A Presentation of the 2011 IA-MN-SD Drainage Research Forum

November 22, 2011
Okoboji, Iowa
Phosphorus Loss Through Subsurface Tile Drainage


Iowa State University
Nutrient Loss and Water Quality

• High P loss impairs water resources
• P has to be transported to groundwater or off fields to streams in order to impair water
• Deviations from agronomic BMPs can't be directly used to estimate risk of P loss
• Transported P forms:
  – Dissolved P: immediate, short-term impact
  – Sediment bound: delayed, long-term impact
  – Bioavailable P: A laboratory estimate of forms with "medium-term" impact
Pathways for P Loss

- **Soil erosion:**
  - gully
  - sheet and rill
  - stream bank

- **Surface runoff:**
  - infiltration excess
  - saturation excess
  - seepage

- **Subsurface drainage:**
  - tiles
  - coarse soil/subsoil
P Index Three Components

Soil Erosion
(Particulate P)

Surface Runoff
(Dissolved P)

Subsurface Drainage
(Dissolved P)

Source Factors
- soil P
- application method, timing, and rate

Soil and water conservation practices
Applied P, Soil-Test P, and P Loss

- Fertilizer or manure P application in excess of crop removal increases the soil P level and the risk of P loss with runoff or subsurface drainage.

- The risk of P loss with surface runoff begin to increase significantly at soil-test P levels slightly higher then Optimum for crops.

- Risk of P loss with tile drainage begin to increase significantly at levels 4-5 times higher than Optimum for crops.
P Loss through Tile Drainage

- Vertical P flow is mediated by water infiltration, flow, P concentration and also the soil/subsoil properties and desorbable P concentration
- Subsurface tile drains collect P containing profile water and discharge to surface drains or streams
- Lateral water and P flow to tiles should be affected by the subsoil hydrological and chemical properties
Applied P, Soil-Test P, and P Loss

• Good fertilizer management to avoid STP buildup and bad application is easy

• But with manures things get complicated
  – Uncertain nutrient concentration
  – Difficult/expensive uniform application
  – Storage needs to apply only at the best times
  – N-based manure for corn may apply excess P
    • Poultry manure for corn of corn-soybean rotations or continuous corn
    • Any manure for continuous corn
Early Data: STP and Tile Drainage P Loss

- Kenyon-Clyde soils, swine manure and P fertilizer
- Nicollet-Webster soils, poultry manure
- Nicollet-Webster soils, swine manure

Mehlich-3 Soil-Test P (ppm)

Tile Drainage Dissolved P (mg/L)

- 16 to 20 ppm optimum level for corn and soybean

Environmental Change Point

< 0.5 lb P₂O₅ lost/acre/year

Project supported by the Iowa Water Center and the Leopold Center

Mallarino, Haq, Klatt, Baker, Kanwar, Pedersen, & Pecinovsky. ISU
Three Long-Term Experiments

- Central Iowa, poultry manure rates, corn-soybean rotations
- Northeast Iowa, fertilizer or swine manure management, corn-soybean rotations or continuous corn
- Central Iowa, fertilizer or swine manure management, corn-soybean rotation, continuous corn, switchgrass, corn harvest systems for bioenergy
Central Iowa Poultry Manure Site

- 9-year study (1999-2006)
- Nicollet/Webster loam soil, loam subsoil
- 1-acre plots, ½ corn and ½ soybean, tiles at 1.2 m depth collected the combined drainage from corn and soybean areas of each plot
- 3 treatments applied in spring only for corn
  - Inorganic N fertilizer (no P)
  - Low manure rate @ 150 lb N/acre (230 lb P$_2$O$_5$)
  - High manure rate @ 300 lb N/acre (410 lb P$_2$O$_5$)
  - Therefore, 115 or 205 lb P$_2$O$_5$/acre/CS plot/year
Management Effects on Profile Soil P

Bray-1 Soil P (mg kg\(^{-1}\))

Soil Depth (cm)

PM2
PM1
No P
## Subsurface Water Flow

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*cm*
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## Dissolved Reactive P Loss

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<td>5</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>4</td>
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<td>LSD_{0.10}</td>
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<td>ns</td>
<td>ns</td>
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Correlation with Soil-Test P

Annual means or sums by treatment

\[
\text{DRP} = 5.22 + 0.0895P \\
r^2 = 0.07, P < 0.04
\]

\[
P_{\text{load}} = 4.65 + 0.0764P \\
r^2 = 0.05, P < 0.09
\]
• Soil-test P buildup was significant even for the N-based low manure rate, due to the usually low poultry manure N:P ratio
• Subsoil P was increased to a 30-cm depth
• Only the high manure rate increased P loss over the no-P control, and only on average across all years
  – The P loss was very small, ranged from just 2 to 42 g P/ha over time; on average 15 g P/ha
Northeast Iowa Experimental Site

• 11-year study (2000-2010)

• Site in Northeast Iowa:
  – 0.4-ha plots, 1 to 4% slope
  – Kenyon/Floyd/Readlyn (Aquic/Typic Hapludolls)
  – Loam to clay loam subsoil
  – Tiles at 1.2 m depth, 28.5 m spacing
  – Three replications

• Four nutrient/tillage management systems for continuous corn or corn-soybean rotations
# Management Systems

<table>
<thead>
<tr>
<th>Code</th>
<th>System</th>
<th>Crop</th>
<th>Tillage</th>
<th>Target N Rate</th>
<th>Actual P Rate</th>
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<td>Fertilizer</td>
<td>Corn</td>
<td>Chisel/Disk</td>
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<td>50</td>
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<td>Soybean</td>
<td>Disk</td>
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<tr>
<td>MNCST</td>
<td>Manure†</td>
<td>Corn</td>
<td>Chisel/Disk</td>
<td>168</td>
<td>45</td>
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<td>Soybean</td>
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<tr>
<td>MNCSNT</td>
<td>Manure†</td>
<td>Corn</td>
<td>No-till</td>
<td>168</td>
<td>43</td>
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<td></td>
<td></td>
<td>Soybean</td>
<td>No-till</td>
<td>none</td>
<td>none</td>
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<tr>
<td>MNCCT</td>
<td>Manure†</td>
<td>CS-CC‡</td>
<td>Chisel/Disk</td>
<td>200</td>
<td>73</td>
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</tbody>
</table>

† The manure always was injected.
‡ Manure to corn and soybean until 2006, continuous corn since then.
Management Effects on Profile Soil P

Soil Bray-1 P (mg kg$^{-1}$)

Soil Depth (cm)

- FP Corn-Soybean
- MN Corn-Soybean
- MN Continuous Corn
Subsurface Water Flow

11-year Average

Management System
FPCST  MNCST  MNCSNT  MNCCT

Drainage Flow (cm)

Corn
Soybean

Corn ns  LSD soyb

Management System
FPCST  MNCST  MNCSNT  MNCCT
Dissolved Reactive P Concentration

11-year Average

- Corn
- Soybean

DRP (µg L⁻¹)

Management System
- FPCST
- MNCST
- MNCSNT
- MNCCT

LSD corn Soy ns
Dissolved Reactive P Loss

11-year Average

Management system

FPCST  MNCST  MNCSNT  MNCCT

DRP Loss (g ha$^{-1}$)

Corn  Soybean

LSD corn  Soyb ns

Corn

Soybean

Management system

FPCST  MNCST  MNCSNT  MNCCT

DRP Loss (g ha$^{-1}$)

0  5  10  15  20  25

Corn

Soybean

LSD corn  Soyb ns
Correlation with Soil-Test P

Significant trend only in 2008, data by plot, a year of exceptionally high flow and P loss.
Northeast Site Conclusions

- STP buildup was large for N-based swine manure applied to continuous corn, but small for corn-soybean rotations

- Subsoil P was increased to a 30-cm depth

- P loss was highest for manure applied every year (23 g P/ha), intermediate and similar for corn-soybean rotation managed with no-till or tillage (12 g P/ha), and lowest for the fertilizer system designed to maintain an Optimum STP (4 g P/ha)
Central Iowa Bioenergy Production Systems Site
- Ongoing study (since 2008)
- Clarion/Nicollet loam soil
- Loam subsoils
- 2,000-square feet plots
- Tiles at 1.2 m depth
# Management Systems

- Chisel-plow/Disk tillage for all row crops
- Fertilizer P to maintain an Optimum soil-test level
- 150 lb N/acre for corn after soybean, and 200 lb N/acre for continuous corn
- Spring-applied treatments

<table>
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<tr>
<th>Treatment</th>
<th>Cropping System</th>
<th>Nutrient Management</th>
<th>Harvest Management</th>
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<td>1</td>
<td>Continuous corn</td>
<td>Fertilizer N and P</td>
<td>Grain</td>
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<tr>
<td>2</td>
<td>Continuous corn</td>
<td>Fertilizer N and P</td>
<td>Grain + Baled Stover</td>
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<tr>
<td>3</td>
<td>Continuous corn</td>
<td>Fertilizer N and P</td>
<td>Total Biomass</td>
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<tr>
<td>4</td>
<td>Continuous corn</td>
<td>N-Based Swine Manure</td>
<td>Grain</td>
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<td>5</td>
<td>Continuous corn</td>
<td>N-Based Swine Manure</td>
<td>Total Biomass</td>
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<tr>
<td>6</td>
<td>Corn/soybean</td>
<td>N-Based Swine Manure</td>
<td>Grain</td>
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<tr>
<td>7</td>
<td>Switchgrass</td>
<td>Fertilizer N and P</td>
<td>Total Biomass</td>
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<td>8</td>
<td>Switchgrass</td>
<td>High manure history</td>
<td>Total Biomass</td>
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</table>
Management Effects on Soil P

Soil-Test P Levels (6-inch depth) After 4 Years of Treatment Application

- Bray-1 Soil-Test P (ppm)
- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160
- 180
- P-Based Fertilizer
- N-Based
- Swine Manure
- CC
- Grain
- CC
- Biom
- Switch
- CC
- Grain
- C-S
- Grain
- Very High P History
- Switch
Reactive P Concentration

Four-Year Averages

DRP in Tile Drainage (ug L⁻¹)

P-Based Fertilizer

CC Grain

CC Biom

Switch

C-S Grain

CC Grain

CC Biom

Very High P History

Switch

N-Based Swine Manure
Reactive P Loss

Four-Year Annual Averages

Very High P History
Switch

N-Based Swine Manure

P-Based Fertilizer

C-S Grain

CC Grain

CC Biom

CC Grain

Switch

CC Biom

CC Grain

DRP in Tile Drainage (g ha$^{-1}$)
P Loss through Tile Drainage

- P loss with tile drainage begins to increase significantly at STP levels 4-5 times higher than Optimum for crops, and much lower than loss with erosion or surface runoff.
- Difficult to detect consistent management effects at lower STP levels.
- Greater soil P buildup or higher rates may significantly increase P loss with drainage by preferential flow or reducing the subsoil P filtering capacity.
Low P Subsoils Filter Soluble P

Lateral Distance (m) from a Concentrated P Solution at a 60 - 75 cm Subsoil Depth

V Olsen P (mg kg⁻¹)

Site 1
Y = 0.26 + 49.9 (-5.7^X)
R² = 0.96, P < 0.01

Site 2
Y = 1.5 + 24.2 (-4.6^X)
R² = 0.97, P < 0.01

Allen, Mallarino, Baker, and Lore; 2011
<table>
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<th>Index Component</th>
<th>Factors</th>
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<td>Bray 1-P: 200 ppm</td>
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