Phosphorus in a global context
Persistent issues in research and management

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Understanding Algal Blooms: State of the Science
September 13, 2018. Toledo, OH.
Discovery of phosphorus

1669

A MODERN, SCIENTIFIC PROTOCOL

1. Boil urine to reduce it to a thick syrup.
2. Heat until a red oil distills up from it, and draw that off.
3. Allow the remainder to cool, where it consists of a black spongy upper part and a salty lower part.
4. Discard the salt, mix the red oil back into the black material.
5. Heat that mixture strongly for 16 hours.
6. First white fumes come off, then an oil, then phosphorus.
7. The phosphorus may be passed into cold water to solidify.

5,500 L (1,400 gal) of pee gets you 120 g (1/4 lb) of P!

Hennig Brand and the Philosopher’s Stone
Devilishly useful
Phosphorus as a crop nutrient
A pillar of modern crop production

SYNTHETIC FERTILIZER USE

Courtesy H. Poffenbarger.
Challenge: the inequity of resource distribution

Overcoming soil P buffering

Phosphorus fertility - historical priority

Fertilizing the soil to get to the crop

P in the soil solution, ppm

P bound to soil particles, ppm

Soil with low buffer capacity leaves more P for plant

Soil with high P buffer capacity binds more P

Plant root

P

2-4 mm

NH₄, K
15 mm

NO₃, SO₄
40 mm

Historical priority

Fertilizing the soil to get to the crop
Inherently inefficient

$P$ loss to water

**Dissolved P**

tile drainage

(mg/L)

**Crop response threshold**

- **Mehlich-3 P**, upper 2 inches

Source: King, USDA-ARS
Dissolved P - the universal headache
aka “soluble P”

Maumee

Sandusky

Cuyahoga

Chesapeake

Lake Erie

Baltic Sea
Eutrophication persists despite decades of watershed mitigation efforts

Image credit: World Resources Institute
Thinking of P as a resource

*a matter of budgets*

<table>
<thead>
<tr>
<th></th>
<th>Crop</th>
<th>Dairy</th>
<th>Swine</th>
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<tbody>
<tr>
<td><strong>P imported</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>fertilizer</td>
<td>18</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>feed</td>
<td>0</td>
<td>30</td>
<td>104</td>
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<tr>
<td><strong>P exported</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>milk/animals</td>
<td>0</td>
<td>12</td>
<td>20</td>
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<tr>
<td>crops</td>
<td>16</td>
<td>1</td>
<td>0</td>
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<tr>
<td><strong>P balance</strong></td>
<td>2</td>
<td>29</td>
<td>84</td>
</tr>
</tbody>
</table>

Source: Lanyon (1999)
“Legacy P” and animal agriculture intensification and specialization of farming systems

Regional P imbalances

Poultry
Swine
Cattle
Phosphorus: circular economy poster child

DEAD ZONES
Point and non-point source polluters increase excess phosphorus in waterways creating algae blooms that destroy precious ecosystems.

CIRCULAR ECONOMY
Ostara’s Pearl process recovers nutrients from a renewable source and transforms them into an environmentally friendly high value fertilizer.
Phosphorus: more valuable than oil?

Cordell et al., 2009

USGS, 2010

IFDC, 2010

Resource

Commercial reserves

16

60

Phosphate rock (Billion tons)

Phosphorus production (MTPYr)

Million tons

0 50 100 150 200 250

1900 1920 1940 1960 1980 2000

Peak Phosphorus curve

Actual

Modelled

USGS, 2010

IFDC, 2010

0 100 200 300

0 50 100 150 200
Commercial reserves of rock phosphate – 2016

National case for food security

Morocco, 70%

Russia, 2%

Syria, 3%

Finland, 3%

S. Africa, 2%

Peru, 1%

USA, 2%

Algeria, 3%

Australia, 1%

China, 5%

Egypt, 2%

Iraq, 1%

Jordan, 2%

S. Africa, 2%

USA, 2%
Opportunities for improvement

P Use Efficiency, Consumption, Recovery

RECOVERY

*a wastewater centric perspective*

- Food
- Agriculture
- Humans
- Biosolids
- Recovery - liquid
- Recovery - solids
- Sewage
- Sewage sludge
- Treatment Plant
Biosolids Land Application

*Increasingly Challenged*

**Conclusions**

- It would be a devastating step backwards to lose sludge as a source of nutrients.
- Cooperation ... efficient way.
- Working at high quality contributes to... 

**This Is A Dirty Bomb**

- Phosphorus recovery from water phase

**NH₄MgPO₄·6H₂O**

**Struvite Recovery**

**Ash2Phos**

**Phosphate recovery from water phase**

**HSY – New Research**
Nutrient recovery systems for CAFOs

99.6% removal of P from this dairy manure
Implementation challenges

Policies, markets, scale, incentives

- Purdue litter pelletizing plant
- Fibrominn turkey litter power plant
- Valio 5500 Finnish Dairies N and P recovery system
- Dane County Wisconsin manure digester
- Arkansas poultry litter baling
Food production and environmental health

Moving beyond win-win assumptions

Obtained from Withers et al., 2017, displaying relationships of Poulton et al. (2013) and Heckrath et al. (1998)
Critical Source Area Management

Managing sources and transport pathways

HOT SPOTS

Regional diagram showing critical source areas and flows that bypass native buffers.

HOT MOMENTS

Graph showing tile flow (ft) and dissolved P (mg/L) from April to June.

Source: King, USDA-ARS
Critical Source Area Management

Disconnecting sources and transport pathways

HOT SPOTS

Phosphorus Source

Transport Mechanism

HOT MOMENTS

Tile flow (ft)

Dissolved P (mg/L)

Source: King, USDA-ARS
Critical source areas

Chesapeake Bay uplands

WE-38 Watershed (7.3 km²)

Mattern (11 ha)
Fragipan soils enhance runoff

Infiltration excess
Saturation excess

4620 L

46 L

92 L

Berks soil
No fragipan, well drained

Albrights soil
Fragipan, poorly drained
Even modest sources can create large loads when they are hydrologically active.

- Albrights soil: Fragipan, poorly drained
  - Mehlich-3 P: 78 mg/kg
  - Total P: 6 kg/ha/yr

- Berks soil: No fragipan, well drained
  - Mehlich-3 P: <1 kg/ha/yr
  - Total P: <1 kg/ha/yr

- 1 kg/ha/yr
Field drainage – ditches and tiles

lower water tables, faster travel times, increased connectivity
Drainage in the P Index

Comparison with ditch P loadings

Maryland’s P Management Tool

North Carolina’s P Loss Assessment Tool

Dissolved P load (kg/ha/yr)

PMT Subsurface Score

PLAT’s Subsurface Score

Shober et al., 2017. Univ. Delaware
The allure of magic dust
structured liming and gypsum
Reactors
4R Nutrient Stewardship
A framework for strategic management
Soil fertility recommendations

Complex, old and opaque

North American Tests
- Ammonium Lactate
- Bray-Kurtz 1, Bray-Kurtz 2
- Morgan’s, Cornell Morgan’s
- Modified Morgan’s
- Mehlich-1
- Mehlich-3
- Kelowna, Modified Kelowna
- Miller-Axley
- Olsen
- Saskatchewan

Proposed Tests
- Fe-oxide strip
- Resin
- Haney soil health test?

Soil P maintenance and land rental

**Contractual obligations**

- 39% of U.S. cropland rented in 2012
- More than 50% of cropland in Western Lake Erie is rented
- Soil P maintenance required in rental agreement
Revisiting P fertilizer recommendations

*How low can you go?*

Early season signs of deficiency are not the same as yield decline.
**Struvite – slow release fertilizer**

*generally substitutes for high solubility fertilizers*

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<table>
<thead>
<tr>
<th>Citation</th>
<th>Year</th>
<th>Type</th>
<th>Crop</th>
<th>Struvite Source</th>
<th>Improvement in crop*</th>
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</thead>
<tbody>
<tr>
<td>(Bridger et al.)</td>
<td>1962</td>
<td>pot</td>
<td>Herbaceous flowers, tomatoes</td>
<td>USA, chemical reagents</td>
<td>0–100 NR SOL</td>
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<tr>
<td>(Bridger et al.)</td>
<td>1962</td>
<td>field</td>
<td>Shrubs, grasses</td>
<td>USA, chemical reagents</td>
<td>40–75 NR</td>
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<tr>
<td>(Terman &amp; Taylor)</td>
<td>1965</td>
<td>pot</td>
<td>Maize</td>
<td>USA, chemical reagents</td>
<td>40 SS</td>
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<td>(Ghosh et al.)</td>
<td>1996</td>
<td>pot</td>
<td>Chickpea, gram</td>
<td>India, chemical reagents</td>
<td>50 SS SOL</td>
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<tr>
<td>(Goto)</td>
<td>1998</td>
<td>pot</td>
<td>Komatsuna, green vegetable</td>
<td>Japan, &quot;recovered&quot; struvite</td>
<td>50 SS SOL</td>
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<tr>
<td>(Johnston &amp; Richards)</td>
<td>2003</td>
<td>pot</td>
<td>Ryegrass</td>
<td>UK, chemical reagents</td>
<td>100 SS SOL</td>
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<tr>
<td>(Johnston &amp; Richards)</td>
<td>2003</td>
<td>pot</td>
<td>Ryegrass</td>
<td>Japanese sewage, and Dutch sewage &amp; manure</td>
<td>100 SS SOL</td>
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<tr>
<td>(Johnston &amp; Richards)</td>
<td>2003</td>
<td>pot</td>
<td>Ryegrass</td>
<td>Spanish red dye liquor, US corn liquor</td>
<td>100 SS SOL</td>
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<tr>
<td>(Li &amp; Zhao)</td>
<td>2003</td>
<td>pot</td>
<td>Cabbage, chard, spinach, etc</td>
<td>Hong Kong, landfill leachate</td>
<td>&gt;100 SS</td>
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<td>(Romer)</td>
<td>2006</td>
<td>pot</td>
<td>Ryegrass</td>
<td>German and USA manure</td>
<td>&gt;100 SS SOL</td>
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<tr>
<td>(Romer)</td>
<td>2006</td>
<td>pot</td>
<td>Ryegrass</td>
<td>German, Italian, and Japanese sewage</td>
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<td>(Gonzalez Ponce &amp; Lopez-de-Sa)</td>
<td>2007</td>
<td>pot</td>
<td>Perennial ryegrass</td>
<td>Spain, municipal wastewater</td>
<td>SS &gt;SOL</td>
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<td>(Montag et al.)</td>
<td>2007</td>
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<td></td>
<td>Germany, sewage sludge</td>
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<td>(Plaza et al.)</td>
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<td>Ryegrass</td>
<td>Spain, municipal wastewater</td>
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<td>(Garrot et al.)</td>
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<td>pot</td>
<td>Wheat</td>
<td>Sweden, human urine, also</td>
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<td>(Gonzalez Ponce &amp; Lopez-de-Sa)</td>
<td>2008</td>
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<td>White lupine</td>
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<td>(Cabeza Perez et al.)</td>
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<td>(Cabeza Perez et al.)</td>
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<td>Rapeseed and winter barley</td>
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<td>(DLV)</td>
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<td>Flowers, potatoes, Brussels sprouts</td>
<td>Netherlands, potato wastewater</td>
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<td>(Massey et al.)</td>
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<td>Spring wheat</td>
<td>USA, dairy waste and process wastewater</td>
<td>&lt;25 SS &lt;SOL</td>
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<td>(Gonzalez Ponce et al.)</td>
<td>2009</td>
<td>pot</td>
<td>Lettuce</td>
<td>Spain, municipal wastewater</td>
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<td>(Weinfurter et al.)</td>
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<td>pot</td>
<td>Maize</td>
<td>Germany, sewage sludge</td>
<td>20–100 SS SOL</td>
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<td>(Yetilmezsoy &amp; Sapci-Zengin)</td>
<td>2009</td>
<td>field</td>
<td>Parslane, cress, grass</td>
<td>Turkey, digested poultry manure</td>
<td>&gt;100 NR</td>
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<tr>
<td>(This study)</td>
<td>2010</td>
<td>field</td>
<td>Maize</td>
<td>Netherlands, urine and black water</td>
<td>&lt;30 NS SOL</td>
</tr>
</tbody>
</table>

* Number refers to % improvement over control in P-uptake and/or yield; SS = improvement is statistically significant; NS = improvement is not statistically significant; NR = statistics not reported; SOL = comparable to soluble fertilizer.

Adapted from Thompson et al., 2013. Iowa State Univ.

Adapted from Gell et al., 2010
Better Fertilizer Decisions for Cropping Systems

Australia’s model program
Better Fertilizer Decisions for Cropping Systems

Australia’s model program

BFDC Database
5000 soil test/crop response relationships
1960s to present
Standardized (depth, response units, etc)

Calibration

BFDC Interrogator program
Transparency
Consistency

Certification
Training
Hennig Brand and the Philosopher’s Stone

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