organic fertilizers characterizing N availability in the year of application.

Want More Info?

• table of mineralization rates
  – extension.umd.edu/anmp
  – *Plan Writing Tools*, Chapter 3

• January 2014 webinar
  – extension.umd.edu/anmp
  – *Workshop Tools*, nitrogen grid
Immobilization

• utilization of available nitrogen by microbes
  – occurring to some extent when conditions are favorable
  – “opposite” of mineralization
  – mineralization $\leftrightarrow$ immobilization

• net immobilization is observed when organic materials with a wide carbon-nitrogen ratio are added to soil
  – $C/N > 20/1$ (differences of opinion; 18/1 to 25/1)
Changes in NO$_3^-$ levels when organic additions have wide C/N

Adapted from F.J. Stevenson, 1986
<table>
<thead>
<tr>
<th>Material Type</th>
<th>Mineralization Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huck’s <em>Hen Blend</em> (VA)</td>
<td>0.002</td>
</tr>
<tr>
<td>(8 yard waste - 1 hen manure, C/N = 29)</td>
<td></td>
</tr>
<tr>
<td>Panorama <em>Pay Dirt</em> (VA)</td>
<td>0.05</td>
</tr>
<tr>
<td>(1 yard waste - 2 poultry litter, C/N = 18)</td>
<td></td>
</tr>
<tr>
<td>leaves (fresh) (NJ)</td>
<td>-0.08 (scl) – 0.05 (sl)</td>
</tr>
<tr>
<td>MSW (Trumen, MN) (C/N = 33)</td>
<td>0</td>
</tr>
<tr>
<td>MSW (St. Cloud, MN) (C/N = 14)</td>
<td>0</td>
</tr>
<tr>
<td>MSW (Benson, MN) (C/N = 14)</td>
<td>0</td>
</tr>
</tbody>
</table>
Carbon - Nitrogen Ratio (C/N) of Rye Cover Crop at Two Locations (1990)

<table>
<thead>
<tr>
<th>Kill Date</th>
<th>Piedmont C/N</th>
<th>Coastal Plain C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>early winter</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>late March</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>early April</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>late April</td>
<td>32</td>
<td>57</td>
</tr>
</tbody>
</table>

Coastal Plain - Matapeake
Piedmont - Chester sil
Clark and Decker
Biological Nitrogen Fixation (BNF)

- symbiotic BNF
  - legumes-Rhizobia bacteria
- takes several weeks for nodules to form
- suppressed by available nitrogen supply
- 2013 webinar (Dr. Jude Maul, USDA)
Effect of previous crop on symbiotic N\textsubscript{2} fixation and soil N uptake by three cultivars of soybeans

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>N from Fixation (lbs/A)</th>
<th>N from Soil (lbs/A)</th>
<th>Fraction of Total N Fixed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln</td>
<td>60</td>
<td>141</td>
<td>131</td>
</tr>
<tr>
<td>Shelby</td>
<td>70</td>
<td>161</td>
<td>113</td>
</tr>
<tr>
<td>Williams</td>
<td>77</td>
<td>190</td>
<td>202</td>
</tr>
<tr>
<td>Mean\textsuperscript{3}</td>
<td>69</td>
<td>164</td>
<td>149</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Alf. is a previous crop of alfalfa; Soy is a previous crop of soybeans; \textsuperscript{15}N labeled nitrogen fertilizer.

Coale et al., 1985, Plant and Soil, 86: 362
Nitrogen Credits

• nitrogen released from organic sources applied to grown previous years
  – manures and other organic sources
    • previous 2 seasons
  – legumes in rotation
## Nitrogen Credits

<table>
<thead>
<tr>
<th>Species</th>
<th>pounds N/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>crimson clover</td>
<td>50 - 100</td>
</tr>
<tr>
<td>hairy vetch</td>
<td>75 - 150</td>
</tr>
<tr>
<td>Austrian winter pea</td>
<td>75 – 150</td>
</tr>
<tr>
<td>alfalfa</td>
<td>100 - 150</td>
</tr>
<tr>
<td>red clover</td>
<td>40</td>
</tr>
<tr>
<td>soybeans</td>
<td>15</td>
</tr>
</tbody>
</table>
Fig. 1. Corn grain yields in 1991 following sunn-hemp and fallow plots measured across four N rates at the E.V. Smith Research and Extension Center in Shorter, AL.

- Fallow: $Y = 2.43 + 0.03x; R^2 = 0.92^*$
- Sunn-hemp: $Y = 5.83 + 0.01x; R^2 = 0.96^{**}$
Ammonia Volatilization - A Gaseous Loss

• loss of ammonia-N to the atmosphere
• ammonium in the presence of hydroxyl (OH\(^-\)) can produce ammonia gas

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

• affects all surface-applied N sources that contain or convert to ammonium
  – urea, UAN, ammonium nitrate, manure
• enhanced by warm, dry atmospheric conditions
Micro-meteorological ammonia sampling mast in center of manure circle
Wind Tunnel for Ammonia Research

- X-Section Sampler
- Acid Scrubbers
- Pump and Flow meters
- 20 inches
Cumulative NH$_3$ Loss from
Old vs New Loss Estimates

- **Cumulative NH$_3$ Loss, % of NH$_4$-N**
- **Time after surface application, hrs.**

- **Dairy Slurry Measured Losses**
- **Poultry Litter Measured Losses**
- **Previous MD Estimated Losses**
### Ammonium Conservation Factors

**Solid Manures (except litter)**

<table>
<thead>
<tr>
<th>Time to Incorporation</th>
<th>Conventional Tillage</th>
<th>Conservation Tillage</th>
<th>No-till or Tillage &gt; 3 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 hour</td>
<td>0.96</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>1-3 hours</td>
<td>0.93</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>3-6 hours</td>
<td>0.78</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>6-12 hours</td>
<td>0.71</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>12-24 hours</td>
<td>0.63</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>1-2 days</td>
<td>0.58</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>2-3 days</td>
<td>0.53</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>&gt; 3 days (no-till)</td>
<td></td>
<td></td>
<td>0.35</td>
</tr>
</tbody>
</table>
Groundwater-Surface Water Interaction

Figure 12. Relation between land use and nitrate concentrations in ground water in shallow flow systems in the surficial aquifer in the Delmarva Peninsula.
Nitrogen at Watershed Outlet

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Baseflow</th>
<th>Stormflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>forest</td>
<td>0.5</td>
<td>1.7</td>
</tr>
<tr>
<td>pasture</td>
<td>0.7</td>
<td>4.9</td>
</tr>
<tr>
<td>cropland</td>
<td>2.4</td>
<td>4.7</td>
</tr>
<tr>
<td>mixed</td>
<td>1</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Rhode River sub-watersheds, Correll et.al; SERC; WWR, 1999
Minimizing Leaching Losses

• “right timing”
  – split application
  – beware “vulnerable” times

• “right rate”

• “right source”

• grow cover crops for scavenging end-of-season nitrate
Enhancing Synchrony: Minimize Vulnerable Nitrogen

- if the N is not yet applied, it cannot be lost
- here’s why split application (Penn State Agronomy 12)
Measuring Soil Water (Vadose Zone)

Fig. 2. Schematic diagram of pan lysimeter and its structural support (adapted from Jemison, 1991).
Pre – 175#/A N preplant
PSNT-1 – 80#/A preplant; remaining at side-dress
PSNT-2 – no pre-plant N
Woodbridge fine sandy loam; CT; Guillard, Morris and Kopp: JEQ 1999
No difference in yield
lysimeters at bottom of root zone (2 ft.)
Corn Yield and Nitrate Leaching in Maryland

![Graph showing the relationship between fertilizer nitrogen (Fert. N) and corn grain yield, along with soil NO3-N levels.](image)

- **Y-axis**: Grain Yield, bu/ac or Soil NO3-N lbs N/ac
- **X-axis**: Fert. N, lbs N/ac

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(Coale rotation study; Meisinger slide)
Cover Crops as Nitrate Scavengers

• non-legume crops, especially small grain crops
• nitrate uptake in fall prior to “leaching season”
• nitrate is incorporated in CC biomass and thus protected from leaching
UM-Wye REC, Mattapex silt loam

Cover crop planting date
- October 1
- October 14
- October 30

Cover crop N accumulation (kg/ha)
- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160
- 180

Oct Nov Dec Jan Feb Mar

1988 1989
### N Uptake in Spring
(pounds per acre, wheat, Beltsville, 2007-2008)

<table>
<thead>
<tr>
<th>Method</th>
<th>early estab.</th>
<th>late estab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>No-till drilled</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Disked</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>

Kratochvil & Fisher, Agronomy Journal, 2011; early estab: 10-1; late estab: 10-20 to 11-1; dry summer, no rain till late Oct
Is more N required when a small grain is grown?
Corn Yield (bu/A) With and Without Preceding Rye Cover Crop
(Clark and Decker, CP, 1990)

<table>
<thead>
<tr>
<th>Kill Date</th>
<th>N Rate (#A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>early April</td>
<td></td>
</tr>
<tr>
<td>check</td>
<td>60</td>
</tr>
<tr>
<td>rye</td>
<td>34</td>
</tr>
<tr>
<td>late April</td>
<td></td>
</tr>
<tr>
<td>check</td>
<td>74</td>
</tr>
<tr>
<td>rye</td>
<td>54</td>
</tr>
</tbody>
</table>
Corn Growth Patterns & Opportunities

Schepers, USDA retired

In-Season N Management

Nitrogen

Dry Matter

Vegetation Growth Stage

Relative Accumulation (%)
After the Plan...

• developing a nutrient management plan is the first step (Les Lanyon, PSU, deceased)

• use in-season tools if/when available and “calibrated” for our region
  – PSNT
  – chlorophyll meters
  – proximal optimal sensing (“Greenseeker”)
  – ramp strips
Wrapping up!

• losses are tied to the hydrologic cycle
• minimize vulnerable N
• advances in in-season management may mean changes in behavior
• scavenge end-of-season nitrate

2015 International Year of Soils