Institute of Ag Professionals

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How is Phosphorus Moving from Fertilizer and Manure Sources to Surface Waters

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BACK GROUND

Section 1
- Basic concepts of soil available P

Section 2
- P behavior in soil

Section 3
- Movement of P in soils
  - Keeping P in the field
THE SOIL P CYCLE
THE SOIL P CYCLE

Components

Inputs

Outputs

Organic Fertilizer
Manure + Biosolids + Residue

Mineral Fertilizers

Nutrient Addition

Organic P
- Microbial
- Residue
- OM

Inorganic + Organic P

Plant uptake

Immobilization
Mineralization

Runoff
Leaching

Solution P

Labile P

Secondary Mineral

Primary Mineral

Adsorption
Desorption

Dissolution
Precipitation

Nutrient Addition
INORGANIC P

Agricultural soils:

- $\text{H}_2\text{PO}_4^-$
- $\text{HPO}_4^{2-}$

Soil pH determines the specific form:

- $\text{H}_2\text{PO}_4^-$ when soil pH 2.2 – 7.2
- $\text{HPO}_4^{2-}$ when soil pH 7.2 – 12.2
MINERAL FERTILIZER

- **MAP**
  - \( \text{NH}_4\text{H}_2\text{PO}_4 \rightarrow \text{H}_2\text{PO}_4^- \)

- **DAP**
  - \( (\text{NH}_4)_2\text{HPO}_4 \rightarrow \text{HPO}_4^{2-} \)

- **TSP**
  - \( \text{Ca}(\text{H}_2\text{PO}_4)_2 \rightarrow 2\text{H}_2\text{PO}_4^- \)
FERTILIZER P

Don’t get confused

\( \text{H}_2\text{PO}_4^- \) and \( \text{HPO}_4^{2-} \) is for chemistry

\( \text{P}_2\text{O}_5 \) is for fertilizer application rate

This is what is shown in fertilizer bags

\( \text{TSP} = 46\% \ \text{P}_2\text{O}_5 = 20\% \ \text{H}_2\text{PO}_4^- \)
MINERAL FERTILIZER

Solution P ↔ Labile P

\[ \text{NH}_4\text{H}_2\text{PO}_4 \leftrightarrow \text{NH}_4^+ + \text{H}_2\text{PO}_4^- \]

Solution ↔ Adsorption ↔ Desorption

H\(_2\)PO\(_4^-\) ↔ Adsorption ↔ Desorption

Always goes towards very low concentration
~0.25 – 0.5 ppm

Clay ↔ H\(_2\)PO\(_4\)

Al Oxide ↔ H\(_2\)PO\(_4\)

Fe Oxide ↔ H\(_2\)PO\(_4\)
MINERAL FERTILIZER

Solution P $\leftrightarrow$ Dissolution $\leftrightarrow$ Precipitation $\leftrightarrow$ Secondary Mineral

$\text{NH}_4\text{H}_2\text{PO}_4 \leftrightarrow \text{NH}_4^+ + \text{H}_2\text{PO}_4^-$


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MINERAL FERTILIZER

Solution P

\[ \text{NH}_4\text{H}_2\text{PO}_4 \leftrightarrow \text{NH}_4^+ + \text{H}_2\text{PO}_4^- \]

Dissolution

Precipitation

Secondary Mineral

Labile P

Insoluble P

\[ \text{Al-OH}_{2} + \text{H}_2\text{PO}_4^- \leftrightarrow \text{Al-OH} \quad + \text{H}_2\text{O} \]

\[ \text{Al-OH}_{2} \quad - \text{H}_2\text{O} \]

\[ \text{Al-OH}_{2} \quad + \text{H}_2\text{O} \]

\[ \text{Al-OH}_{2} \quad - \text{H}_2\text{O} \]

\[ \text{Al-OH}_{2} \quad \text{OH} \]

\[ \text{Al-OH}_{2} \quad \text{OH} \]

\[ \text{Al-OH}_{2} \quad \text{OH} \]

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\[ \text{Al-OH}_{2} \quad \text{OH} \]
MINERAL FERTILIZER

Primary Mineral \[ \xrightarrow{\text{Dissolution}} \] Solution P

\[ \text{Ca}_5(\text{PO}_4)_3\text{OH} \xrightarrow{-x\text{H}_2\text{O}} 5\text{Ca}^{2+} + 3\text{HPO}_4^{2-} + (x+1)\text{OH}^- + x\text{H}_2\text{O} \]

Rock Phosphate

Only a problem in soil with extremely high P levels
MINERAL FERTILIZER

Soil Phosphorus Buffer Capacity

Solution P → Adsorption → Desorption → Labile P

Solution P → Dissolution → Precipitation → Secondary Mineral

Solution P → Dissolution → Primary Mineral

Always goes towards very low concentration ~0.25 – 0.5 ppm
ORGANIC P

† Organic Sources:
  † Manure
  † Biosolids
  † Residue

† Both forms of P
  † Organic
  † Inorganic
# MANURE P DISTRIBUTION

<table>
<thead>
<tr>
<th>Manure</th>
<th># Samples</th>
<th>( P_i )</th>
<th>( P_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef</td>
<td>8</td>
<td>Range</td>
<td>48 – 67</td>
</tr>
<tr>
<td>Dairy</td>
<td>18</td>
<td>Range</td>
<td>28 – 96</td>
</tr>
<tr>
<td>Swine</td>
<td>4</td>
<td>Range</td>
<td>54 – 92</td>
</tr>
</tbody>
</table>

\( P_i = \) inorganic P in manure; \( P_o = \) organic P in manure
ORGANIC P

Organic Sources:
- Manure
- Biosolids
- Residue

Phytate

Phospholipids

DNA
ORGANIC P

Plants can only use inorganic P (H$_2$PO$_4^-$ or HPO$_4^{2-}$)

Organic P

hydrolyzed by phosphatase enzymes

pH dependent

http://en.wikipedia.org/wiki/Alkaline_phosphatase#mediaviewer/File:1ALK.png
ORGANIC P HYDROLYSIS

Behaves as inorganic P from inorganic fertilizer
ORGANIC P IMMOBILIZATION

$H_2O + 6 \rightarrow 6 OH^- + OH$

$Al^{3+}, Fe^{3+}, Ca^{2+}$

Adsorbed Labile Phosphate

Precipitated Non-labile Phosphate

Time

OH

OH

OH
ORGANIC P IN SOLUTION

Very small concentration

Controlled by clay affinity, soil organic matter, pH, and organic compound

- pH<1.5
- pH<3.5
- pH<7.5
CLAY AND ORGANIC MATTER
CLAY AND ORGANIC MATTER
P IN CLAY
P IN CLAY

[Diagram showing interactions between clay, ions, and nutrients such as Ca, Mg, K, NH₄, H₂PO₄⁻, and Ca-H₂PO₄.]
P BEHAVIOR IN SOIL

P in Agricultural soils

- ~ 50% inorganic
- ~ 50% organic
P BEHAVIOR IN SOIL

P in Agricultural soils
- ~ 50% inorganic
- ~ 50% organic

SOM C to P, C:P ratio
- < 200 net mineralization of organic P
- > 300 new immobilization of inorganic P
ORGANIC P BEHAVIOR IN SOIL

![Graph showing the relationship between total organic P (ppm) and organic P mineralized (ppm).](image)

- X-axis: Total Organic P (ppm)
- Y-axis: Organic P Mineralized (ppm)

The graph illustrates the increasing trend of organic P mineralized as total organic P (ppm) increases.
ORGANIC P BEHAVIOR IN SOIL

![Graph showing the relationship between inorganic P immobilization (ppm) and C:organic P ratio.](image-url)
ORGANIC P BEHAVIOR IN SOIL

Inorganic P Immobilization (ppm)

C:organic P Ratio
ORGANIC P BEHAVIOR IN SOIL

Soil with low inorganic P
Soil with high inorganic P
EXTRACTABLE P BEHAVIOR

Effect of organic amendment on soil P levels
EXTRACTABLE P BEHAVIOR

Effect of fertilizer addition on soil P levels
FERTILIZER P BEHAVIOR

P saturated region, high concentration of $\text{H}_3\text{PO}_4$ with pH 1.5

P saturated region, high concentration of $\text{H}_2\text{PO}_4^-$ with pH > 2.2

P precipitation region, low concentration of $\text{H}_2\text{PO}_4^-$ pH = soil pH

Formation of CaHPO$_4$ and Al/Fe phosphate minerals
P IN CLAY
P BEHAVIOR IN SOIL

Organic P (ppm)  Inorganic P (ppm)

Depth (inches)

75  150  225  500  800

6”  12”  18”  24”  36”  48”
CLAY AND ORGANIC MATTER
FIELD TRIAL

Experiment has been conducted at SWROC, Lamberton, MN from 1999 to present on a Normania loam initial STP 8 ppm

P sources
- Liquid swine manure (analyzed before application)
- Triple superphosphate

P rates
- 0, 90, and 180 lb P$_2$O$_5$ ac$^{-1}$
- Other nutrients applied to sufficiency level

P application methods
- Broadcast
- Injected (knifed for fertilizer, sweep for manure)
FIELD TRIAL


Samples were taken from 0”- 4”, 4”- 8”, and 8”- 12”
SOIL BRAY-1 P  4 – 8”

Year
Soil Bray-1 P (mg kg⁻¹)
10
20
30
fert:broad
CT
fert:knifed
CT
man:broad
NT
man:sweep
NT

Year

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SOIL BRAY-1 P  8 – 12”
LAB STUDY

- Manure applied at 40 lb total P ac\(^{-1}\)
- 25 agricultural soils
- 42 manure samples (beef, dairy, swine, poultry, goat, sheep, horse)
- Incubated for 70 days
- Moisture content = 60% during incubation
- Determined Bray-1 P at the end
MANURE P SOLUBILITY IN SOIL

Increase in Soil Test P (ppm)

Reactive Phosphorus Applied (lb ac$^{-1}$)
P IN SURFACE WATERS

Two forms: Reactive & Particulate

Runoff water
- The major path for P loss
  - Inorganic fertilizer broadcast not incorporated
  - Manure broadcast not incorporated
  - Soil with high levels of P

Leaching
- P concentration in solution
  - ~0.25 to 0.5 mg L$^{-1}$
P IN RUNOFF WATER

All together, a "little" polluted run-off adds up to BIG PROBLEMS

- Silt covered spawning beds
- Fewer game fish
- More rough fish
- Too much weed and algae growth
- Destroyed Habitats
- Unpleasant Views

http://clean-water.uwex.edu/pubs/clipart/lakesign.lakeart.htm
P IN DRAINAGE WATER

P concentration in drainage water is similar to P in soil solution (~ 0.25-0.5 ppm)
P IN DRAINAGE WATER

The problem happens when soil particles loaded with P move through preferential flow paths.

Manure and fertilizer can move down through soil channels.
KEEPING P IN THE FIELD

Two different philosophies exist for P management

- Build up and maintain
- Crop uptake

Neither is better, both have pros and cons

- Land owner might prefer build up and maintain
- Renter might prefer crop uptake
KEEPING P IN THE FIELD

Avoid elevating P concentration to extremely high values, e.g. 100ppm

Incorporate fertilizer soon after application

Incorporate manure/biosolids the same day or next after application, also good for N
**KEEPING P IN THE FIELD**

Avoid manure winter application:
- 100% of inorganic P in manure can move with rain water/snow melt
- Best time to apply? When manure can be incorporated

Tillage can help
- Use tillage practices that help reduce runoff
- Keep some residue cover
KEEPING P IN THE FIELD

Cover crop?

Grain crops only need up to 60-70 lbs of P for maximum yield
Thank you for attending

Questions?