N Management Recommendations for Maize: Quantification of Environmental Impacts and Approaches to Precise Management

by

Harold M. van Es

Department of Crop and Soil Sciences
Cornell University
(hmv1@cornell.edu)
NRCS 590 categories defining leaching potential are: low (below 2), medium (2-10) and high (>10). Producers are expected to implement best management practices if the Leaching Index score for a field is high (>10). Producers are expected to consider these practices if the LI score for a field is medium (2-10).

Selected BMP’s for Soils with Medium-High Leaching Potential

- Cornell-recommended rates for N application must be followed
- Sod crops should not be incorporated in the fall. Chemical sod killing may be carried out when the soil temperature at 10 cm depth is approaching 8 °C, probably not before October 1, depending on location.
- Fall and/or winter manure application on grass and/or legume sod fields that are to be rotated the following spring must be minimized.
Manure may only be applied in the Fall where there is a growing crop. Judicious amounts of manure can be applied to or in conjunction with perennial crops or winter hardy cover crops. Applications should generally not exceed the greater of 45 kg ha$^{-1}$ of actual N or 50% of the expected N requirement of next year’s crop.

Frost incorporation/injection is acceptable when soil conditions are suitable (See Cornell Guide, page 21 “Frost Tillage” (Cornell Cooperative Extension, 2002)), but winter applications should be made in accordance with the New York Phosphorus Index.
Major Soil Types and Research Locations
Cornell University Willsboro Experimental Farm
Cross-sectional view of water flow in a lysimeter plot

Soil Surface

- Water table
- "impermeable layer"
- Drain
- Liner

18 m (clay loam) / 15 m (loamy sand)
Experiment 1

Effect of N fertilizer rate and sod plowdown on nitrate leaching, crop N use, and N budgets under maize production

Fertilizer Treatments on Maize

Clay loam site was previously in alfalfa sod, which was plowed in Fall 1991. Loamy sand site was previously in grass sod, which was plowed in Spring 1992.

N fertilizer treatments (1992-1994) were:

- 22 kg ha\(^{-1}\) applied at planting
- 100 kg ha\(^{-1}\): 22 kg ha\(^{-1}\) at planting plus 78 kg ha\(^{-1}\) as sidedress based on Univ. of Vermont PSNT
- 134 kg ha\(^{-1}\): 22 kg ha\(^{-1}\) at planting plus 112 kg ha\(^{-1}\) as sidedress
Flow-Weighted Mean Nitrate Concentrations - Loamy-Sand

<table>
<thead>
<tr>
<th></th>
<th>22 kg ha⁻¹</th>
<th>100 kg ha⁻¹ (PSNT)</th>
<th>134 kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>12.0 a</td>
<td>13.3 a</td>
<td>14.3 a</td>
</tr>
<tr>
<td>1993</td>
<td>5.2 a</td>
<td>6.8 a</td>
<td>12.4 b</td>
</tr>
<tr>
<td>1994</td>
<td>4.9 a</td>
<td>7.0 b</td>
<td>11.8 c</td>
</tr>
</tbody>
</table>

EPA standard = 10 mg L⁻¹
Flow-Weighted Mean Nitrate Concentrations - Clay-Loam

<table>
<thead>
<tr>
<th></th>
<th>22 kg ha(^{-1})</th>
<th>100 kg ha(^{-1}) (PSNT)</th>
<th>134 kg ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>18.0 a</td>
<td></td>
<td>19.5 b</td>
</tr>
<tr>
<td>1993</td>
<td>5.5 a</td>
<td>5.0 a</td>
<td>10.9 b</td>
</tr>
<tr>
<td>1994</td>
<td>2.2 a</td>
<td>2.5 a</td>
<td>7.7 b</td>
</tr>
</tbody>
</table>

EPA standard = 10 mg L\(^{-1}\)
N LEACHING LOSSES (kg ha\(^{-1}\))

![Graph showing the relationship between fertilizer N rate and NO\(_3\)-N leaching losses for sand and clay soils in 1993 and 1994. The graph displays the increase in leaching losses with increasing fertilizer N rate.]
Conclusions From Experiment 1

• Sod plowing may cause high nitrate levels
• Groundwater nitrate concentrations remain at safe levels ($<10 \text{ mg L}^{-1}$) with moderate (economic) fertilizer rates
• They may readily exceed it with moderate overfertilization on coarse-textured soils
Clay loam

Precipitation (mm)
- Drained, 7.5 cm
- Undrained, 7.5 cm
- Drained, 22.5 cm
- Undrained, 22.5 cm

Soil NO₃-N (mg kg⁻¹)

Error bars indicate + or – 1 standard error

Loamy sand

Error bars indicate + or – 1 standard error
# N Transformation Rate Coefficients From LEACHM-N Model Calibration

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Rate Coefficient</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nitrification</td>
<td>Denitrification</td>
<td></td>
</tr>
<tr>
<td>Cosad Loamy Sand</td>
<td>0.391</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Kingsbury Clay Loam</td>
<td>0.240</td>
<td>0.106</td>
<td></td>
</tr>
</tbody>
</table>


Experiment 2
(1997-2000)

The effect of the timing of animal manure application on N and P leaching losses in clay loam and loamy sand soils under maize and orchardgrass


Treatments on Maize:
• early fall (Oct 1) - 93,800 L ha\(^{-1}\)
• late fall (Nov 1) - 93,800 L ha\(^{-1}\)
• early spring (April 15) - 93,800 L ha\(^{-1}\)
• split early spring (April 15) and sidedress (June 20) – 46,900 L ha\(^{-1}\) each

Treatments on Orchardgrass:
• early spring and after 1\(^{st}\) cut - 46,900 L ha\(^{-1}\) each
• after 1\(^{st}\) and 3\(^{rd}\) cut - 46,900 L ha\(^{-1}\) each
• fertilizer only – 3 x 75 kg ha\(^{-1}\) in early spring and after 1st and 2nd cut
PLOT LAYOUT OF MANURE APPLICATION STUDY (1997-2000)

*Orchardgrass*

- Early 13
  - FALL
  - after cut 1 after cut 2

- FERT. 9
  - Early, after cut 1 and 2

- Early 5
  - FALL
  - after cut 1 after cut 2

- Early 1
  - SPRING
  - after cut 1 after cut 2

Maize

- EARLY 14
  - SPRING

- EARLY 6
  - LATE SPRING

- EARLY 2
  - FERT.
  - EARLY FALL

- FERT. 3
  - Early, after cut 1 after cut 2

*Orchardgrass*

- Early 15
  - SPRING
  - after cut 1 after cut 2

- Early 11
  - FALL
  - after cut 1 after cut 2

- EARLY 7
  - SPRING
  - after cut 1 after cut 2

- EARLY 4
  - EARLY SPRING

Maize

- EARLY 16
  - FALL

- EARLY 12
  - and LATE SPRING

- LATE 8
  - FALL

- LATE 10
  - SPRING

farm lane
Leachate Nitrate Concentrations

Maize - SAND Site

Manure Treatments
- early fall
- late fall
- early spring
- split application
- precipitation

Tile outflow nitrate level (ppm)

Time
- Fall 1997
- Spring 1998
- Fall 1998
- Spring 1999
- Fall 1999
- Spring 2000

Precipitation (inches)
- 0.0
- 1.0
- 2.0
- 3.0
Leachate Nitrate Concentrations
Leachate Nitrate Concentrations
Leachate Nitrate Concentrations

Grass - CLAY Site

Manure Treatments:
- early fall
- early spring
- fertilizer only
- precipitation

Tile outflow nitrate level (ppm)

Precipitation (inches)

Time:
- Fall 1997
- Spring 1998
- Fall 1998
- Spring 1999
- Fall 1999
- Spring 2000
Flow-weighted mean NITRATE-N concentrations (mg L$^{-1}$)

<table>
<thead>
<tr>
<th></th>
<th>loamy sand</th>
<th>clay loam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIZE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>23.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Late Fall</td>
<td>19.3</td>
<td>11.8</td>
</tr>
<tr>
<td>Early Spring</td>
<td>11.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Split Applic</td>
<td>12.6</td>
<td>7.2</td>
</tr>
<tr>
<td><strong>GRASS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>2.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Early Spring</td>
<td>2.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>6.3</td>
<td>2.1</td>
</tr>
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</table>

EPA standard = 10 mg L$^{-1}$
Leachate P Concentrations

Maize - SAND Site

Manure Treatments
- early fall
- late fall
- early spring
- split application
- precipitation

Total P Concentration (mg*L^-1)

Precipitation (inches)

Time
- Fall 1997
- Spring 1998
- Fall 1998
- Spring 1999
- Fall 1999
- Spring 2000
Leachate P Concentrations

Grass - SAND Site

Manure Treatments
- early fall
- early spring
- fertilizer only
- precipitation

Total P Concentration (mg*L^-1)

Time
- Fall 1997
- Spring 1998
- Fall 1998
- Spring 1999
- Fall 1999
- Spring 2000

Precipitation (inches)
Flow-weighted mean Total P concentrations (mg L\(^{-1}\))
SAND site

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>MAIZE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Late Fall</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.09</td>
<td>0.04</td>
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<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>Split Applic</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>GRASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
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<tr>
<td>Early Spring</td>
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<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>No P</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Precip (mm)</td>
<td>216.0</td>
<td>510.0</td>
<td>183.0</td>
<td>140.0</td>
<td>127.0</td>
<td></td>
</tr>
</tbody>
</table>
Leachate P Concentrations

Maize - CLAY Site

Manure Treatments
- early fall
- late fall
- early spring
- split application
- precipitation

Total P Concentration (mg*L⁻¹)

Precipitation (inches)

Time:
- Fall 1997
- Spring 1998
- Fall 1998
- Spring 1999
- Fall 1999
- Spring 2000
Leachate P Concentrations
## Flow-weighted mean Total P concentrations (mg L\(^{-1}\)) - CLAY site

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIZE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>0.75</td>
<td>0.03</td>
<td>1.86</td>
<td>0.62</td>
<td>0.49</td>
<td>0.61 A</td>
</tr>
<tr>
<td>Late Fall</td>
<td>0.40</td>
<td>0.03</td>
<td>0.12</td>
<td>0.09</td>
<td>0.39</td>
<td>0.27 B</td>
</tr>
<tr>
<td>Early Spring</td>
<td>0.00</td>
<td>0.09</td>
<td>0.19</td>
<td>0.31</td>
<td>0.42</td>
<td>0.28 B</td>
</tr>
<tr>
<td>Split Applic</td>
<td>0.00</td>
<td>0.11</td>
<td>0.39</td>
<td>0.19</td>
<td>0.40</td>
<td>0.29 B</td>
</tr>
<tr>
<td><strong>GRASS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Fall</td>
<td>0.15</td>
<td>0.01</td>
<td>5.87</td>
<td>2.88</td>
<td>0.02</td>
<td>1.44 A</td>
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<td>Early Spring</td>
<td>0.00</td>
<td>0.01</td>
<td>0.26</td>
<td>0.92</td>
<td>0.18</td>
<td>0.19 B</td>
</tr>
<tr>
<td><strong>No P</strong></td>
<td>0.00</td>
<td>0.01</td>
<td>0.61</td>
<td>0.81</td>
<td>0.19</td>
<td>0.30 B</td>
</tr>
</tbody>
</table>
Conclusions From Experiment 2

- N leaching losses from manure application are greater for sandy compared to clay soils.
- Timing of application and incorporation of manure greatly affect N leaching losses.
- Incorporated applications in the fall result in high groundwater nitrate concentrations.
- N leaching losses from manure and fertilizer are greatly influenced by weather-related factors.
- P leaching losses on tile-drained clay soils are high, especially with fall applications. P losses are not necessarily related to manure application.
N Management in the Precision Agriculture Context

Experiment 3:

Maize N availability and use as affected by drainage class and annual weather variation

Soil Nitrate Accumulation and Losses (no crop)

- Normal year
- Wet late spring

Nitrate-N (kg ha⁻¹)

40-50 kg ha⁻¹

Early spring

Late summer
# LEACHM-Simulated Environmental N Losses

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Mineralized</th>
<th>Denitrified</th>
<th>Leached</th>
<th>Environm. Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeoye-Lima (moderately well drained)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>36.0</td>
<td>5.0</td>
<td>14.0</td>
<td>19.0</td>
</tr>
<tr>
<td>1979</td>
<td>36.0</td>
<td>5.4</td>
<td>14.0</td>
<td>19.4</td>
</tr>
<tr>
<td>1980</td>
<td>38.0</td>
<td>12.0</td>
<td>40.0</td>
<td>52.0</td>
</tr>
<tr>
<td>1981</td>
<td>36.0</td>
<td>6.0</td>
<td>11.0</td>
<td>17.0</td>
</tr>
<tr>
<td>1982</td>
<td>33.0</td>
<td>15.0</td>
<td>35.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Kendaia (somewhat poorly drained)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>42.0</td>
<td>14.4</td>
<td>10.7</td>
<td>25.0</td>
</tr>
<tr>
<td>1979</td>
<td>44.0</td>
<td>16.0</td>
<td>11.0</td>
<td>27.0</td>
</tr>
<tr>
<td>1980</td>
<td>43.0</td>
<td>50.8</td>
<td>14.6</td>
<td>65.4</td>
</tr>
<tr>
<td>1981</td>
<td>47.0</td>
<td>17.0</td>
<td>7.0</td>
<td>24.0</td>
</tr>
<tr>
<td>1982</td>
<td>46.0</td>
<td>54.7</td>
<td>11.4</td>
<td>65.0</td>
</tr>
<tr>
<td>Lyons (poorly drained)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>50.0</td>
<td>16.5</td>
<td>9.0</td>
<td>25.5</td>
</tr>
<tr>
<td>1979</td>
<td>51.0</td>
<td>17.5</td>
<td>9.0</td>
<td>26.5</td>
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<td>1980</td>
<td>50.0</td>
<td>53.0</td>
<td>14.0</td>
<td>67.0</td>
</tr>
<tr>
<td>1981</td>
<td>53.0</td>
<td>21.0</td>
<td>5.0</td>
<td>26.0</td>
</tr>
<tr>
<td>1982</td>
<td>52.0</td>
<td>56.4</td>
<td>11.7</td>
<td>68.0</td>
</tr>
</tbody>
</table>
Experiment 4
(1998-2001)

Spatial and temporal variability of maize response to N fertilizer under continuous maize and soybean-maize rotation
Methods
1998-2001 Research Effort

Rotation
CC  CS  SC

Tillage Treatments
CZCZCZCZ

Nitrogen Treatments
ZCZCZCZC

1234 etc
Profit change from the mean of the yearly 50 kg ha$^{-1}$ Rate treatment (Check rate).

• Yield values were adjusted to reflect the cost of additional N and the value of the grain produced.

• Years 1999 and 2000 show no increase in profitability beyond the 100 kg / ha rate in this experiment.

• 1998 we found profit increasing to the 220 kg / ha rate indicating higher fertilizer need for that year.
1998: 220-165 kg N ha$^{-1}$

$\Delta$Yield

$\Delta$Return

Mg ha$^{-1}$

-4 - 0

0 - 2

2 - 4

> 4

$\$ ha$^{-1}$

< -5

-5 - 5

5 - 30

30 - 120

Kahabka, J.E., H.M. van Es, and W.J. Cox. Potential for use of variable rate technology for nutrient management in New York. Precision Agriculture. Precision Agric. (in review)
Experiment 5

Field-scale N research on five farmer fields
• Five fields, two dairy, three cash grain
• Two hybrids: Pioneer 3752 and 37M81
• Two N rates: 28 kg/ha above and below recommended N rate
Soil NO$_3$-N in 1999, 2000 and 2001 at the Onondaga 1 and Onondaga 2 sites

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;12 mg kg$^{-1}$</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>12 –25</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>25-50</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
<tr>
<td>50-75</td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>75-100</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
<tr>
<td>&gt;100</td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
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</tbody>
</table>
Corn yields in 1999, 2000 and 2001 at the Onondaga 1 and Onondaga 2 sites

<table>
<thead>
<tr>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<tr>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- # < 6.0 Mg ha⁻¹
- # 6.0-7.5
- # 7.5-9.0
- # > 9.0
Corn yields in 1999, 2000 and 2001 at the Seneca 1, Seneca 2 and Seneca 3 sites

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>#</td>
<td>&lt;6.0 Mg ha⁻¹</td>
<td>6.0-7.5</td>
<td>7.5-9.0</td>
</tr>
</tbody>
</table>

*Note: The images represent the yield distribution across the sites for each year.*
Corn yield differences based on LSD (0.05) interaction values, in 1999 and 2001 between N rates at Seneca 3 (a = 1 Mg ha⁻¹ LSD, b = 0.9 Mg ha⁻¹).

<table>
<thead>
<tr>
<th>Year</th>
<th>N2=N1</th>
<th>N2&gt;N1</th>
<th>N2&lt;N1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
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Legend:
- N2=N1
- N2>N1
- N2<N1
Conclusions

- Yield showed spatial variability with temporal stability across all years at only two sites.
- On the dairy sites, the use of PSNT was not precise enough to identify areas that responded to variable N management.
- On cash crop farm, yield goal-based N applications based on yield map data would have resulted in over fertilization of N in 25% of the field where yields were greatest and under fertilization on 15% of the field where yields were least.
- Adoption of site-specific N management requires more information than late spring soil NO$_3$-N and/or yield rate map data.