The N cycle and denitrification in tile drained agricultural watersheds: Estimates and modeling

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presenting work of
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Tile drainage
- reduces the extent and duration of saturation
- accelerates water and nitrate movement

Illinois EPA Average Concentrations of Nitrate + Nitrite-N in Streams 1988-1996

Illinois EPA Average Concentrations of Nitrate + Nitrite-N in Streams 1988-1996

Tile drainage in the upper Embarras River watershed, Illinois

From Richard Coske
Big Ditch Watershed N Balance
99 km², NW Champaign Co., Water Years 2001-2
All values in kg N ha⁻¹ yr⁻¹ averaged over the entire watershed area

Inputs
155
- Deposition 8
- Fertilizer 85
- Soybean N₂ Fixation 62
Other fixation?

Outputs
167
- Deep Harvest 129
- Field Denitrification 2
- Shallow Groundwater Denitrification 2
- In-stream Denitrification <1
- Crop Harvest 129
- Stream Export 36
- Other fixation?

Internal cycling releases 36
From soil org. mat.?

Unfertilized corn uptake from soil 76
Fertilized corn + soybean residues 40

Soil N Concentration of Morrow Plots
Top 15 cm
(Source: Aref and Wander, 1998)

Soil N content to 1 m depth
East central IL cultivated fields; 1957 (USDA Soil Survey) & 2001-2
Application of ADAPT to Vermilion River Watershed above Pontiac (1500 km²)
(Sogbedji and McIsaac 2006)

ADAPT: field scale model
developed at Ohio State U by combining Drainmod and GLEAMS

First order denitrification rate coefficient in a soil layer is a function of
1) temperature
2) “active” organic carbon: fresh crop residues, manure, and
potentially mineralizable N
3) soil moisture: linear reduction from saturation to 110% of field capacity
4) calibration variable

ADAPT simulated vs measured nitrate flux in the
Vermilion River at Pontiac 1994-1997
Simulated the watershed as two large fields:
one in corn, the other in soybeans
In-stream denitrification was estimated using a separate
empirical first order decay function. The estimated in-stream
denitrification (avg. 7 kg N ha⁻¹ yr⁻¹) was added to the
observed riverine flux to estimate the edge-of-field losses,
which ADAPT was calibrated to, and simulated.

ADAPT Simulated Corn-Soybean N Budget for the Vermilion River Basin

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Applied N fertilizer</td>
<td>+ 95</td>
<td>+ 100</td>
</tr>
<tr>
<td>Manure N</td>
<td>+ 6</td>
<td>+ 6</td>
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<tr>
<td>Fixed N</td>
<td>+ 124</td>
<td>+ 126</td>
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<tr>
<td>N in rain</td>
<td>+ 8</td>
<td>+ 7</td>
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<tr>
<td>Harvest N</td>
<td>- 124</td>
<td>- 133</td>
</tr>
<tr>
<td>NO₃-N in runoff, tile drainage, and deep seepage</td>
<td>- 50</td>
<td>- 30</td>
</tr>
<tr>
<td>Denitrified N</td>
<td>- 6</td>
<td>- 4</td>
</tr>
<tr>
<td>Balance</td>
<td>+ 83</td>
<td>+ 72</td>
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</table>

Calibration Validation

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Application of SWAT to the Upper Embarras River Watershed

Soil Water Assessment Tool (SWAT)
Developed by USDA based on EPIC and SWRBB

Denitrification is estimated for the soil profile, but not streams
For each soil layer a first order denitrification rate coefficient is estimated based on
1) Calibration (default base value of 0.8 day⁻¹; calibrated for Embarras: 0.3 day⁻¹)
2) Temperature
3) Total organic carbon in the soil layer
4) If soil moisture < 95% of saturation, denitrification = 0

 SWAT Results – Monthly Nitrate Load

Calibration in Upper Embarras River
(Hu et al., in revision)

Validation in Upper Embarras River

Hydrologic Response Units
Simulated N budgets and crop yields under baseline and reduced N fertilizer rates in the Upper Embarras watershed for 1985-2002.

<table>
<thead>
<tr>
<th>N Fertilizer Reduction</th>
<th>Baseline</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>50%</th>
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<tbody>
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<td>N inputs</td>
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<td>Fertilizer</td>
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<td>87</td>
<td>77</td>
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<td>(N_2) fixation</td>
<td>98</td>
<td>99</td>
<td>101</td>
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<td>Atmospheric deposition</td>
<td>10</td>
<td>10</td>
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<tr>
<td>N outputs</td>
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<td>N removed in harvest</td>
<td>147</td>
<td>143</td>
<td>140</td>
<td>135</td>
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<td>Denitrification</td>
<td>22</td>
<td>20</td>
<td>18</td>
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<td>13</td>
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<td>(NO_3) loss to stream</td>
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<td>7.4</td>
<td>6.8</td>
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<td>Soybean yield</td>
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</tr>
</tbody>
</table>

(Hu et al., in revision)

Summary:

We don’t know how much denitrification is occurring in tile drained watersheds. A 2 yr N budget based on measurements in the Big Ditch watershed suggests in-field denitrification may be 24 kg N hr\(^{-1}\) yr\(^{-1}\), and that soil organic N is declining.

Model estimates, with calibration:

- SWAT applied to upper Embarras watershed estimates 22 kg N ha\(^{-1}\) yr\(^{-1}\).
- ADAPT applied to the Vermilion River watershed estimates ~12* kg N ha\(^{-1}\) yr\(^{-1}\) (*including over estimated in-stream denitrification).

But both models overestimate soybean N fixation, and simulate increasing soil organic N.

By way of comparison, DNDC estimates average denitrification of 30 kg N ha\(^{-1}\) yr\(^{-1}\).