Managing Phosphorus
4R
Crops and Environment

Tom Bruulsema, Phosphorus Program Director
The International Plant Nutrition Institute is supported by leading fertilizer manufacturers.

Formed in 2007 from the Potash & Phosphate Institute, its mission is to develop and promote science for responsible management of crop nutrition.
Outline

1. Sustainable Phosphorus
2. 4R
3. Effective Practices

http://phosphorus.ipni.net
Phosphorus Sustainability Initiatives:

- resource consumption & use efficiency
- trace element loading
- water quality impacts

“Phosphorus Footprint”

“Peak Phosphorus”

Rostock (Germany), September 12-16, 2016 PHOSPHORUS 2020 —
CHALLENGES FOR SYNTHESIS, AGRICULTURE, AND ECOSYSTEMS

IPW8: 8th International Phosphorus Workshop
Phosphorus Issues

- Eutrophication
- Hypoxia
- Harmful algal blooms
- Excess levels in soil, stratification
- Deficient levels in soil, crop yield limitation

- Finite resource, geopolitical distribution
- Declining quality of reserves
- Heavy metals, trace elements and cadmium
- Environmental impact of mining
As a sustainability system, 4R Nutrient Stewardship needs METRICS.
Nutrient Stewardship Metrics for Sustainable Crop Nutrition

**Enablers (process metrics)**
- Extension & professionals
- Infrastructure
- Research & innovation
- Stakeholder engagement

**Actions (adoption metrics)**
- Cropland area under 4R [Requires regional definitions of 4R practices]

**Outcomes (impact metrics)**
1. Farmland productivity
2. Soil health
3. Nutrient use efficiency
4. Water quality
5. Air quality
6. Greenhouse gases
7. Food & nutrition security
8. Biodiversity
9. Economic value
4R Outcome Metrics are influenced by 4R and more.
OUTCOMES of nutrient stewardship are influenced by crop and pest management, and by soil and water conservation practices in the context of changing weather and climate.
High-yield crops take up large amounts of P. Most of it is removed with grain harvest.

Maize grain yield
12 t/ha
Illinois, 2010

2010 data from two sites and six hybrids
Research shows potential for altered P placement needs in high density high yield maize

- Banding P fertilizer
- 10-15 cm deep

Yield, t/ha

<table>
<thead>
<tr>
<th></th>
<th>Yield, t/ha</th>
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<tbody>
<tr>
<td>none</td>
<td>11.7</td>
</tr>
<tr>
<td>15 cm beside</td>
<td>12.0</td>
</tr>
<tr>
<td>under</td>
<td>13.0</td>
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Dr. F.E. Below, University of Illinois
Crop yield contribution from phosphorus use is very substantial in the long term.

How much crop yield can be attributed to P in the short term (one year)?

- Expected to be zero, or very small, on soils with adequate P levels
- When soil test P is below critical levels:
  - ~15% (0-23%) for soy
  - ~20% (0-30%) for corn
  - ~40% (10-50%) for wheat, oats, alfalfa and clover in Illinois (Figure 8.5, Illinois Agronomy Handbook)

![Figure 8.5. Relationship between expected yield and soil P, measured colorimetrically by the Bray P$_1$ or Mehlich-3 procedures on neutral-to-acid soils, or by the Mehlich-3 procedure on soils with pH > 7.3.](image-url)
Illinois soil test P declined from 2001 to 2015

Phosphorus sample distribution: Illinois

- 2001: 142,619
- 2005: 534,904
- 2010: 224,860
- 2015: 725,960

2015: 39% of soils below critical
20% optimal

Bray and Kurtz P1 soil test, ppm

http://soiltest.ipni.net
PUE: Ratio of removal to use varies across US cropland
Phosphorus Balance, corn belt – on average, seldom in surplus
Environmental Impact

- Eutrophication
- Hypoxia
- Harmful Algal Blooms

Photo credit: Carrie Vollmer-Sanders, The Nature Conservancy
<table>
<thead>
<tr>
<th>Condition Category</th>
<th>2012 Percentage of Lakes</th>
</tr>
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<tbody>
<tr>
<td>Most Disturbed</td>
<td>40%</td>
</tr>
<tr>
<td>Moderately Disturbed</td>
<td>15%</td>
</tr>
<tr>
<td>Least Disturbed</td>
<td>45%</td>
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</table>
Defining 4R phosphorus practices at the continental scale.
4R P Practices - Participating Scientists

1. Brian Arnall, Oklahoma State U
2. Doug Beegle, Penn State U
3. Don Flaten, U of Manitoba
4. Laura Good, U of Wisconsin
5. Kevin King, USDA-ARS, Columbus, OH
6. Quirine Ketterings, Cornell U
7. Josh McGrath, U of Kentucky
8. Antonio Mallarino, Iowa State U
9. Rao Mylavarapu, U of Florida with input from other colleagues.
10. David Mulla, U of Minnesota
11. Nathan Nelson, Kansas State U
12. Keith Reid, Agriculture and Agri-Food Canada
13. Nathan Slaton, U of Arkansas
14. Charles Shapiro, U of Nebraska
15. Andrew Sharpley, U of Arkansas
16. Doug Smith, USDA-ARS, Temple, TX
17. Ivan O’Halloran, U of Guelph
18. Deanna Osmond, North Carolina State U
19. David Tarkalson, USDA-ARS, Kimberly, ID
Regions and Cropping Systems

1. Western Corn and Soybean
2. Eastern Cereals and Oilseeds
3. Wheat in the Great Plains
4. Irrigated Potatoes in the Northwest
5. Rice
6. Irrigated vegetables

4R Phosphorus Practices for Western Crops (including Illinois)

• Basic
  – Source: known or guaranteed analysis
  – Rate: recommended soil sampling and soil test interpretation
  – Timing: avoid frozen and snow-covered soils, forecast rainfall
  – Placement: subsurface band encouraged; on surface only for no-till when risk index is low

• Intermediate
  – Source: manure sampled for nutrients
  – Rate: as in basic, plus: P index used
  – Timing: as in basic, & use P Index and avoid seasonal rainfall intensity
  – Placement: as in basic, plus avoid furrows of furrow-irrigated crops
4R Phosphorus Practices for Western Crops (including Illinois)

• Advanced
  – Source: as in intermediate
  – Rate: as in intermediate, plus: zone-specific based on soil sampling every 2 years, and crop yield maps
  – Timing: as in intermediate
  – Placement: as in intermediate, plus: terrain analysis to manage P loss

ADAPTIVE MANAGEMENT
  – Decisions are site-specific and adaptive to changing conditions. Not everything can be written down.
Western Lake Erie: dissolved P trends increasing since 2002

1. David Baker & Laura Johnson, National Center for Water Quality Research, Tiffin, OH
Soil test P distribution with depth in a long-term tillage experiment on a poorly drained Chalmers silty clay loam soil near West Lafayette, Indiana. Moldboard and chisel plots were plowed annually to a depth of 20 cm. Data from Gál (2005) and Vyn (2000). Fertilizer P applied broadcast.
Fertilizer P is Soluble P

- MAP (11-52-0) has water solubility of 370 g/L
- = 84 grams P per litre
- = 84,000 mg P per litre

- Maumee river target for DRP = 0.047 mg P per litre

- Targets for Lake Erie:
  Western Basin – 0.012 mg/L
  Central Basin – 0.006 mg/L
  Eastern Basin – 0.006 mg/L
Ohio
P loss monitoring at edge of field
Soil Drainage Research Unit

Right Rate

Spring (Mar through Jul) Water Year (Oct through Sep)

DRP load (kg/ha)

TP load (kg/ha)

Mehlich III soil test P (mg/kg)

Kevin King, USDA-ARS, Columbus, Ohio
When is the right time?

Kevin King, USDA-ARS, Columbus, Ohio
Right Timing

Time of Application

- Greatest potential for surface and tile losses occurs with fall and winter application
- Applying P in spring or after wheat harvest seems to minimize surface and tile losses

Kevin King, USDA-ARS, Columbus, Ohio
1. Intense rainstorms following broadcast of P can generate high P concentrations in runoff even though losses are small relative to amount applied.

2. As the time intervals increase between surface broadcast P applications and runoff-producing rainfall events, DRP concentrations spike less.
Broadcast? at the right time to avoid runoff
Right Place – in the soil, not on the soil

**Soil type:** Silt loam  
**Tile depth:** 90 cm  
**Soil test P:** 30 ppm Mehlich-3P  
**Tillage:** No-till

**2014 management**  
*May 6th – Applied MAP @ 45 kg P/ha*  
*May 8th – Tilled field TD1 (disc)*  
(TD2 remained no-till)

Compared P transport out of the tile drains  
1. Broadcast P incorporated versus  
2. Broadcast P not incorporated

*Williams and King, USDA-ARS, Columbus, Ohio*
Before P application & tillage (April 28th)

After P application & tillage (May 12th)

P incorporated  P not incorporated

Incorporating reduced DRP loss from 0.27 to 0.04 lb P$_2$O$_5$ per acre

Williams and King, USDA-ARS, Columbus, Ohio
Some growers fertilize all their crops in bands near the seed.
Fall Strip-till Banding

- Puts the P in the soil
- Keeps residue on the soil
- RTK GPS for precision planting

Greg LaBarge, Ohio State University Extension
Strip tillage with granular placement puts P in the right place – and controls erosion.
**4R efficacy for reducing P loss, % reduction**

- ranges found in field experiments across the USA and Canada

<table>
<thead>
<tr>
<th>Practice</th>
<th>Dissolved P</th>
<th>Particulate P</th>
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<tbody>
<tr>
<td>Source</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Rate</td>
<td>60 to 88%</td>
<td>negligible</td>
</tr>
<tr>
<td>Time</td>
<td>41 to 42%</td>
<td>negligible</td>
</tr>
<tr>
<td>Place</td>
<td>20 to 98%</td>
<td>-60% to NS</td>
</tr>
<tr>
<td>Soil inversion</td>
<td>NS to 92%</td>
<td>-59% to NS</td>
</tr>
<tr>
<td>Conservation tillage</td>
<td>-308 to -40%</td>
<td>-33 to 96%</td>
</tr>
</tbody>
</table>


1. **Wide range of efficacies demands more site-specific focus.**
2. **Trade-off between dissolved and particulate is important.**
4R NUTRIENT STEWARDSHIP CERTIFICATION PROGRAM

Western Lake Erie Basin - Ohio, Michigan & Indiana

Voluntary program for agricultural retailers & nutrient service providers implementing the 4Rs
4R Ontario is Moving Forward...

- **4R Ontario MOC: 2015-2018**
  - Continue to promote increased adoption of 4R; provide general retailer staff and farmer training; and develop affiliated resources
  - **4R Retailer Certification** – focus on building capacity, industry accountability, relevant targets, program standards
  - Identify research gaps
  - Increased communication efforts
Phosphate Rock Reserves and Quality

• Grade, $P_2O_5$ content, trace elements
• Phosphogypsum
• Peak phosphorus by 2033? Cordell & White, 2009:
Map of World P Resources
250 billion tonnes
in >100 countries

Sources: IFDC; USGS (2002, 2013)
“No matter how much phosphate rock exists, it is a non-renewable resource”
IFDC, 2010

<table>
<thead>
<tr>
<th>Country</th>
<th>2014-15 Production</th>
<th>Reserves</th>
<th>R/P ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco</td>
<td>30 Mt</td>
<td>50,000 Mt</td>
<td>1670 Years</td>
</tr>
<tr>
<td>South Africa</td>
<td>2 Mt</td>
<td>1,500 Mt</td>
<td>750 Years</td>
</tr>
<tr>
<td>Jordan</td>
<td>7 Mt</td>
<td>1,300 Mt</td>
<td>186 Years</td>
</tr>
<tr>
<td>Russia</td>
<td>12 Mt</td>
<td>1,300 Mt</td>
<td>108 Years</td>
</tr>
<tr>
<td>USA</td>
<td>26 Mt</td>
<td>1,100 Mt</td>
<td>42 Years</td>
</tr>
<tr>
<td>China</td>
<td>100 Mt</td>
<td>3,700 Mt</td>
<td>37 Years</td>
</tr>
<tr>
<td>World Total</td>
<td>220 Mt</td>
<td>69,000 Mt</td>
<td>314 Years</td>
</tr>
</tbody>
</table>

Source: USGS, 2016

Cover of The Fertilizer Review Vol. XIII, March–April 1938, No. 2, illustrating the role of the undeveloped Western phosphate deposits in U.S. phosphorus supply considerations. **Depletion concerns about national PR reserves were eminent at the time but could not be substantiated.**


**Global ore tonnage and grade:**
- 1983: 513 Mt @ 14.3% P$_2$O$_5$
- 2013: 661 Mt @ 17.5% P$_2$O$_5$

**Steiner et al., 2015, CRU report.**
Summary

• With 4R, nutrient service providers can engage the sustainability movement to build social trust.

• Site-specific 4R phosphorus practices limit dissolved losses and need to be synergized with conservation practices controlling particulate losses.

• Opportunities to recycle phosphorus could reduce strain on finite natural resources, and can improve water quality where soil P is in surplus.