Nutrient Dynamics
Essential Plant Nutrients

16 Elements are Essential for Plants

O, C, H, N, K, P, Ca, Mg, S, Cl, Fe, B, Mn, Zn, Cu, Mo, Si, Na

- Macronutrients
- Micronutrients
- Species dependent
Lecture 8

NITROGEN

GES175, Science of Soils
<table>
<thead>
<tr>
<th>N Form</th>
<th>Name</th>
<th>Oxidation state</th>
</tr>
</thead>
<tbody>
<tr>
<td>organic-N</td>
<td>ammonium</td>
<td>-3</td>
</tr>
<tr>
<td>NH$_4^+$</td>
<td>dinitrogen gas</td>
<td>0</td>
</tr>
<tr>
<td>NO$_2^-$</td>
<td>nitrite</td>
<td>+3</td>
</tr>
<tr>
<td>NO$_3^-$</td>
<td>nitrate</td>
<td>+5</td>
</tr>
</tbody>
</table>

Fertilizer: $\text{N}$ (first of three digit rating)
Nitrogen Redox Processes

Oxidation: loss of $e^-$
Reduction: gain of $e^-$

$\text{-3} \quad \text{NH}_4^+ \leftrightarrow \text{NO}_3^- \quad \text{+5}$

8 $e^-$ transfer
The N-cycle involves several processes:

1. Mineralization
2. Immobilization
3. Nitrification
4. Denitrification
5. Fixation

Starting from plant & animal residues, nitrate ($\text{NO}_3^-$) can be reduced to nitrogen gas ($\text{N}_2$) through denitrification. Ammonium ($\text{NH}_4^+$) can be converted to nitrate through nitrification. Nitrate can also be converted to nitrite ($\text{NO}_2^-$) and then to nitrate again through nitrification. Nitrate can be reduced to nitrogen gas through denitrification. Nitrogen gas can be fixed back into organic-N through biological processes.
Carbon Pools

Soil

Vegetation

atmosphere

Lakes and Oceans

$\text{CO}_2$
CO₂ → Detritus (Plant Debris) → Fungi → Bacteria → Soil Humus → O₂

Earthworms
Organic Matter Mineralization

C:N

> 25:1

Polysaccharides (cellulose…)
Organic Acids
Amino acids, Peptides, Proteins
Lipids
Nucleotides
Peptides
Lignin

Cellulose
Proteins
Lignin

Humus

CO₂

C:N

10:1

NH₃

NH₃
<table>
<thead>
<tr>
<th>Material</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maple Leaf</td>
<td>45-70</td>
</tr>
<tr>
<td>Pine Needle</td>
<td>60-70</td>
</tr>
<tr>
<td>Wood</td>
<td>130-400</td>
</tr>
<tr>
<td>Grass</td>
<td>20-80</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>9-16</td>
</tr>
<tr>
<td>Bacteria</td>
<td>4-12</td>
</tr>
</tbody>
</table>
Mineralization vs. Immobilization

Fate of N if added to soil???
Low C:N (high N content)

Alfalfa, peas, grass
High C:N (low N)

straw, bark, sawdust
Ammonia Volatilization - gaseous loss of N
Ammonia Volatilization

Urea:

\[ \text{CO(NH}_2\text{)}_2 \xrightarrow{\text{urea soil enzymes} \text{ & } \text{H}_2\text{O}} \text{NH}_3 + \text{CO}_2 + \text{H}_2\text{O} \]

- Most volatilization when:
  - coarse or sandy-textured soils
  - low clay and low organic matter (which adsorb NH\(_4^+\))
  - dry alkaline surface
Nitrification

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

- ammonium          nitrite               nitrate

- oxidation of N

* Autotrophic bacteria
  - obtain energy from N oxidation
  - \textit{Nitrosomonas} \(\text{NH}_4^+ \rightarrow \text{NO}_2^- + \text{energy}\)
  - \textit{Nitrobacter} \(\text{NO}_2^- \rightarrow \text{NO}_3^- + \text{energy}\)
Nitrification (cont’d)

* Rapid in well-aerated, warm, moist soils
  • aerobic organisms (O₂ is required)
  • little NO₂⁻ accumulation

* Acid-forming process

\[ \text{NH}_4^+ + \frac{3}{2}\text{O}_2 \rightarrow \text{NO}_2^- + 2\text{H}^+ + \text{H}_2\text{O} \]
Nitrogen (nitrate?) Leaching

→ Eutrification
Hypoxic Zone: Gulf of Mexico/ MS River Delta

oxygen depleted zone
N Input Sources to Mississippi River

Soil Mineralization

Fertilizer

Legumes and pasture

Animal manure

Atmospheric nitrate

Atmospheric ammonia

Municipal and industrial point source

N Input (metric tons x $10^6$)
Denitrification

$\text{NO}_3^-$

$\text{N}_2$
Denitrification

Gaseous loss of N upon N reduction

\[ \text{NO}_3^- \quad + \quad e^- \quad \rightarrow \quad \text{NO}_2^- \quad + \quad e^- \quad \rightarrow \quad \text{NO} \quad \rightarrow \quad \text{N}_2\text{O} \quad \rightarrow \quad \text{N}_2 \quad \text{nitric oxide} \quad \text{nitrous oxide} \]
Denitrification (cont’d)

* Microorganisms:
  • facultative anaerobes
    - prefer $O_2$ but will use $NO_3^-$ for a terminal e- acceptor
  • heterotrophic
    - use organic-C for energy source

* Denitrification enhanced by:
  • low $O_2$ (flooding)
  • high O.M. (energy source)
  • high $NO_3^-$
Denitrification (cont’d)

* Metabolic reduction: Denitrification?
  (no N gas formation)

\[
\text{NO}_3^- \rightarrow \text{NH}_4^+ \rightarrow \text{organic-N}
\]

- N is reduced for use in protein formation
Biological Nitrogen Fixation

\[ \text{N}_2 \rightarrow \text{NH}_4^+ \]

* Symbiotic relation between bacteria and plants:
- legumes
- *rhizobium*
Bacteria: *Rhizobium* genus (species specific)
- *R. meliloti* - alfalfa
- *R. trifolii* - clover
- *R. phaseoli* - beans

- bacteria require plant to function as N-fixers
Process:

Rhizobium

nodule
(b) Process:

C from plant photosynthesis ➣ organic-C

N from fixation of N₂ ➣ organic-N

⇒ symbiosis

Rhizobium
Quantity of N Fixed

- Alfalfa and clover
  \[ \approx 100 - 250 \text{ kg N/ha/yr} \]
  (mature stand, good fertility & pH)

- Beans and peas
  less fixation but high protein food
  with minimum N input

- added N fertilizer
  \[ \rightarrow \text{lowered N fixation} \]
Symbiotic Nodules - Nonlegumes
* Actinomycetes - *Frankia* + Alders and other trees

Symbiotic - without nodules
* *Azolla/Anabaena* complex blue-green algae (N-fixer) in leaves of floating ferns
Nonsymbiotic N-fixation: Free-living Organisms

* Bacteria (*Azotobacter, Azospirillum*) and blue-green algae (*Anabaena*)

- aerobic and anaerobic
- small amounts: 5 - 50 kg/ha/yr
- inhibited by available soil N
Microbial Immobilization

\[
\begin{align*}
\text{NH}_4^+ & \quad \text{NO}_3^- \\
\rightarrow & \\
\text{C-NH}_2 & \quad \text{microbes}
\end{align*}
\]