Managing Phosphorus for Crop Production and Environmental Protection

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Fundamentals of P Management

• Phosphorus is not like nitrogen
  – Probably less than 15% of applied P is available in the first year, especially in low P soils
  – Reductions in rate will not improve efficiency in many situations
  – Increases in efficiency will not result in decreases in loss
  – The only way to decrease loss is through management of timing and placement

• There is a dubious (if not non-existent) relationship between P use efficiency and P loss
Why P management?

• P is essential to all forms of life on earth – no known toxic effects

• Adequate P levels in soils are essential for production of agronomic crops

• In most fresh surface water bodies growth of algae or aquatic plants is limited by P availability
P impact on crop production

• Vigorous crop (Shoot/Root) growth
• Improved resource utilization
  – water, nutrients
  – positive environmental implications
• Better resistance to stress
  – disease, pest, moisture, temperature
• Earlier maturity
  – good grain & fruit development
  – better crop quality, yield
Factors influencing P availability and mobility

• Soil pH:
  – In acid soils P precipitates as insoluble Fe and Al minerals
  – In neutral and calcareous soils P precipitates as insoluble Ca phosphates
  – Soil P is most available in the pH range of 5.5 to 6.8
Phosphorus Fixation

Soil pH

Percent of total soil P (%)

Fe & Al chemical fix
Fe & Al oxides
Silicate minerals
"Available" P
Ca phosphates
Factors influencing P availability and mobility

• P moves from soil solids to plant roots through diffusion
  – Occurs over short distances < 0.25”
    • Plant roots can only obtain P located in close proximity
  – Dry soils reduce diffusion
Factors influencing P availability and mobility

• Timing and placement
• Most agricultural soils are naturally low in available P
  – Many years of P fertilization have resulted in many soils that test high in available P
• A small amount of starter fertilizer placed close to the seed may prove beneficial in these soils under cold conditions
Phosphorus Losses: Source and Transport

Sources
- P leaching
- Tile flow
- Erosion

Transport
- Runoff
- Water Body
P transport to surface waters

• Occurs primarily via surface flow
  – Dissolved P – 100% biologically available
  – Particulate P – carried on eroded particles, not immediately bio-available

• Leaching and lateral subsurface flow in limited situations

• If the soil becomes saturated with P the potential for P loss increases significantly
Types of P in Runoff

Particulate Phosphorus (PP)
• Soil organic matter P, mineral P
• Cultivated land: PP = 75% – 90% of total P
• No-till, pastures: PP<50% of total P
• Bioavailability: 10% – 90% of PP

Dissolved Phosphorus (DP)
• Soil solution P
• Cultivated land: DP = 10% – 25% of total P
• No-till, pastures: DP>50% of total P
• Bioavailability: 100%
How Much P is Lost?

Usually less than 5% of applied P is lost but this amount often exceeds the critical values for accelerated eutrophication.
Case Study: Transport overrides source

- P measured in surface runoff during natural storm events (2001 – 2004) in a strip-cropped watershed in central Pennsylvania
- Upper two fields had high soil phosphorus (144 & 177 mg kg$^{-1}$ Mehlich-3 soil phosphorus) and received manure and fertilizer
- Field closest to stream was a grass buffer with no P applied (78 mg kg$^{-1}$ Mehlich-3 soil phosphorus).

Budda et al., 2009
Watershed in Pennsylvania

- Three different areas in the same field going down the slope with different soil P and P loads in runoff.

- Mehlich-3 Soil P
  - 78 mg/kg
  - 144 mg/kg
  - 177 mg/kg
Hydrology overwhelms soil P!

- 8 kg/ha/yr P runoff load
- 4541 L Runoff Volume
- Mehlich-3 Soil P 78 mg/kg

- 1 kg/ha/yr P runoff load
- 66 L Runoff Volume
- Mehlich-3 Soil P 144 mg/kg

- <1 kg/ha/yr P runoff load
- 32 L Runoff Volume
- Mehlich-3 Soil P 177 mg/kg
Hydrology overwhelms soil P!

- Riparian zone was prone to water logging
  - runoff volumes were 46-fold greater than from other two fields combined
- 27% of the runoff from the upper two fields re-infiltrated
- If soil P threshold was used to guide P application, then P losses would have been much higher

8 kg/ha/yr P runoff load
4541 L Runoff Volume

Mehlich-3 Soil P
78 mg/kg

1 kg/ha/yr P runoff load
66 L Runoff Volume

Mehlich-3 Soil P
144 mg/kg

<1 kg/ha/yr P runoff load
32 L Runoff Volume

Mehlich-3 Soil P
177 mg/kg
Cumulative P load from four different tillage practices in *SAME* corn field at Wye Research and Education Center (2006)

Soil Test P = 65 mg kg\(^{-1}\)

**Management over P source**

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Total Phosphorus (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>4.0</td>
</tr>
<tr>
<td>TT</td>
<td>3.0</td>
</tr>
<tr>
<td>ST</td>
<td>2.0</td>
</tr>
<tr>
<td>CHP</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Residue:
- NT: 77%
- TT: 46%
- ST: 39%
- CHP: 11%

McGrath (unpublished)
Ditch Drained Systems

• Flat, low-lying, poorly drained coastal plain soils

• Extensive ditching in MD: 821 miles of ditches drain 183,000 acres of land

• Historic over application has led to elevated soil P
Surface runoff from the field only accounted for 5-22% of annual ditch P export.
Do incidental transfers from fields contribute to dissolved P in ditches?

![Graph showing dissolved P (mg/L) over time from April to September 2003. The graph illustrates a decrease in dissolved P after manure spread in May, with data points indicating lower values in July and August.](image)
APPARENTLY NOT

Dissolved P (mg/L)

Field
Ditch

Manure spread

Apr  May  June  July  Aug  Sept 2003

Courtesy: P. Kleinman
Soil P Decreases Slowly Over Time

Coale, F.J. and R. Kratochvil 2011: Unpublished data
Objectives of revised P index

- Accurately assess relative risk of P transport across physiographic provinces
- Include new science, specifically regarding P transport
- Increased emphasis on management decisions
Major Changes Found in Current Draft

- New Name: University of Maryland – Phosphorus Management Tool (UM-PMT)
- Three interpretative categories (eliminating “Very High”)
- All recommendations now based on P management
- Three major transport pathways separated arithmetically
  - Subsurface + Surface Dissolved + Particulate
<table>
<thead>
<tr>
<th>Score</th>
<th>Generalized Interpretation of P Loss Rating</th>
</tr>
</thead>
</table>
| 0-50  | - **LOW** potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site.  
  - Nitrogen-based nutrient management planning is satisfactory for this site.  
  - Soil P levels and P loss potential may increase in the future due to continued nitrogen-based nutrient management. |
| 51-75 | - **MEDIUM** potential for P movement from this site given current management practices and site characteristics. Practices should be implemented to reduce P losses by surface runoff, subsurface flow, and erosion.  
  - Nitrogen-based nutrient management should be implemented no more than one year out of three.  
  - Phosphorus-based nutrient management planning should be implemented two years out of three during which time P applications should be limited to the amount expected to be removed from the field by crop harvest or soil-test based P application recommendations, whichever is greater. |
| 76-100| - **HIGH** potential for P movement from this site given current management practices and site characteristics.  
  - Phosphorus-based nutrient management planning should be used for this site. Phosphorus applications should be limited to the amount expected to be removed from the field by crop harvest or soil-test based P application recommendations.  
  - All practical management practices for reducing P losses by surface runoff, subsurface flow, or erosion should be implemented. |
| > 100 | - **VERY HIGH** potential for P movement from this site given current management practices and site characteristics.  
  - No phosphorus should be applied to this site.  
  - Active remediation techniques should be implemented in an effort to reduce the P loss potential from this site. |
## Interpretative categories in the revised PSI

<table>
<thead>
<tr>
<th>Score</th>
<th>Generalized Interpretation of P Loss Rating</th>
</tr>
</thead>
</table>
| 0-50  | - **LOW** potential for P movement from this site given current management practices and site characteristics.  
- Soil P levels and P loss potential may increase in the future due to continued nitrogen-based nutrient management.  
- Total phosphorus applications should be limited to no more than a three-year crop removal rate applied over a three-year period. |
| 51-100| - **MEDIUM** potential for P movement from this site given current management practices and site characteristics. Practices should be implemented to reduce P losses by surface runoff, subsurface flow, and erosion.  
- Phosphorus-based nutrient management planning should be used for this site. Phosphorus applications should be limited to the amount expected to be removed from the field by crop harvest or soil-test based P application recommendations. |
| > 100 | - **HIGH** potential for P movement from this site given current management practices and site characteristics.  
- No phosphorus should be applied to this site.  
- Active remediation techniques should be implemented in an effort to reduce the P loss potential from this site. |
How will this impact farmers?

<table>
<thead>
<tr>
<th>Score</th>
<th>Old</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>N Based Planning</td>
<td>3-year P removal</td>
</tr>
<tr>
<td>51-75</td>
<td>N based 1 out of 3 years</td>
<td>P based planning</td>
</tr>
<tr>
<td>76 – 100</td>
<td>P based planning</td>
<td></td>
</tr>
<tr>
<td>&gt;100</td>
<td>No P application</td>
<td>No P application</td>
</tr>
</tbody>
</table>

- Assume continuous corn with yield goal of 150 bu/acre.
- Poultry litter testing 60-60-40 (lbs/ton).

<table>
<thead>
<tr>
<th>Score</th>
<th>Old Rate (tons/acre)</th>
<th>New Rate (tons/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>51-75</td>
<td>5 + 1.5+1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>76 – 100</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt;100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
OLD PSI = A * B

- Part A
  - RUSLE
  - Runoff
  - Leaching
  - Subsurface drainage
  - Distance to water
  - Watershed

- Part B
  - Soil test P
  - P fertilizer rate, solubility, and method
  - Organic P rate, solubility, and method

- Due to multiplicative nature of PSI you would need high transport and high source to get high score (Critical Source Area)
- However, transport pathways were summed so this approach failed where one pathway dominated
- Management was in the background
- Same source for all transport pathways
Management: Critical Source Area

Old Critical Source Area

Transport

Source and Management
Management: Critical Source Area

[Diagram showing overlapping circles labeled Management, Transport, and Source with a pointer to a new critical source area.]
PSI Modifications

- Additive pathway factors

- Subsurface

- Runoff

- Particulate
PSI Modifications

• Additive pathway factors
  – Appropriate in areas where one pathway dominates
New Calculation

- UM-PMT = Subsurface + Runoff + Particulate
- Each pathway essentially will have three parts
New Calculation

- UM-PMT = Subsurface + Runoff + Particulate
- Each pathway essentially will have three parts
New Calculation

- UM-PMT = Subsurface + Runoff + Particulate
- Each pathway essentially will have three parts

- The multiplicative nature of the index remains
  - You have to have high source and high transport potential for pathway to score high
- However, you can significantly reduce your score through improved management
New Factor: Sediment P

- Sediment bound P
  - Transport = RUSLE
  - Source = Soil test P
  - Management: Covered by RUSLE and combined distance – buffer factor
Distance-Buffer Factor

Table 1. Distance from edge of field to surface water† and resulting distance factor.

<table>
<thead>
<tr>
<th>Distance from Surface Water</th>
<th>Distance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;500 feet</td>
<td>0.2</td>
</tr>
<tr>
<td>350 to 500 feet</td>
<td>0.4</td>
</tr>
<tr>
<td>200 to 349 feet</td>
<td>0.6</td>
</tr>
<tr>
<td>100 to 199 feet</td>
<td>0.8</td>
</tr>
<tr>
<td>&lt;100 feet</td>
<td>1.0</td>
</tr>
</tbody>
</table>

†Surface water includes any permanent, continuous, physical conduit for transporting surface water, including permanent streams and ditches even if they only flow intermittently during the course of the year.

Table 2. Types of buffers† and resulting buffer factors that will modify the Distance Risk Factor to yield the combined Distance Buffer Factor.

<table>
<thead>
<tr>
<th>Type of Buffer</th>
<th>Buffer Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;50 feet Riparian Zone</td>
<td>0.7</td>
</tr>
<tr>
<td>&gt;50 feet Permanent Vegetated Buffer Meeting USDA-NRCS Standards</td>
<td>0.8</td>
</tr>
<tr>
<td>&gt;35 feet Permanent Vegetated Buffer</td>
<td>0.9</td>
</tr>
<tr>
<td>&lt;35 feet Vegetated Buffer or No Buffer</td>
<td>1.0</td>
</tr>
</tbody>
</table>

†Permanent vegetated buffers do not receive any phosphorus applications.
New Surface and Subsurface Factors Use PSR instead of STP

```
<table>
<thead>
<tr>
<th>Dissolved Reactive P (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Degree of P Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>75</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>125</td>
</tr>
</tbody>
</table>
```

- Red: Keyport sandy loam
- Yellow: Donlonton sandy loam
- Green: Matapeake silt loam
- Cyan: Mattapex silt loam

**“High P” soil**

\[ P_{ox} / 0.5 (Fe_{ox} + Al_{ox}) \]

Butler & Coale, 2003
New Factor: Surface Dissolved P

- **Surface Dissolved P**
  - **Transport** = Runoff factor from old index
  - **Source** = Soil PSR + Amendment WEP
    - Assumes equal contribution from manure and soil
  - **Management** = Application method & timing and combined distance-buffer factor
## Surface Application Methods

Table 4. Phosphorus application method factor for surface transport component ($AM_r$).

<table>
<thead>
<tr>
<th>Application Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>None Applied</td>
<td>0</td>
</tr>
<tr>
<td>Subsurface placement or immediate full incorporation (&gt;90% residue)</td>
<td>0.2</td>
</tr>
<tr>
<td>Incorporated within 5 days of application (≥50% residue)</td>
<td>0.4</td>
</tr>
<tr>
<td>Surface applied March - Nov. OR incorporated after 5 days OR &lt;50% residue</td>
<td>0.6</td>
</tr>
<tr>
<td>Surface applied or incorporated after 5 days Dec. - Feb.</td>
<td>0.8</td>
</tr>
</tbody>
</table>
New Factor: Subsurface Dissolved P

- **Subsurface Dissolved P**
  - **Transport** = Soil drainage class X Hydrologic soil group
  - **Source** = Soil PSR + Amendment WEP
    - Assumes equal contribution from manure and soil
  - **Management** = Application method & timing
## Subsurface Application Methods

### Table 3. Phosphorus application method factor for subsurface transport component (AM\(_{\text{sub}}\)).

<table>
<thead>
<tr>
<th>Application Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>None Applied</td>
<td>0</td>
</tr>
<tr>
<td>Incorporated within 5 days with soil mixing (precludes straight aerator) March - Nov.</td>
<td>0.32</td>
</tr>
<tr>
<td>Incorporated within 5 days with soil mixing (precludes straight aerator) Dec. - Feb.</td>
<td>0.4</td>
</tr>
<tr>
<td>Surface applied and subsurface placement without soil mixing (includes banded fertilizer and injection without soil mixing) March - Nov.</td>
<td>0.64</td>
</tr>
<tr>
<td>Surface applied and subsurface placement without soil mixing (includes banded fertilizer) Dec. - Feb.</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Summary...

- P is vital to crop productivity
- Repeated over-application presents environmental hazard
- Most P export comes from a small portion of the watershed as a result of relatively few storms
  - if water or soil do not move from a field or below the root zone, then P will not move
- Soil test threshold alone does not identify high risk fields and would be a major step backward
  - Hydrology has a significant influence over potential risk
  - Management must be addressed
Lab for Ag & Environmental Studies

http://www.enst.umd.edu/laes

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