Efficiency of N use in agriculture: What sets the ceiling?

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Nutrient management theory

- Predict plant-available N, P or assess nutrient status of crop
- Optimize delivery of soluble N fertilizer to the crop
- Eliminate all other limiting factors to maximize crop fertilizer uptake

Soluble inorganic N,P
Ammonium $\rightarrow$ nitrite $\rightarrow$ nitrate

N,P fertilizer
Reductions in crop diversity parallel intensification

As a result, large tracts of land are left as bare fallows for 4-8 months.

### Dominant rotation

- Jan: bare fallow
- May: planting
- Oct: harvest
- Dec: bare fallow

### Rotation with a cover crop

- Jan: cover crop
- May: planting
- Oct: harvest
- Dec: cover crop
Fraction of county tile drained
Technical support tracks corn production, misses areas critical for pollution.

Spatial relationship between (A) intensive corn production and (B) technical support services for optimizing fertilizer efficiency. (Wolf and Novak, 1999)
Leakiness 2 (fert N ha + cropf + drain)
What are the relative impacts of different N management practices on NUE?
Strategies for reducing N losses

• Improved placement and timing of fertilizer
• Variable rate application technologies
• Block microbially-mediated transformations
• Improved crop nutrient use efficiency
• Primary focus of N research (~57% of studies)
• Reduction in N losses by 5-20%

• Cover cropping, intercropping
• Use of organic N sources
• Management of plant-microbial interactions
• Perennial grain crops
• Limited research (~20% of studies)
• Reduction in N losses by 30-70%

Gardner and Drinkwater, in review
Tonitto et al., 2006
Both cover cropping and leguminous green manures reduce $\text{NO}_3^{-}$ leaching

Tonitto et al. 2006
The cover crop N “pump”

- **Microbial biomass**
  - Particulate organic matter
  - Humified organic matter

- **Soluble inorganic N**
  - Ammonium $\rightarrow$ nitrate

- **N fertilizer**

- **Gaseous losses**

- **Leaching & run-off**

- **Cover crops**

An average of 40 kg N/ha

Supply $\rightarrow$ Sink
Meta-analysis of $^{15}$N literature

- Organic N source
- More diverse rotation
- Spring fertilizer application
- Proximity to roots
- Reduced N fertilizer rate
- Nitrification inhibitor
- Different inorganic N form

Gardner and Drinkwater, in review
In these studies, the proportion of $^{15}$N fertilizer in crop biomass averages $\leq 40\%$
## Effect of improved fertilizer N efficiency on fate of N

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<thead>
<tr>
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<th>Broadcast</th>
<th>Side dress</th>
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<tbody>
<tr>
<td><strong>Fertilizer N rate</strong></td>
<td>250</td>
<td>180</td>
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<tr>
<td><strong>Yield (MT/ha)</strong></td>
<td>6.08</td>
<td>6.16</td>
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<tr>
<td><strong>Total N grain (%)</strong></td>
<td>2.55</td>
<td>2.54</td>
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<tr>
<td><strong>Total biomass</strong></td>
<td>12.67</td>
<td>12.83</td>
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Matson et al. 1998 and Ortiz-Monasterio, pers. comm.
Distribution of N fertilizer

Drinkwater and Snapp, 2007 based on data from Matson et al. 1998 and Ortiz-Monasterio, pers. comm.
To summarize key challenges:

- Nutrient management focuses on inorganic, soluble pools which are subject to loss and are ephemeral
- Despite surplus fertilizer additions, the majority of crop N uptake is still dependent on internal cycling
- Nutrient management research: Predominance of short-term, studies mainly focus on crop FUE
- Emphasis on crop FUE misses opportunities to proactively manage other processes governing nutrient cycling and NUE
- With the exception of rare instances, the current system requires surplus N additions
- Agricultural infrastructure and farmer behavior: tile drainage, mismatch of fertilization supply structure and technical support with farming needs, farm policy
Upper Mississippi River Basin - nitrogen balance

David, M.B., source David and Gentry, 2000
<table>
<thead>
<tr>
<th>Dominant framework</th>
<th>Ecosystem-based</th>
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<tr>
<td><strong>Nutrient supply</strong></td>
<td>• Optimize delivery of soluble, inorganic fertilizers to cash crop&lt;br&gt;• Single growing season</td>
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<td><strong>Soil pools actively managed</strong></td>
<td>• Inorganic N, extractable P</td>
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<td><strong>Plant-mediated processes</strong></td>
<td>• Manage crop to create a strong sink for fertilizers; remove all growth limiting factors</td>
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<td><strong>Microbial transformations</strong></td>
<td>• Inhibit nitrification</td>
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<tr>
<td><strong>Measures of NUE</strong></td>
<td>• Metrics focus on a single field season, limited to crop uptake (yield, $)</td>
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Nitrogen balance after 15 years by cropping system