Indiana Certified Crop Adviser Conference
14 December 2016
Indianapolis, Indiana

IPNI
INTERNATIONAL
PLANT NUTRITION
INSTITUTE

# Managing Phosphorus
# 4R
# Crops and Environment

**Tom Bruulsema**, Phosphorus Program Director

4R nutrient stewardship

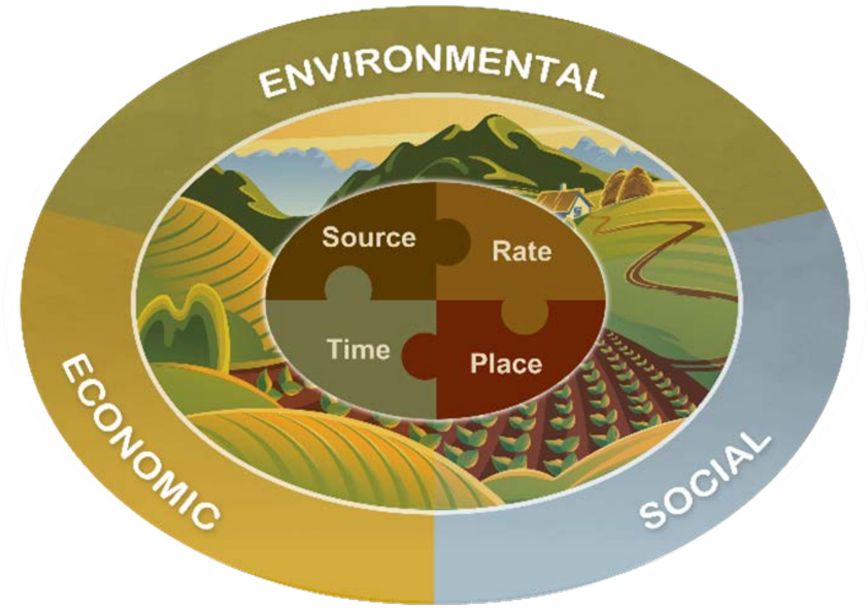
| | | | |
|---|---|---|---|
| Agrium Inc. | Arab Potash Company | BHP Billiton | CF Industries Holdings, Inc. |
| Compass Minerals Plant Nutrition | International Raw Materials LTD | Kingenta Ecological Engineering Group Co., Ltd. | K+S KALI GmbH |
| The Mosaic Company | OCP S.A. | PhosAgro | PotashCorp |
| Shell Sulphur Solutions | Simplot | Sinofert Holdings Limited | SQM |
| Uralchem, JSC | Uralkali | Yara International ASA | |

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




4R nutrient stewardship

http://phosphorus.ipni.net

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# The emerging discipline of phosphorus sustainability science

"Phosphorus Footprint"

"Peak Phosphorus"

## Phosphorus Sustainability Research Coordination Network

**Summary:** The Phosphorus Sustainability Research Coordination Network (P-RCN) was funded by the U.S. NSF to identify solutions for P sustainability by sparking an interdisciplinary synthesis of data, perspectives, and understanding about phosphorus. The P-RCN has over 50 academic participants and meets annually to engage stakeholders and coordinate and integrate P sustainability research.

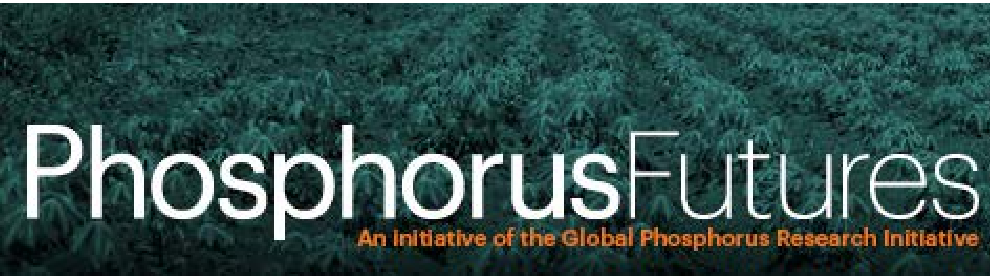
ELSEVIER

Global Environmental Change

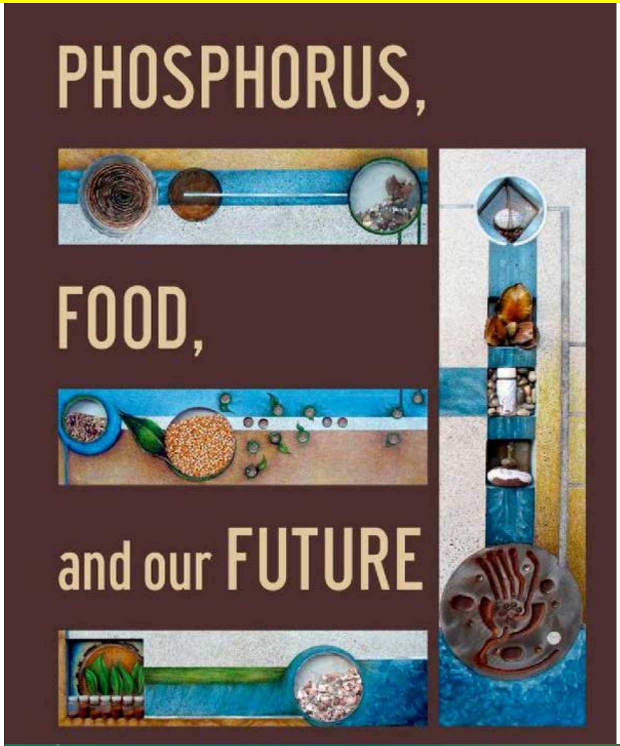
Volume 19, Issue 2, May 2009, Pages 292–305

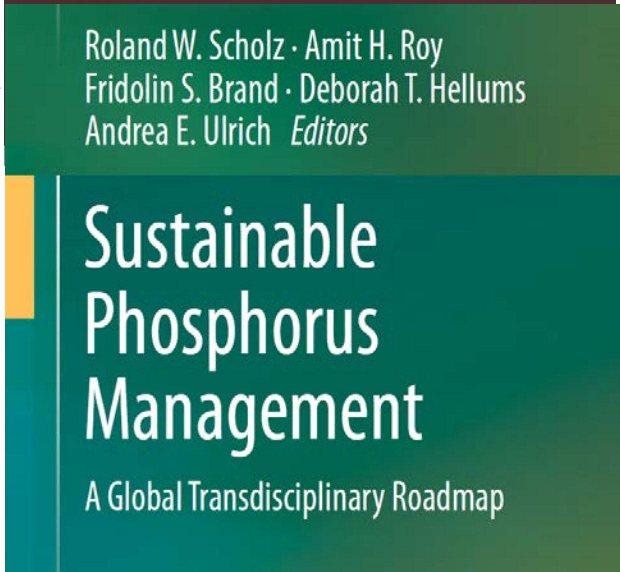
Traditional Peoples and Climate Change

The story of phosphorus: Global food security and food for thought




GLOBAL PHOSPHORUS RESEARCH INITIATIVE



# Phosphorus sustainability initiatives inform policy and the public

Sustainable Phosphorus Alliance

## Our Vision

We envision a food system that manages phosphorus more sustainably to provide abundant, nutritious food while protecting the health of rivers, lakes, and oceans.

GPNM
Global Partnership on Nutrient Management

August 16-20, 2016

Kunming, Yunnan, China

5th Sustainable Phosphorus Summit 2016 (SPS 2016)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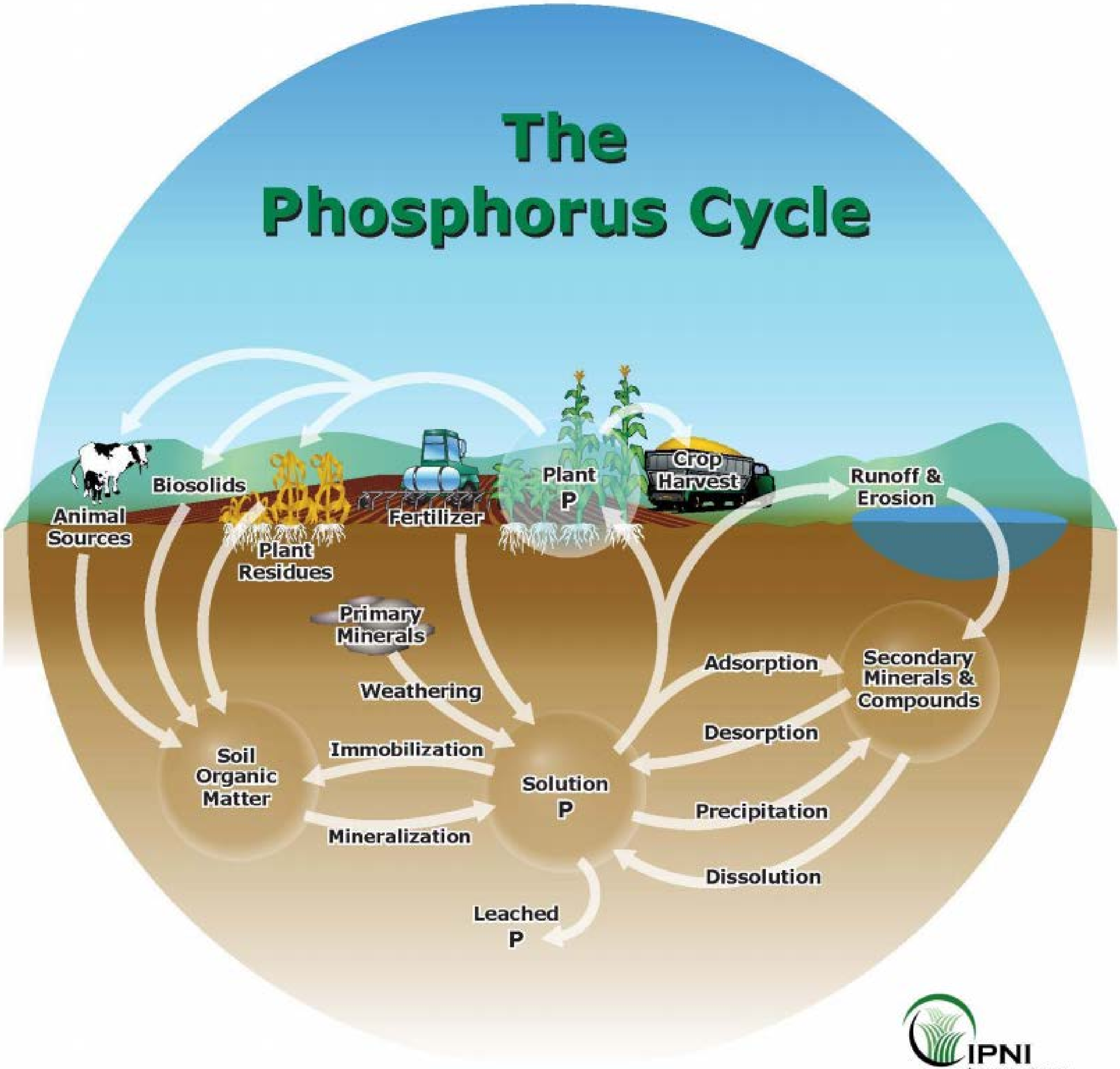
# The farm perspective focuses on the soil and the crop

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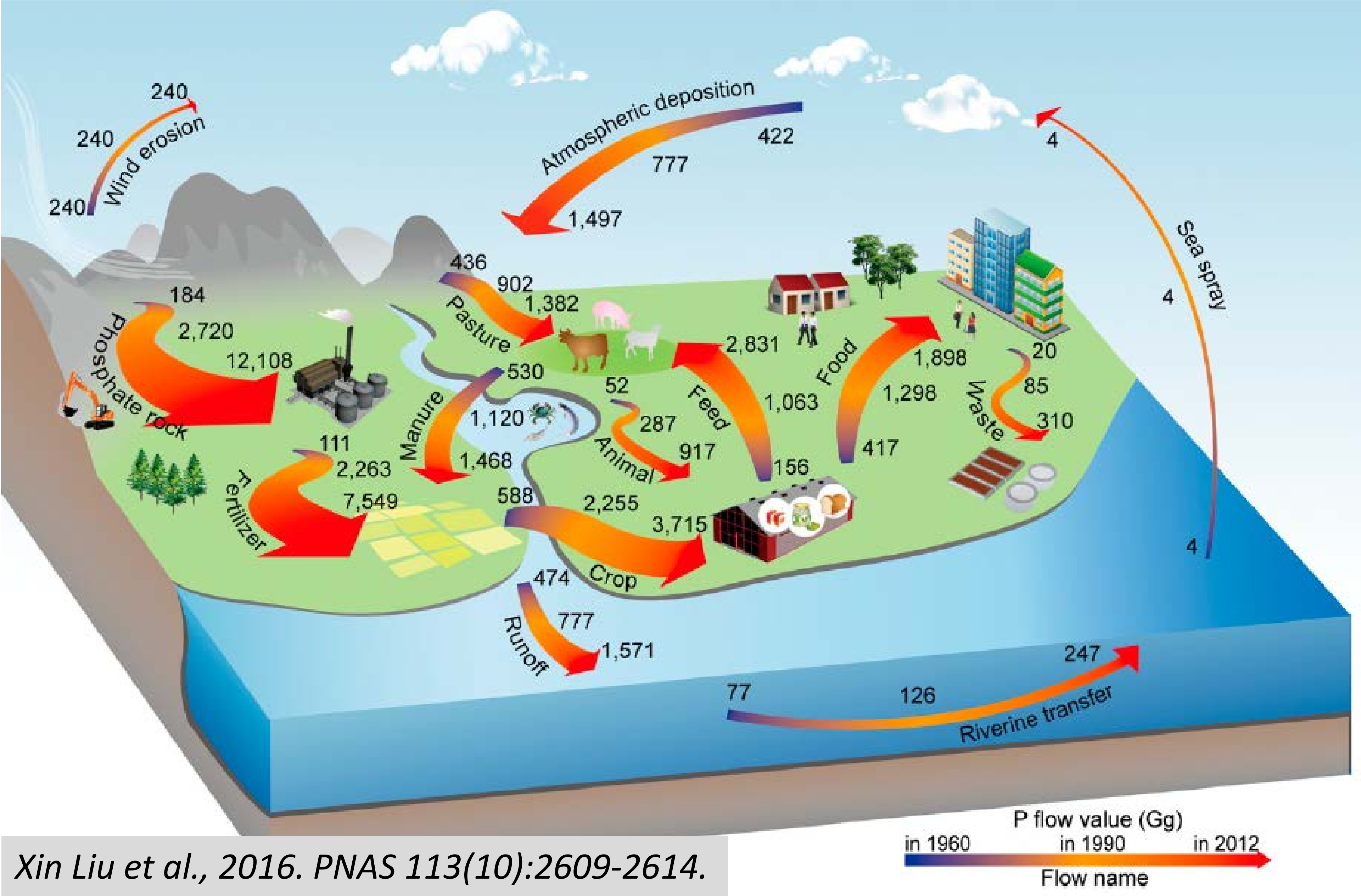
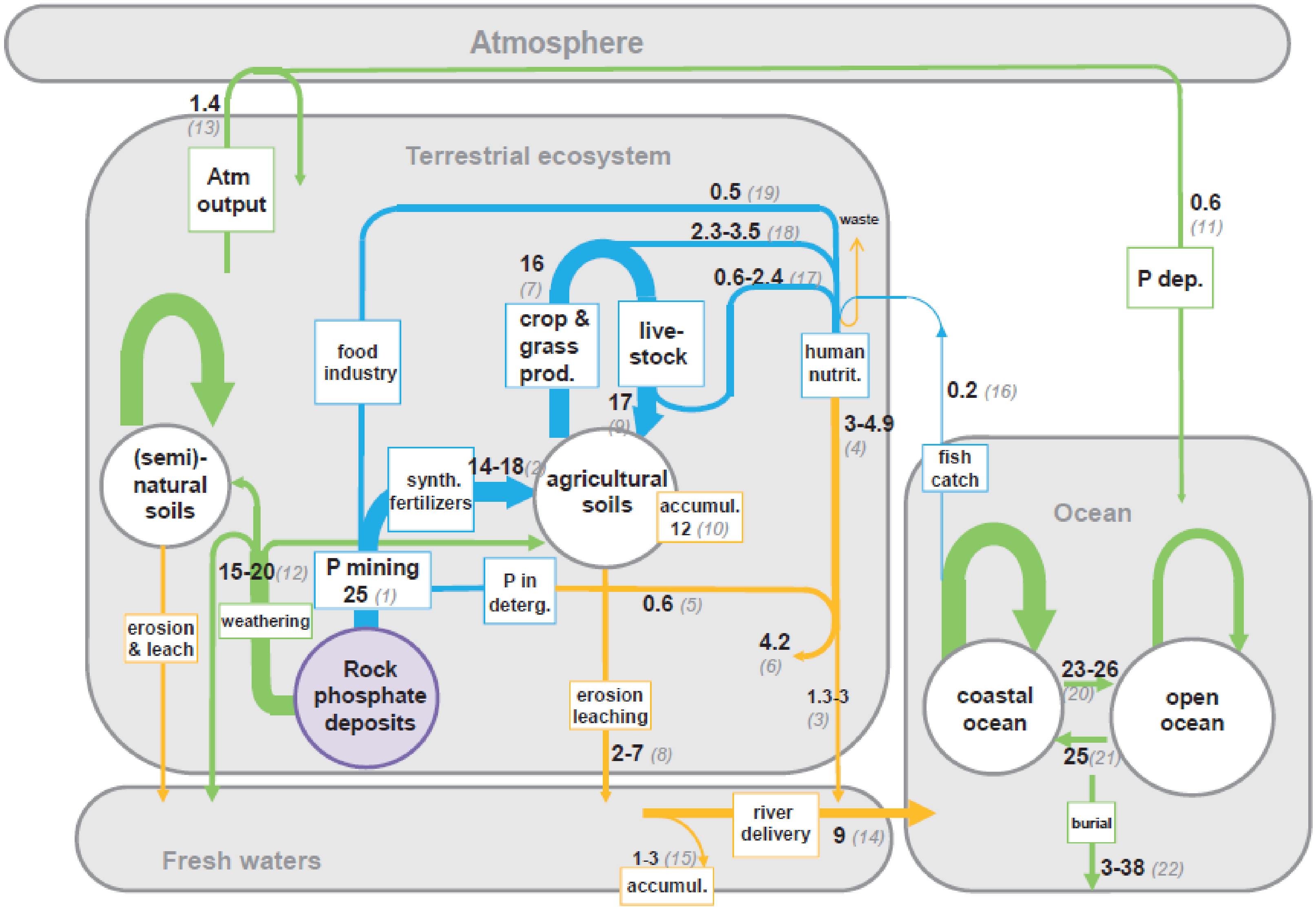
# Phosphorus flows beyond the farm: China, 1960-2012




*Xin Liu et al., 2016. PNAS 113(10):2609-2614.*

# Global P Cycle: Large amounts mined and accumulating in soils




World, around 2000-2010, fluxes in TgP/yr

*Sutton et al., 2013. Our Nutrient World. Center For Ecology and Hydrology, UK.*

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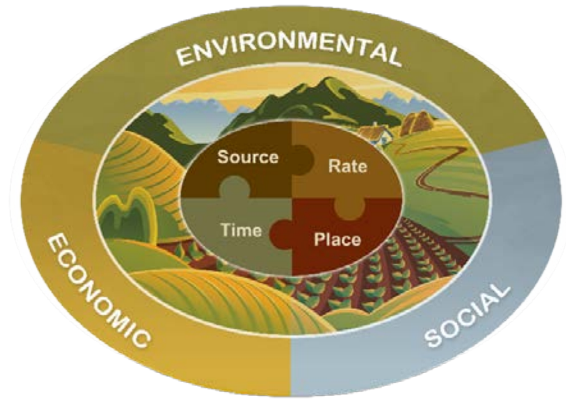
# 4R Nutrient Stewardship: a sustainability system with METRICS.

# Nutrient Stewardship Metrics for Sustainable Crop Nutrition




## *Enablers (process metrics)*

- Extension & professionals
- Infrastructure
- Research & innovation
- Stakeholder engagement

## *Actions (adoption metrics)*

- [Require regional definition of 4R]
- Cropland area under 4R (at various levels)
- Participation in programs
- Equity of adoption (gender, scale, etc.)

## *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 nutrient stewardship

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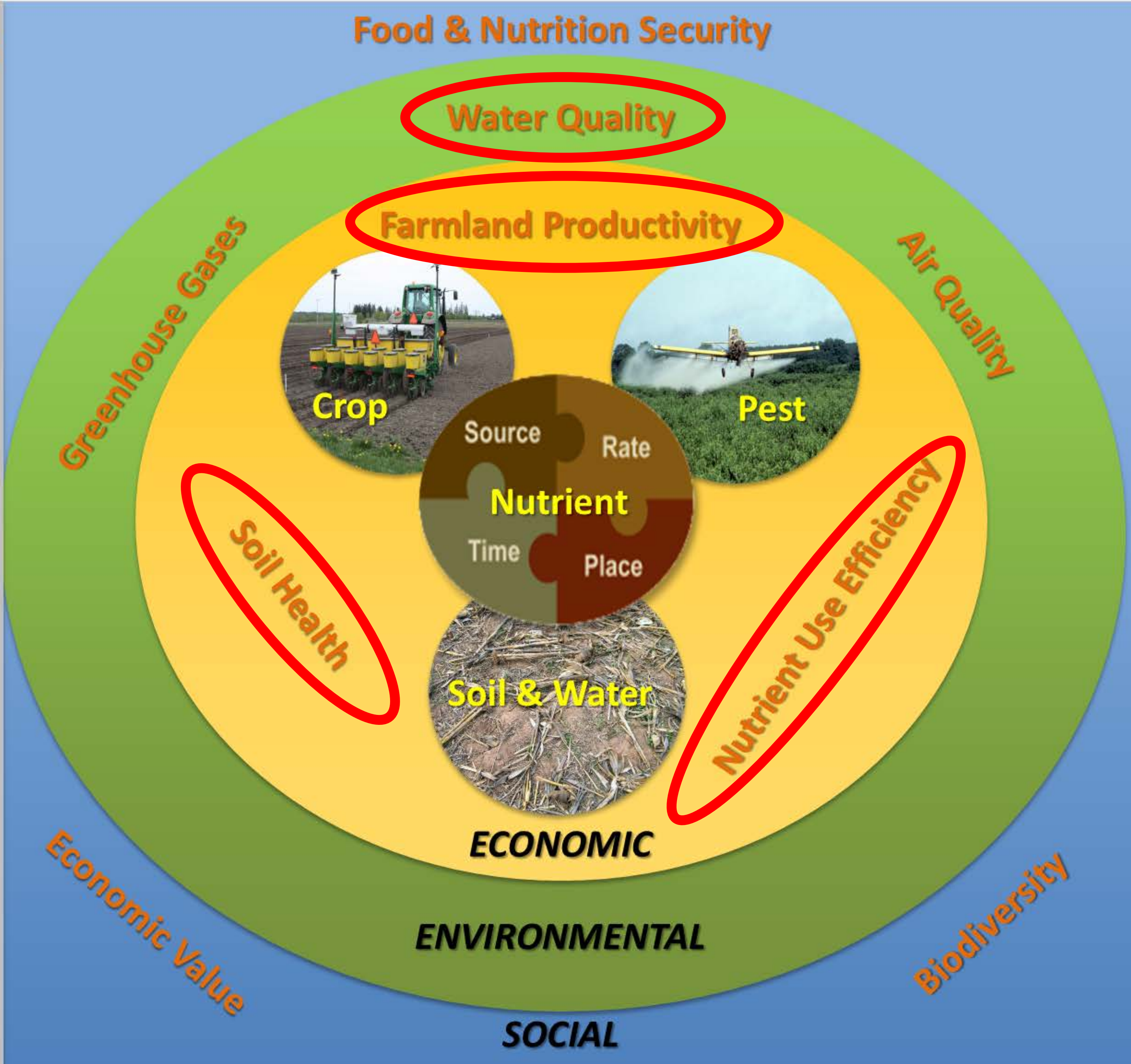
# OUTCOMES

of

4R nutrient stewardship

are influenced by **crop and pest management,** and by **soil and water conservation practices** in the context of changing **weather and climate.**



# Fieldprint® Calculator Sustainability Metrics

- Metrics that matter, usable at farm scale, linked to management with robust science
- Biodiversity, Energy Use, Greenhouse Gas Emissions, Irrigation Water Use, Land Use, Soil Carbon, Soil Conservation, **Water Quality**
- Current water quality metric is USDA NRCS WQI – qualitative
- Developing quantitative water quality outcome model to enable balancing among metrics
- Model requires definition of baseline and better practices
  - Nutrients (N & **P**), sediment, and pesticides

# Comparing stakeholder perspectives

- Public
  - Water quality impact of agriculture is one concern among many
  - Expectation for evidence-based best practices
- Food industry
  - Desires clear simple metrics of sustainability impact, national in scope
  - Reflected in Fieldprint® Calculator
- Producers
  - Burden of reporting requirements of food supply chain
  - Can't be environmentally responsible without profitability
- Scientists
  - Complex relationship between practices and P loss
  - Hesitant to quantify: small differences reverse outcomes
  - Inadequacy of current risk assessment tools – indexes & models

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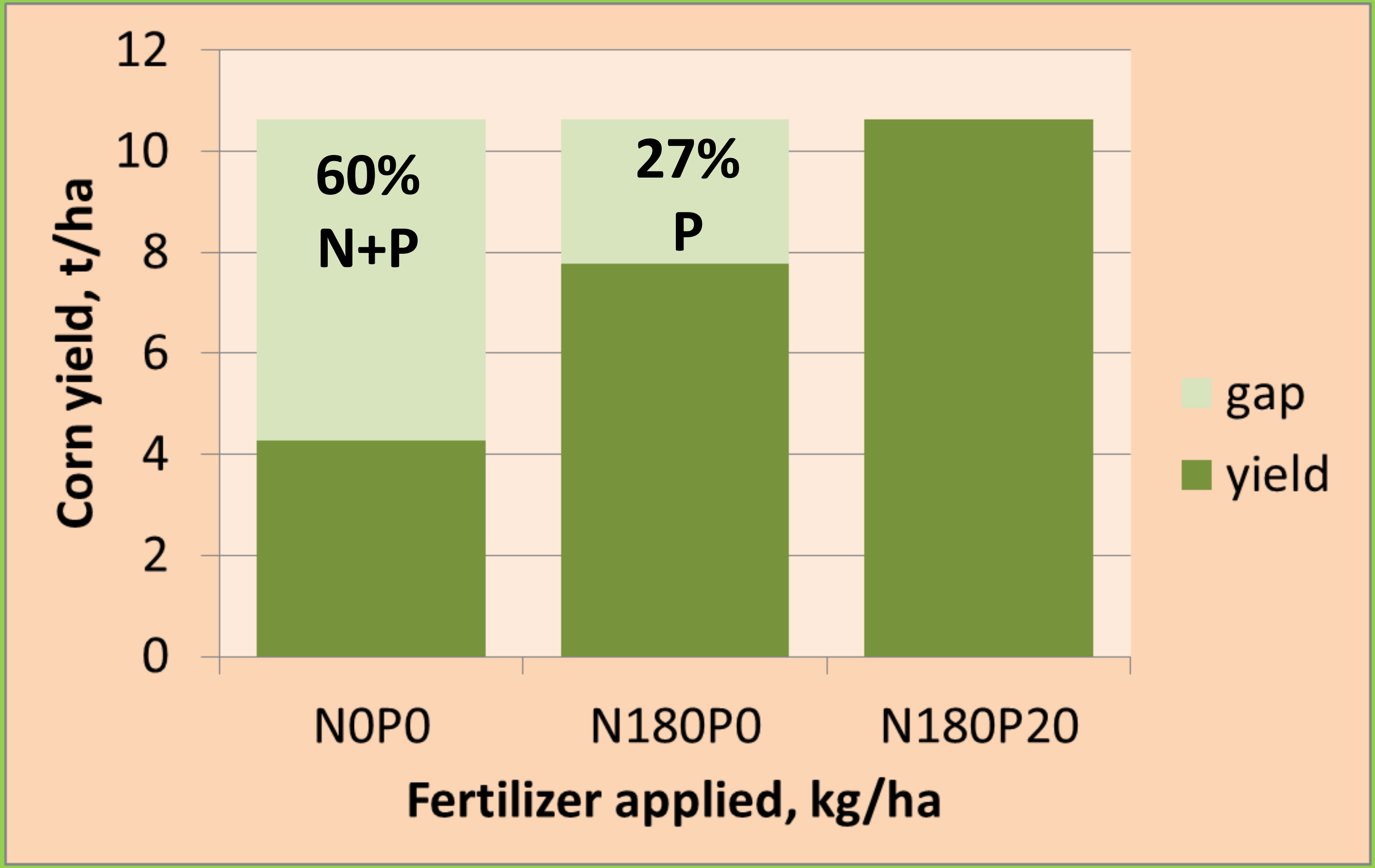
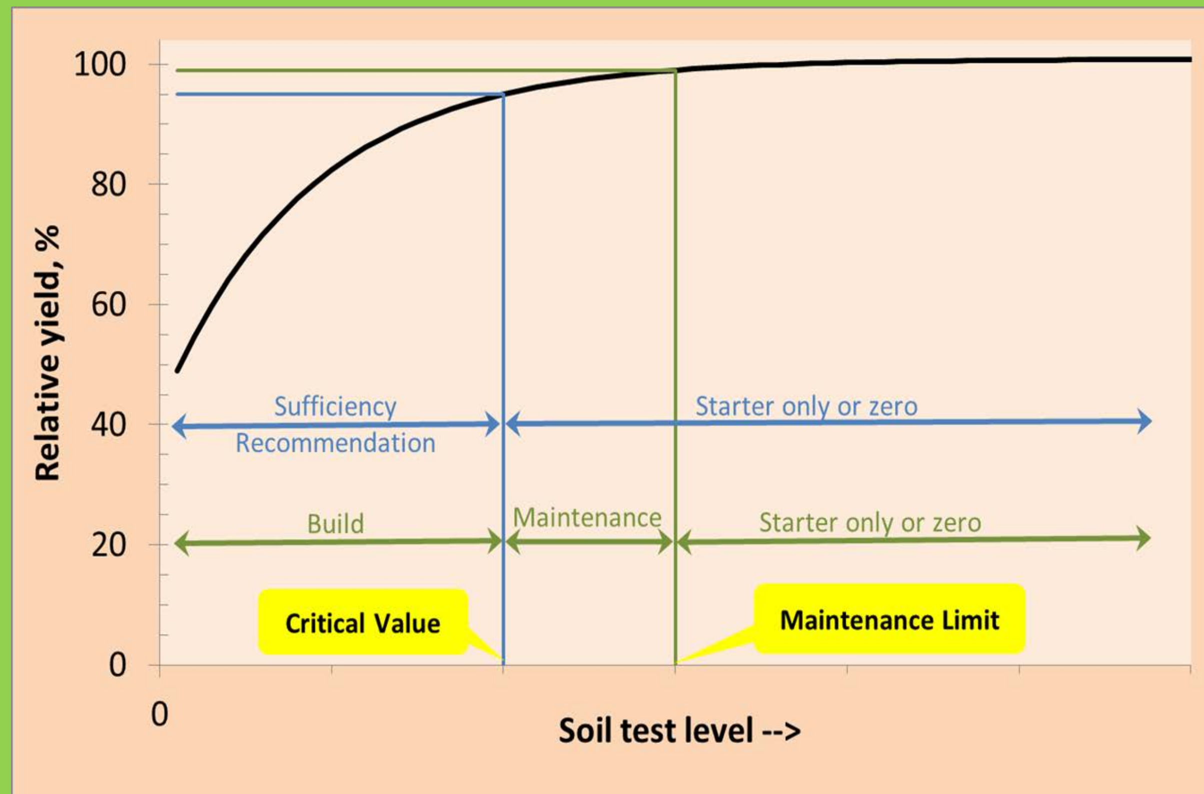
# Crop yield contribution from phosphorus use is very substantial in the long term



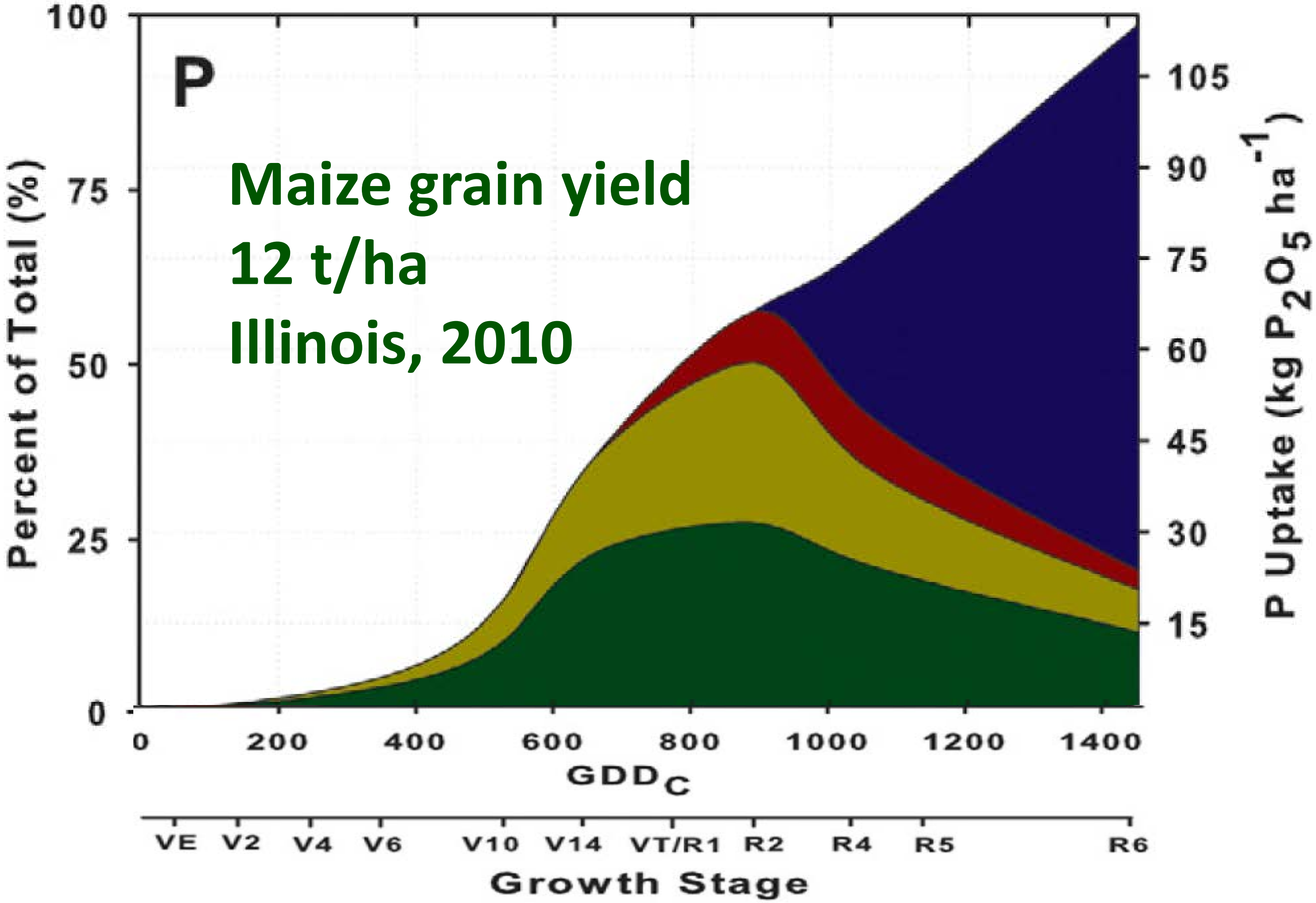

One example: Long-term contribution of P to yield of irrigated corn in Kansas – 40-year average, 1961-2000 (Stewart et al., 2005, Agron. J. 97:1–6)

# Short term crop response to P is much smaller

- 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



# High-yield crops take up large amounts of P. Most of it is removed with grain harvest.

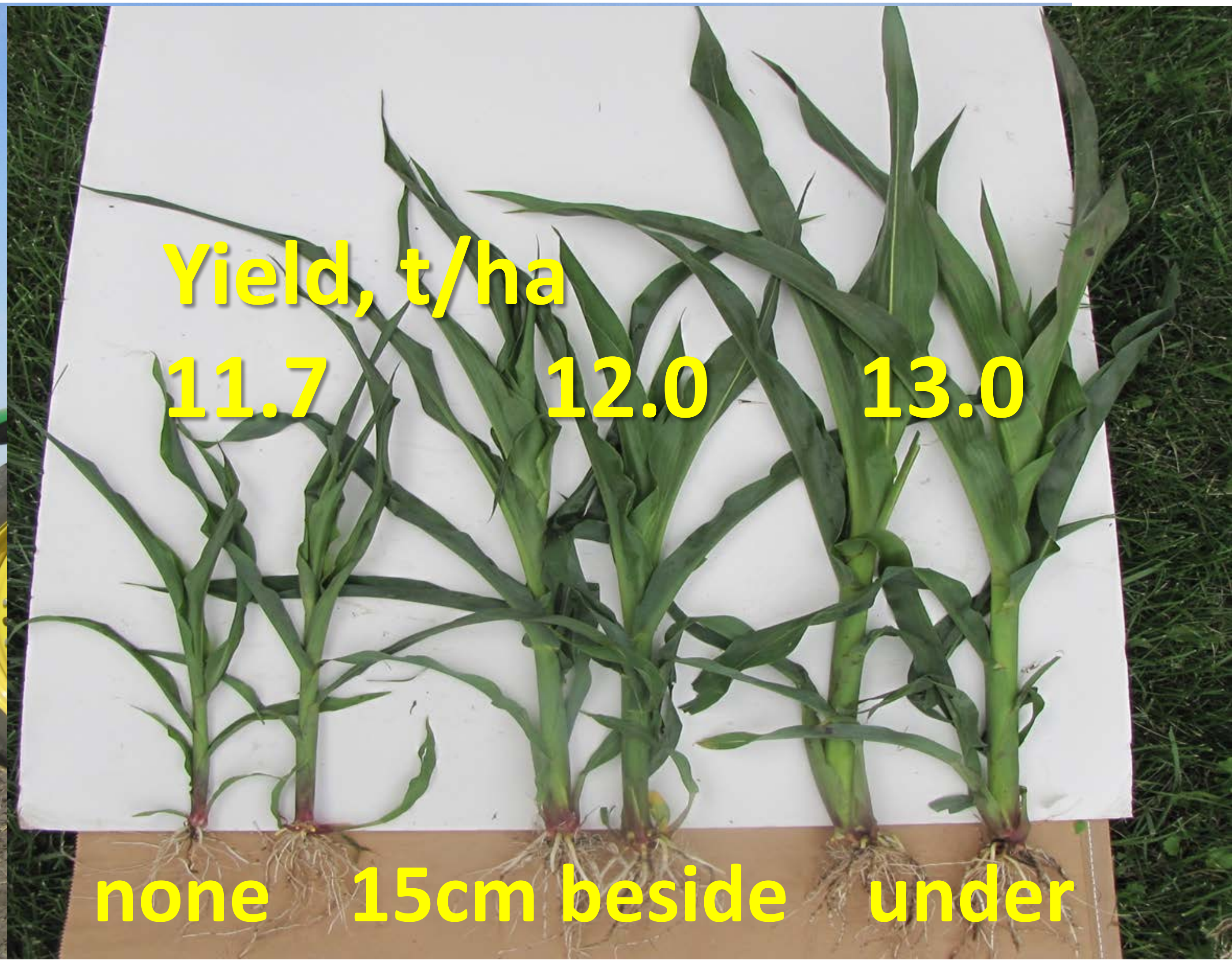



2010 data from two sites and six hybrids

*Dr. F.E. Below, University of Illinois. Agron. J. 105:161-170 (2013)*

Crop Physiology

# Research shows potential for altered P placement needs in high density high yield maize


*Dr. F.E. Below, University of Illinois*

Crop Physiology

# Phosphorus Issues

- Eutrophication
- Hypoxia
- Harmful algal blooms
- Excess levels in soil, stratification

- Finite resource, geopolitical distribution
- Declining quality of reserves
- Heavy metals, trace elements and cadmium
- Environmental impact of mining

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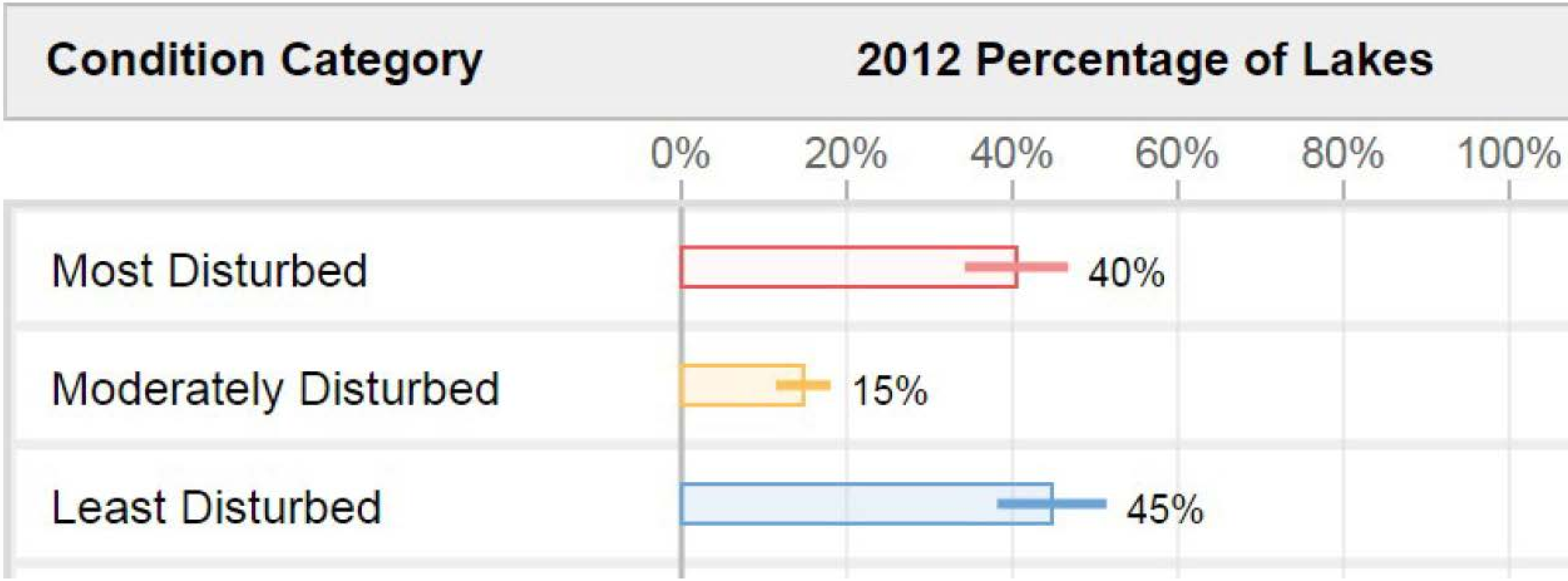
# Environmental Impact

- Eutrophication
- Hypoxia
- Harmful Algal Blooms


*Photo credit: Carrie Vollmer-Sanders, The Nature Conservancy*

# Figure 4.3: Phosphorus (Total) | National Condition Estimates

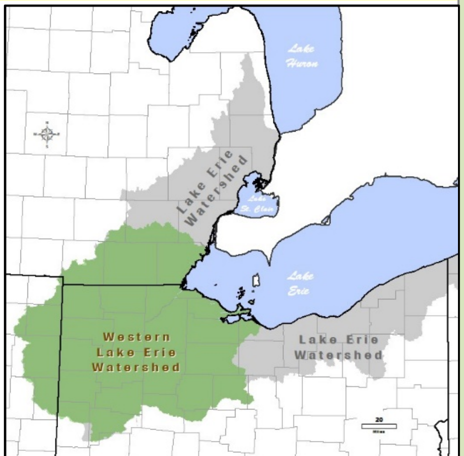


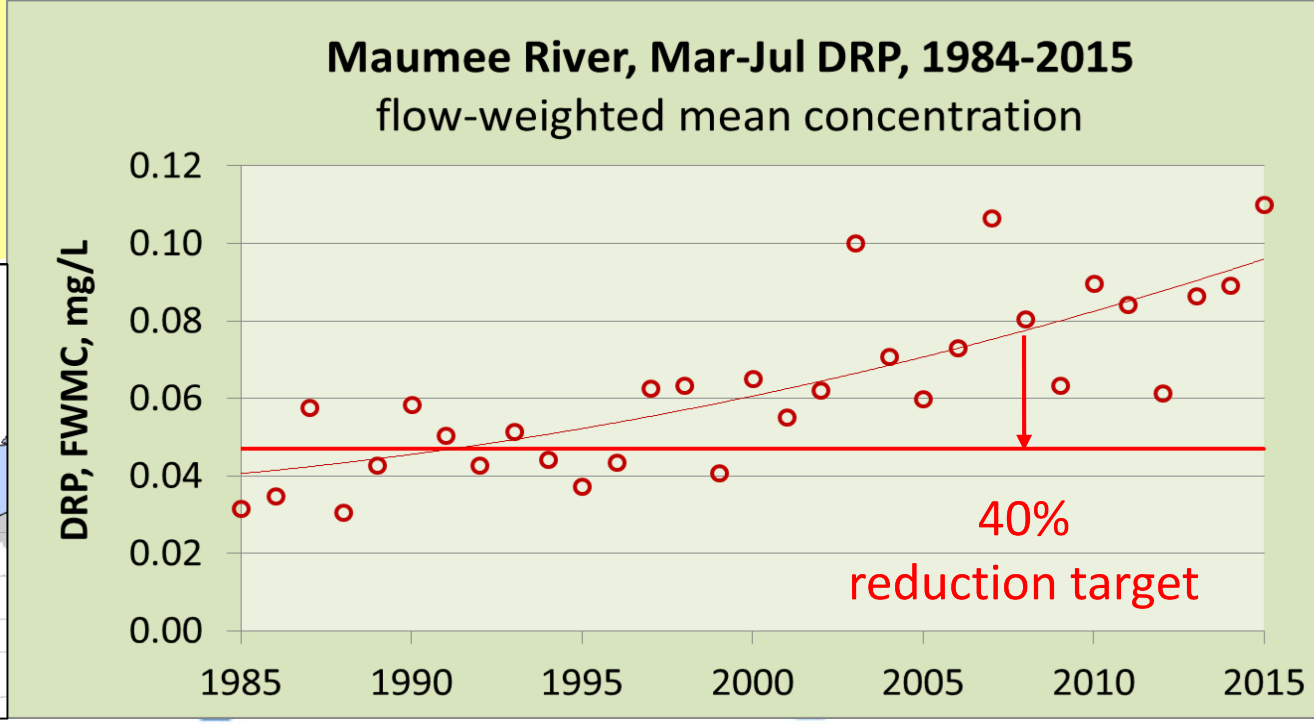

National Lakes Assessment 2012

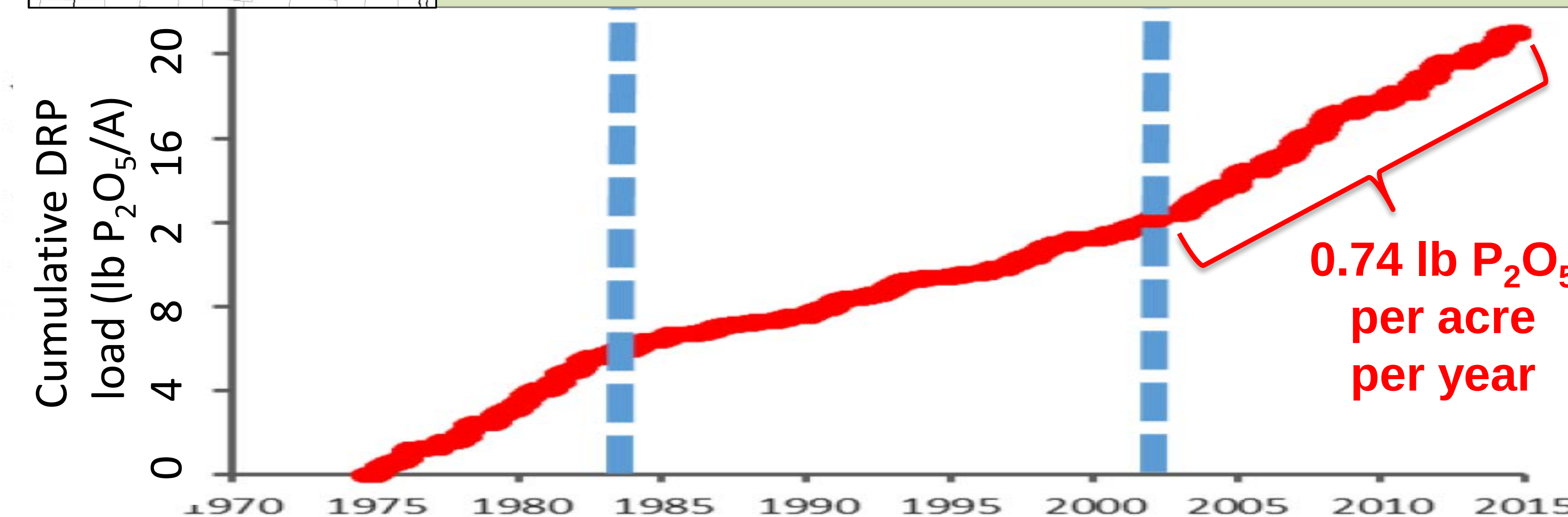
A Collaborative Survey of Lakes in the United States

USEPA 2016 National Lakes Assessment 2012 | A Collaborative Survey of Lakes in the United States

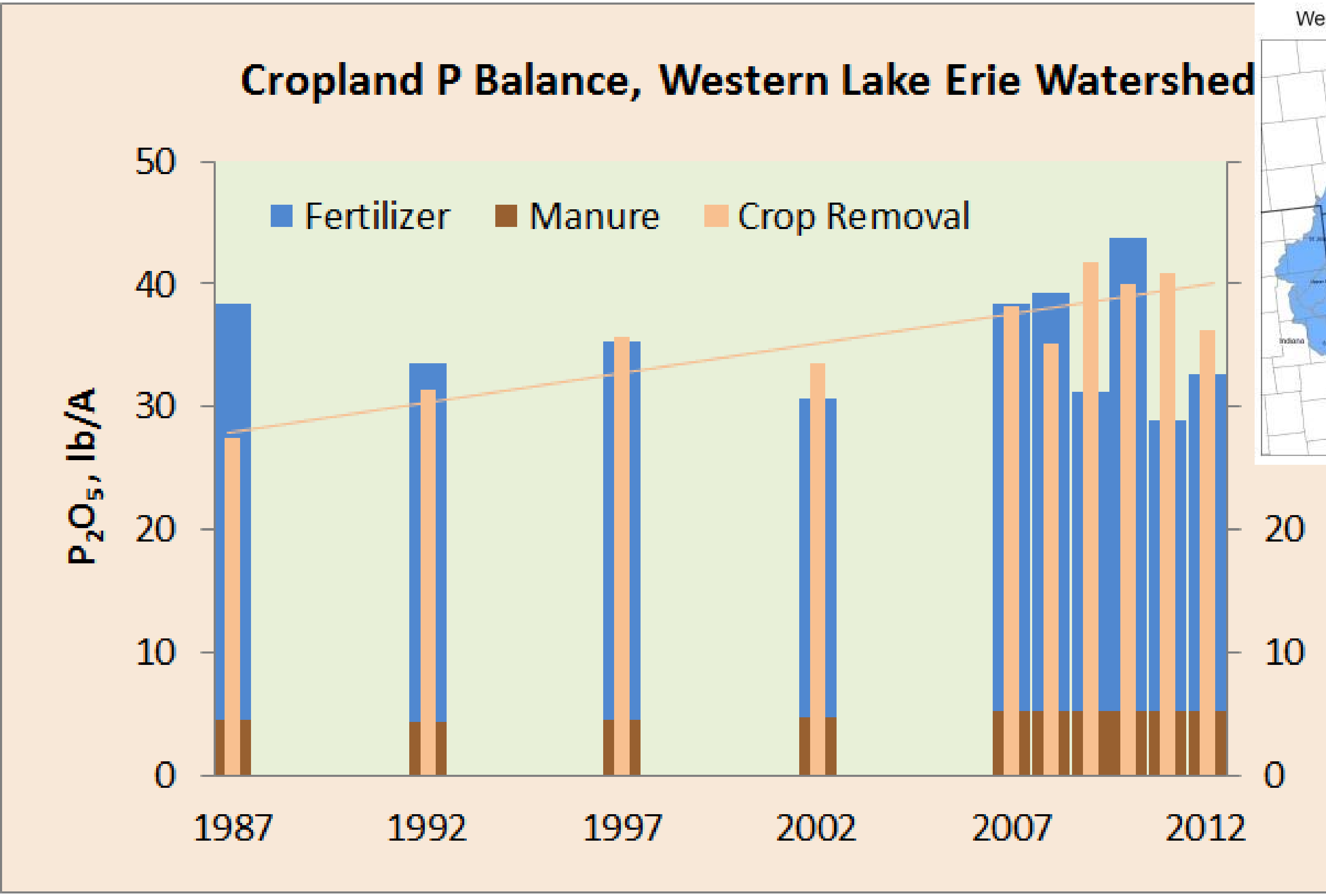
# Western Lake Erie: dissolved P trends increasing since 2002

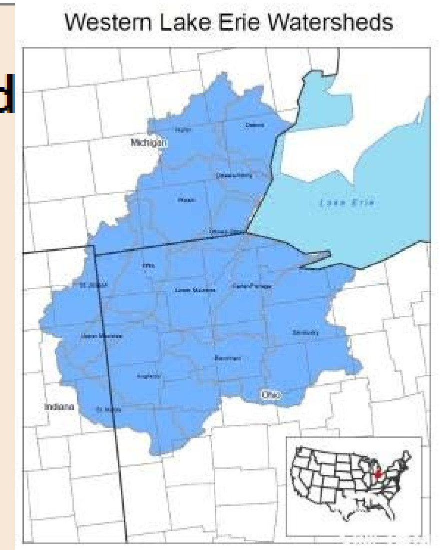



*1. David Baker & Laura Johnson, National Center for Water Quality Research, Tiffin, OH*
*2. Jarvie et al., 2016, J Environ. Qual.*




1. **Crop removal increasing with yield.**
2. **Application rates falling short of crop removal.**

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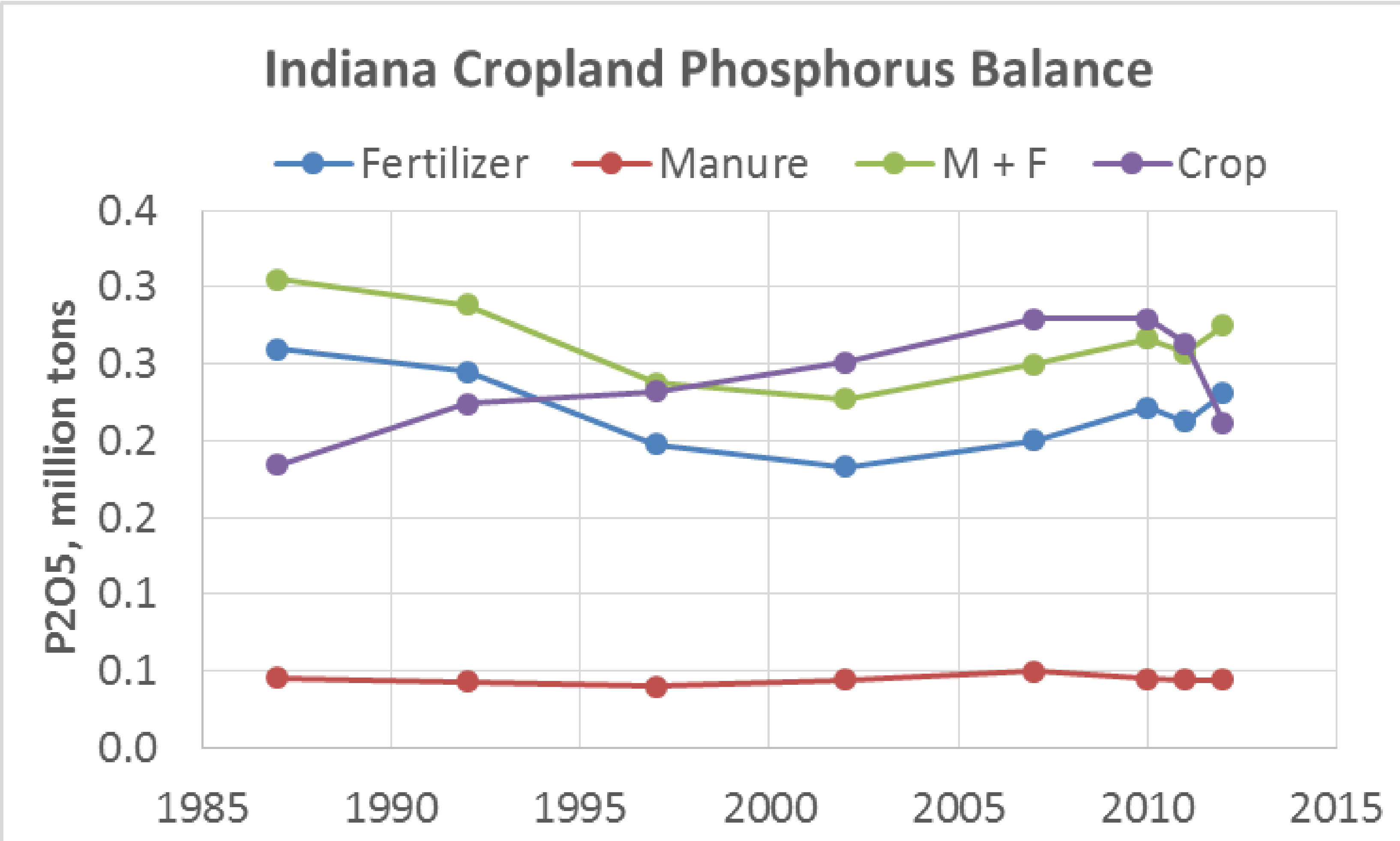
NuGIS
Nutrient Use Geographic Information System

# Indiana P trending to deficit except for 2012

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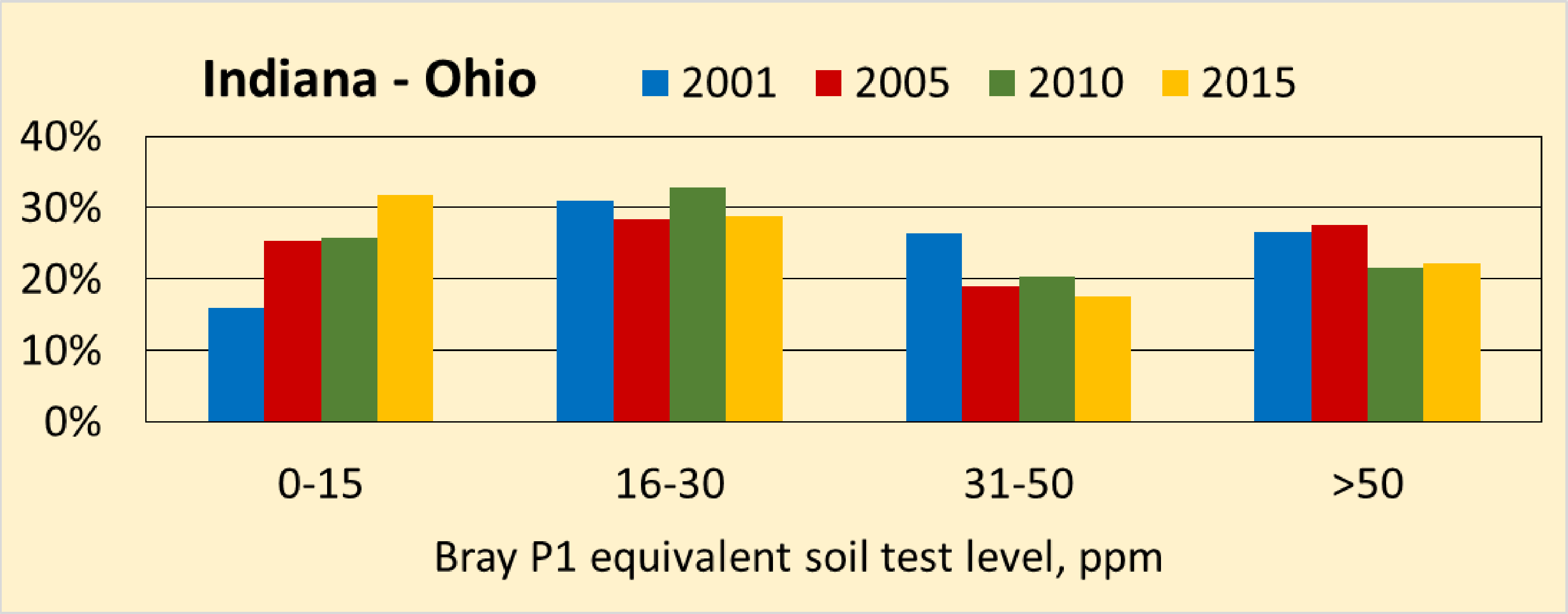
NuGIS
Nutrient Use Geographic Information System

# Soil Test Phosphorus




1. **Soils below critical have increased to 31%.**
2. **Soils at optimum P: 28%.**
3. **Soils to draw down: 41%.**

# 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

IPNI Nutrient Source SPECIFICS

Monoammonium Phosphate (MAP) No. 9

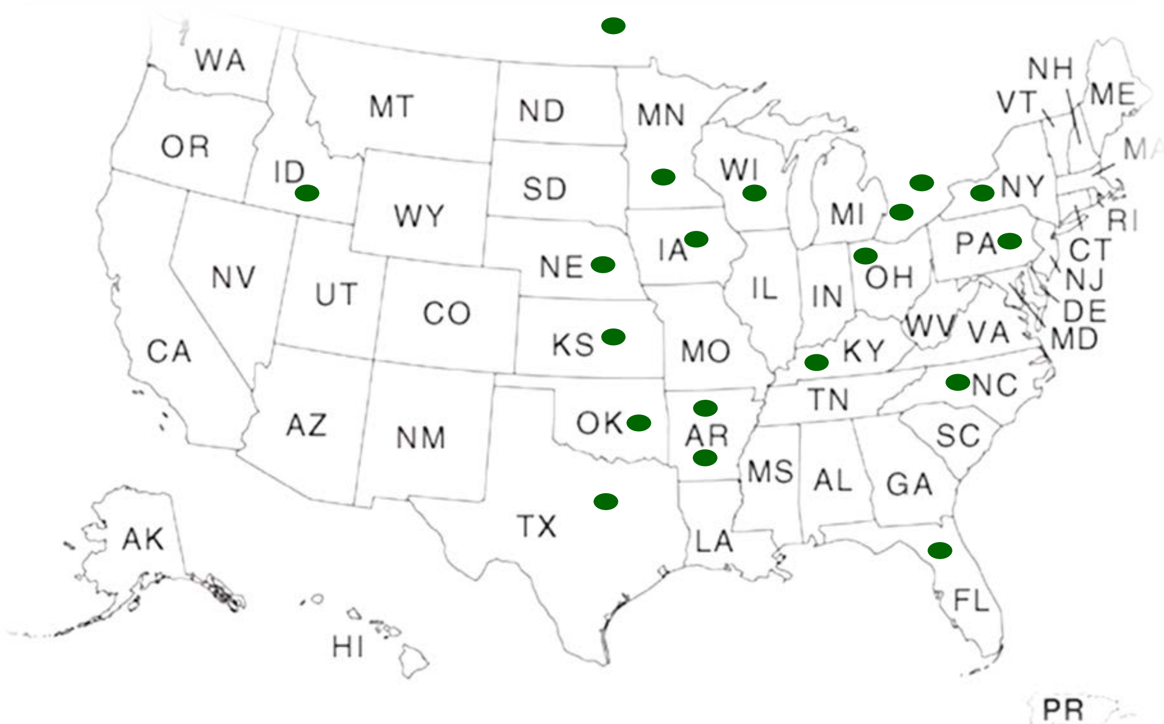
## Chemical Properties

| | |
|---|---|
| Chemical formula: | $NH_4H_2PO_4$ |
| $P_2O_5$ range: | 48 to 61% |
| N range: | 10 to 12% |
| Water solubility (20°) | 370 g/L |
| Solution pH | 4 to 4.5 |

# Defining 4R phosphorus practices at the continental scale.

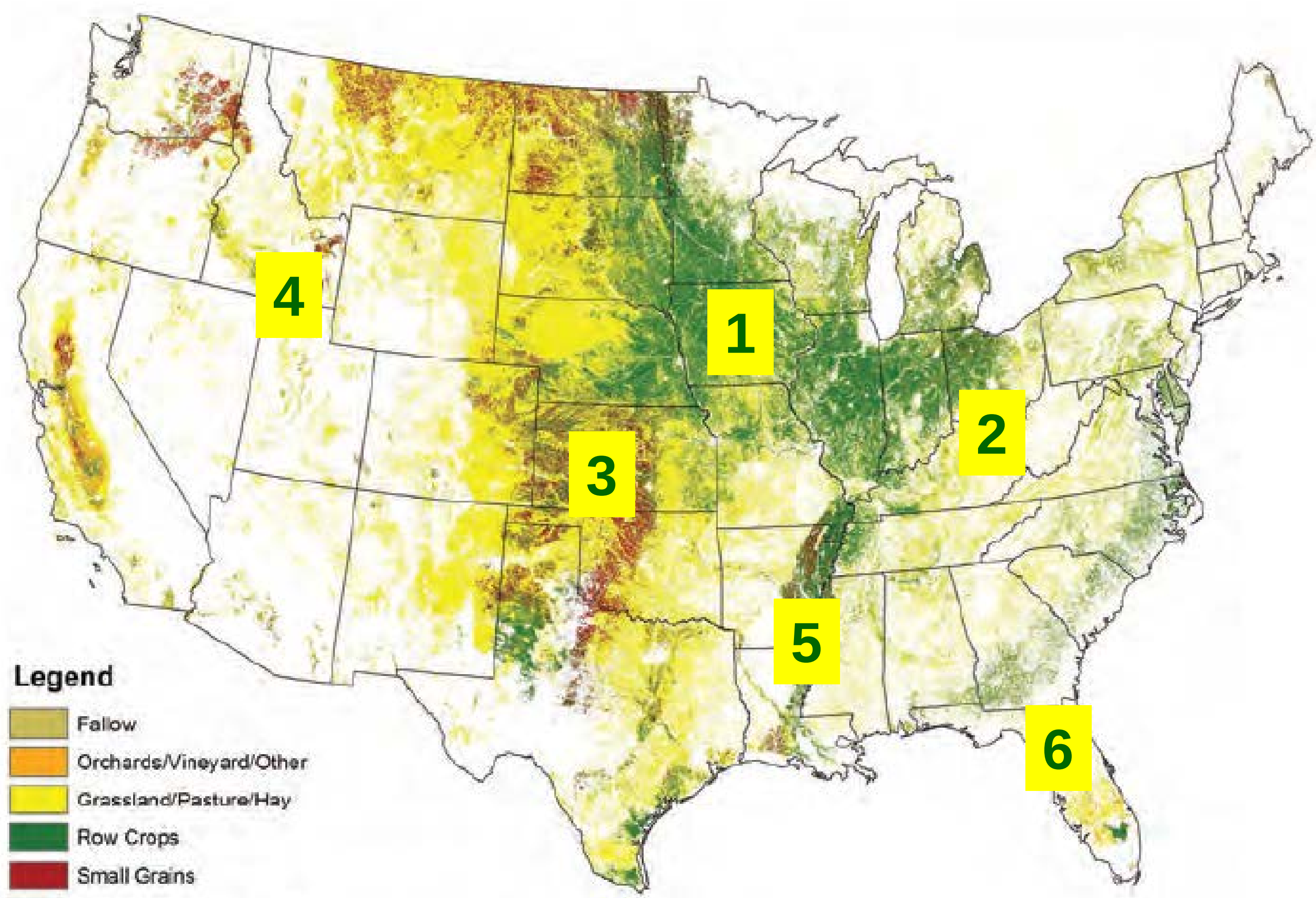
# 4R P Practices - Participating Scientists

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




*2011 National Land Cover Database - [http://www.mrlc.gov](http://www.mrlc.gov)*

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# 4R Phosphorus Practices for Eastern Crops (including Indiana)

- Basic
  - Source: known or guaranteed analysis
  - Rate: recommended soil sampling and soil test interpretation, no more than 3 years crop removal
  - Timing: avoid frozen and snow-covered soils
  - Placement: subsurface band for no-till; on surface only when risk index is low
- Intermediate
  - Source: manure sampled for nutrients
  - Rate: as in basic, plus: P index used when recommended, no more than 2 years crop removal
  - Timing: close to or at planting, P Index
  - Placement: use starter where recommended, P Index

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# 4R Phosphorus Practices for Eastern Crops (including Indiana)

- Advanced
  - Source: as in intermediate
  - Rate: as in intermediate, plus: **zone-specific** based on loss potential and crop response, no more than current crop's needs, P Index
  - Timing: as in intermediate, plus: follow P Index
  - Placement: as in intermediate, plus: follow P Index

ADAPTIVE MANAGEMENT

- Decisions are site-specific and adaptive to changing conditions. Not everything can be written down.

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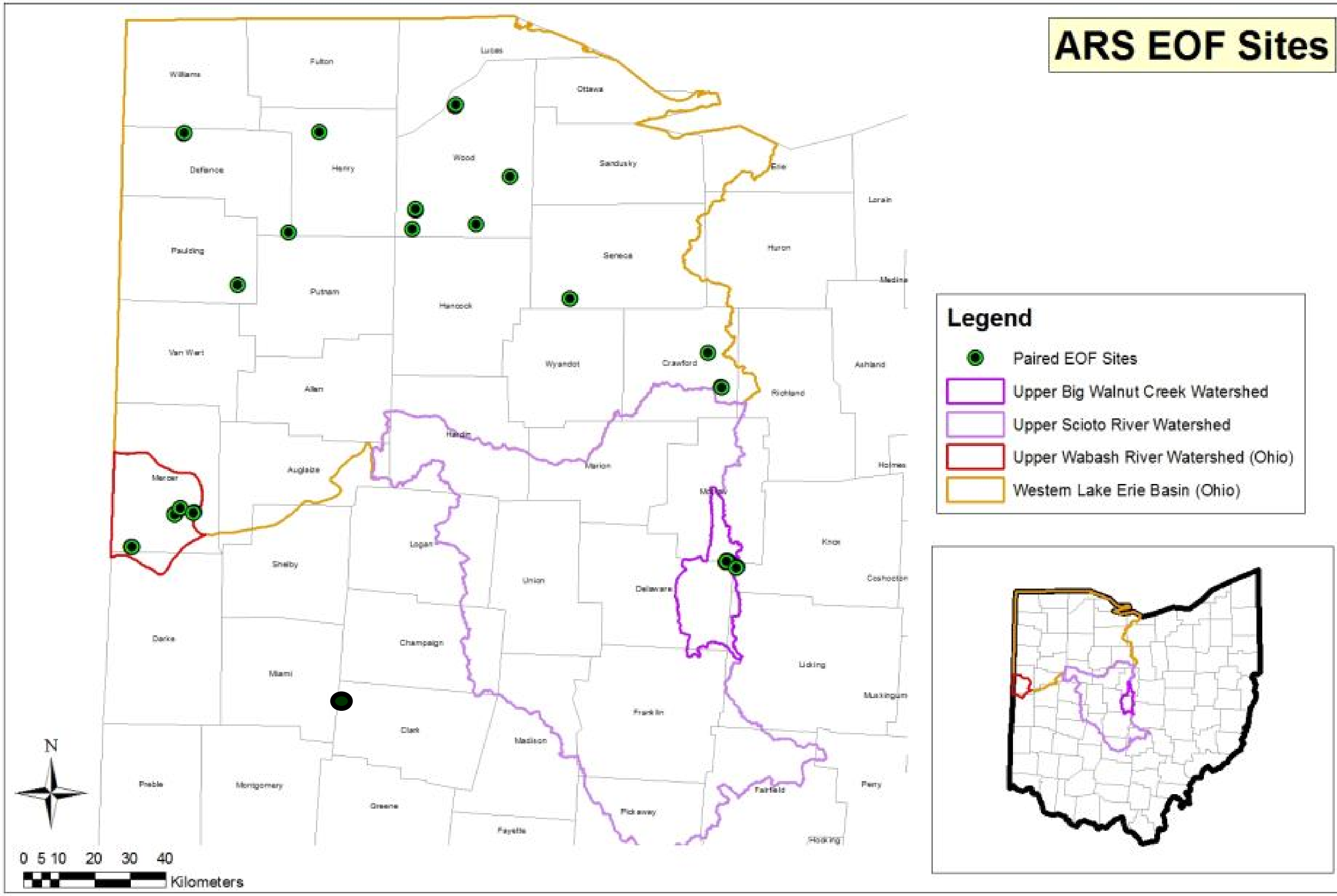
# Ohio P loss monitoring at edge of field



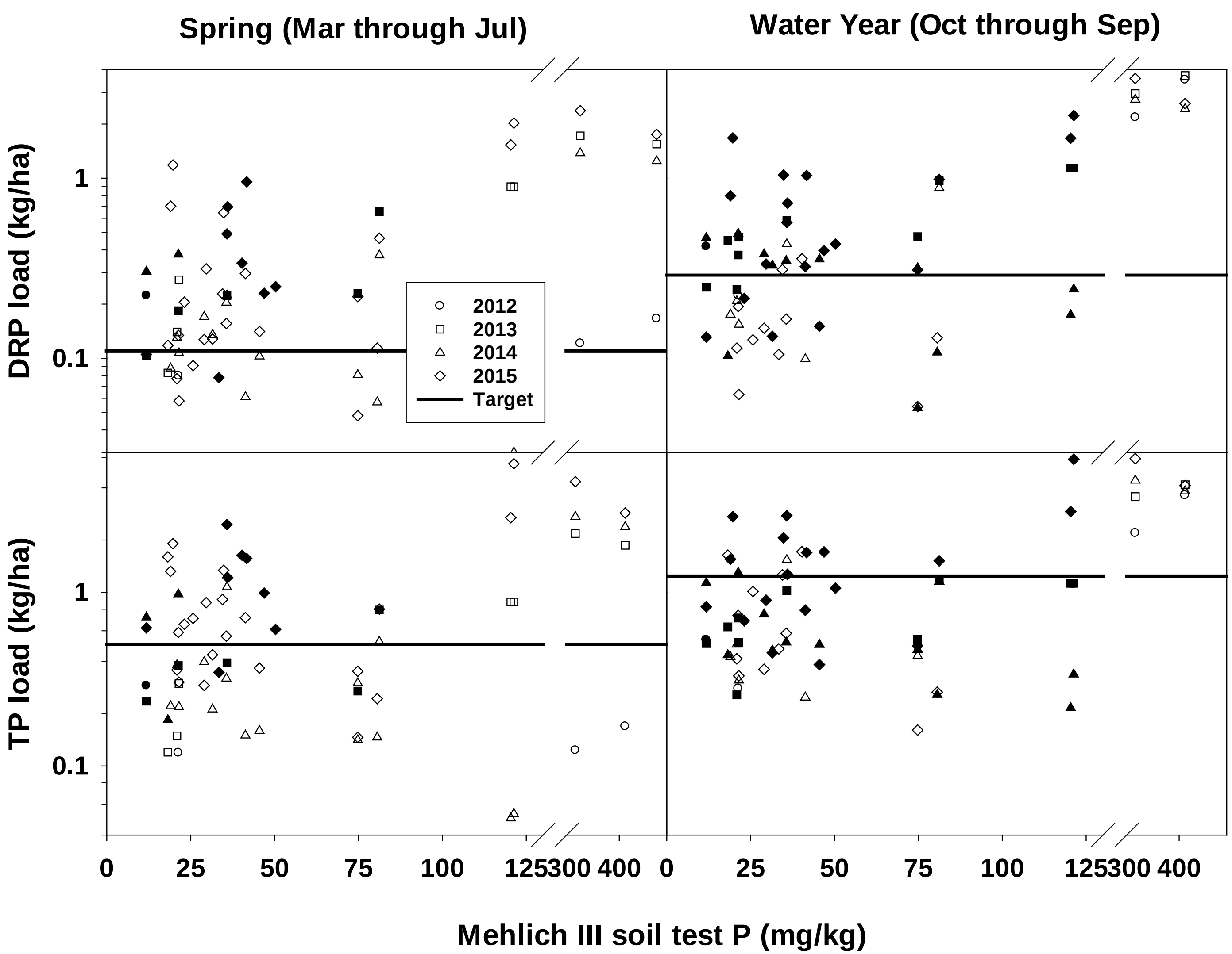

**Funding Sources:**

- 4R Research Fund
- USDA-ARS: USDA-Agriculture Research Service
- CEAP: Conservation Effects Assessment Project
- EPA: DW-12-92342501-0
- Ohio Agri-Businesses
- Ohio Corn and Wheat Growers
- CIG: 69-3A75-12-231 (OSU)
- CIG: 69-3A75-13-216 (Heidelberg University)
- MRBI: Mississippi River Basin Initiative
- The Nature Conservancy
- Becks Hybrids/Ohio State University
- Ohio Soybean Association

USDA ars
Soil Drainage Research Unit

*Kevin King, USDA-ARS, Columbus, Ohio*

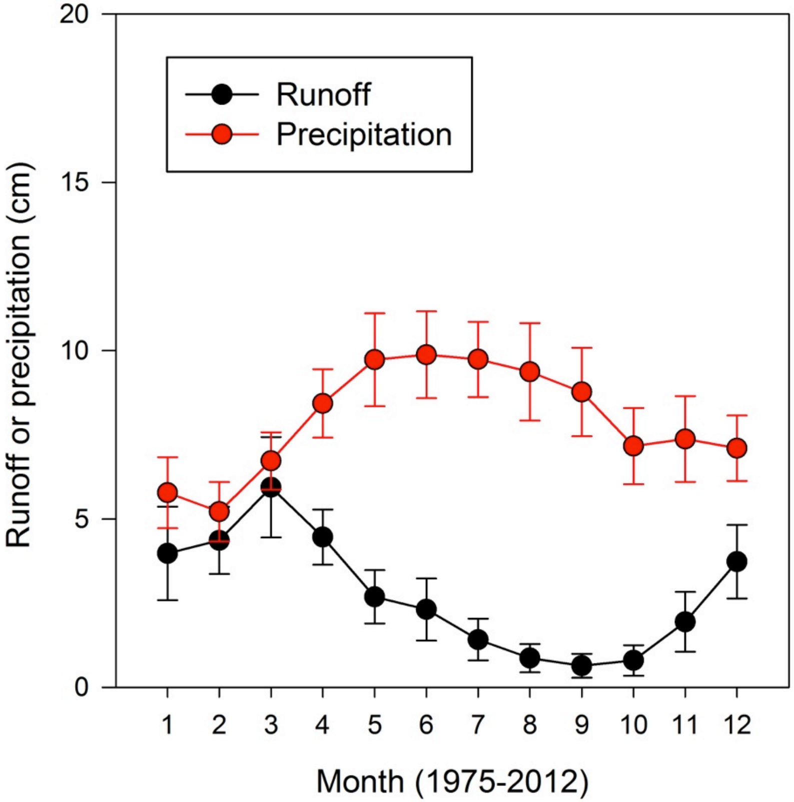
# Right Rate

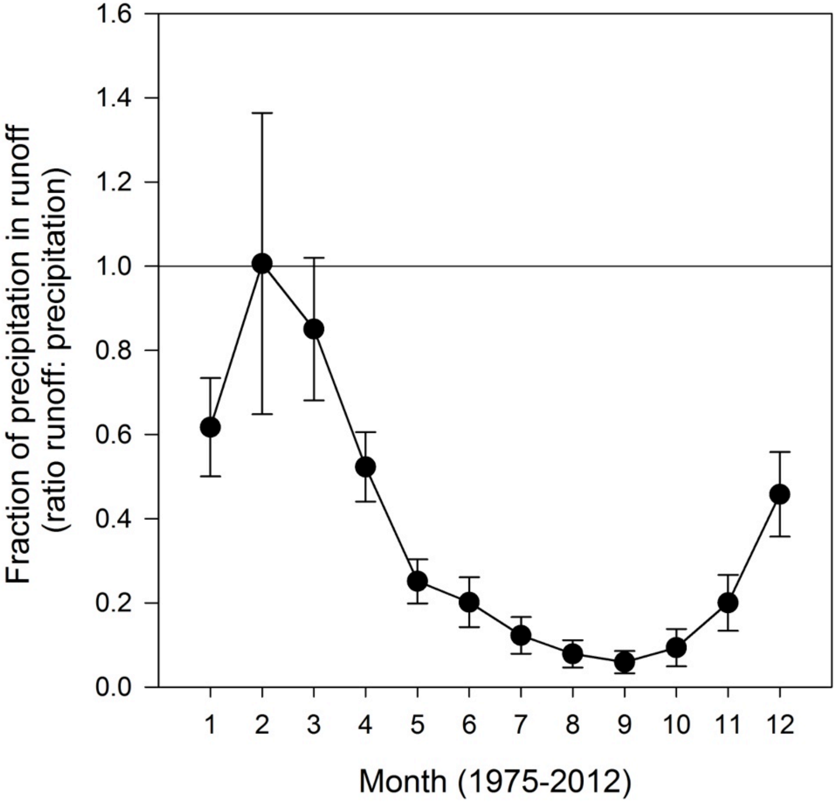



Soil Drainage Research Unit

*Kevin King, USDA-ARS, Columbus, Ohio*

# When is the right time?



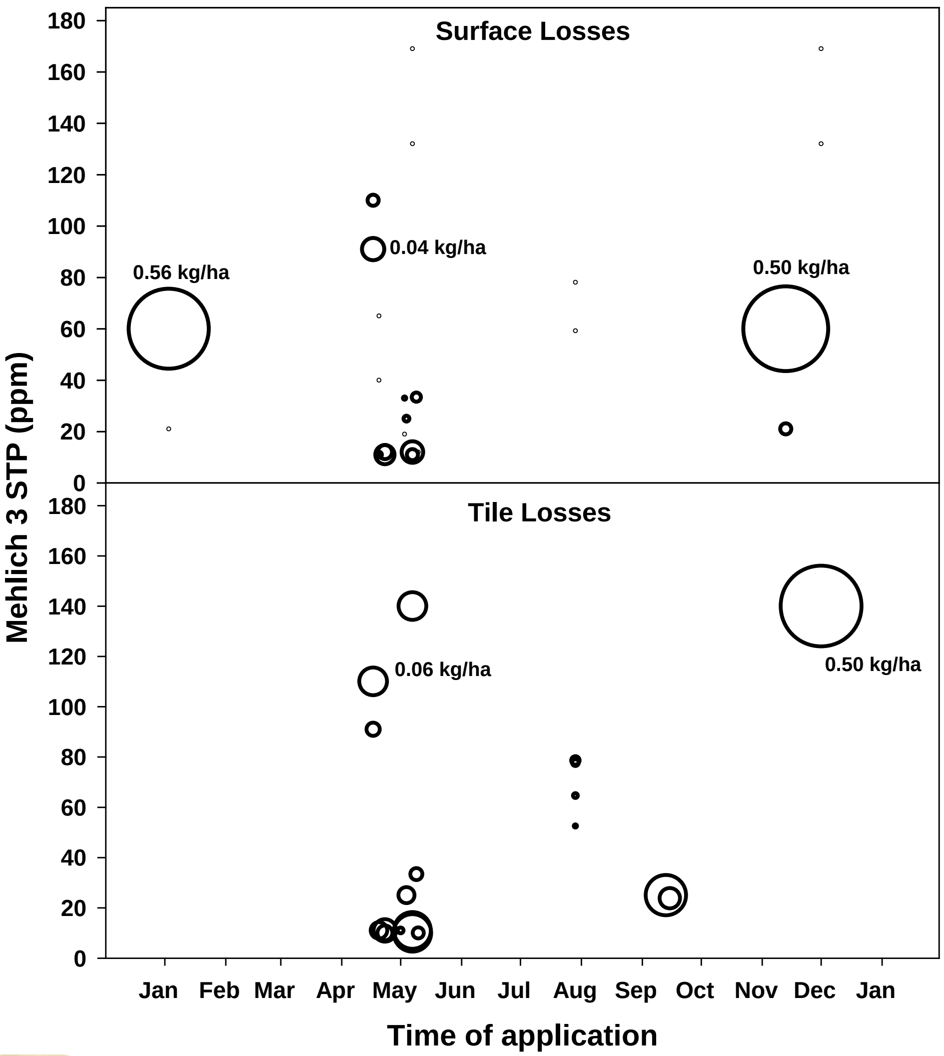




National Center for Water Quality Research
Heidelberg University

USDA ARS
Soil Drainage Research Unit

*Kevin King, USDA-ARS, Columbus, Ohio*

# Right Timing




## Time of Application

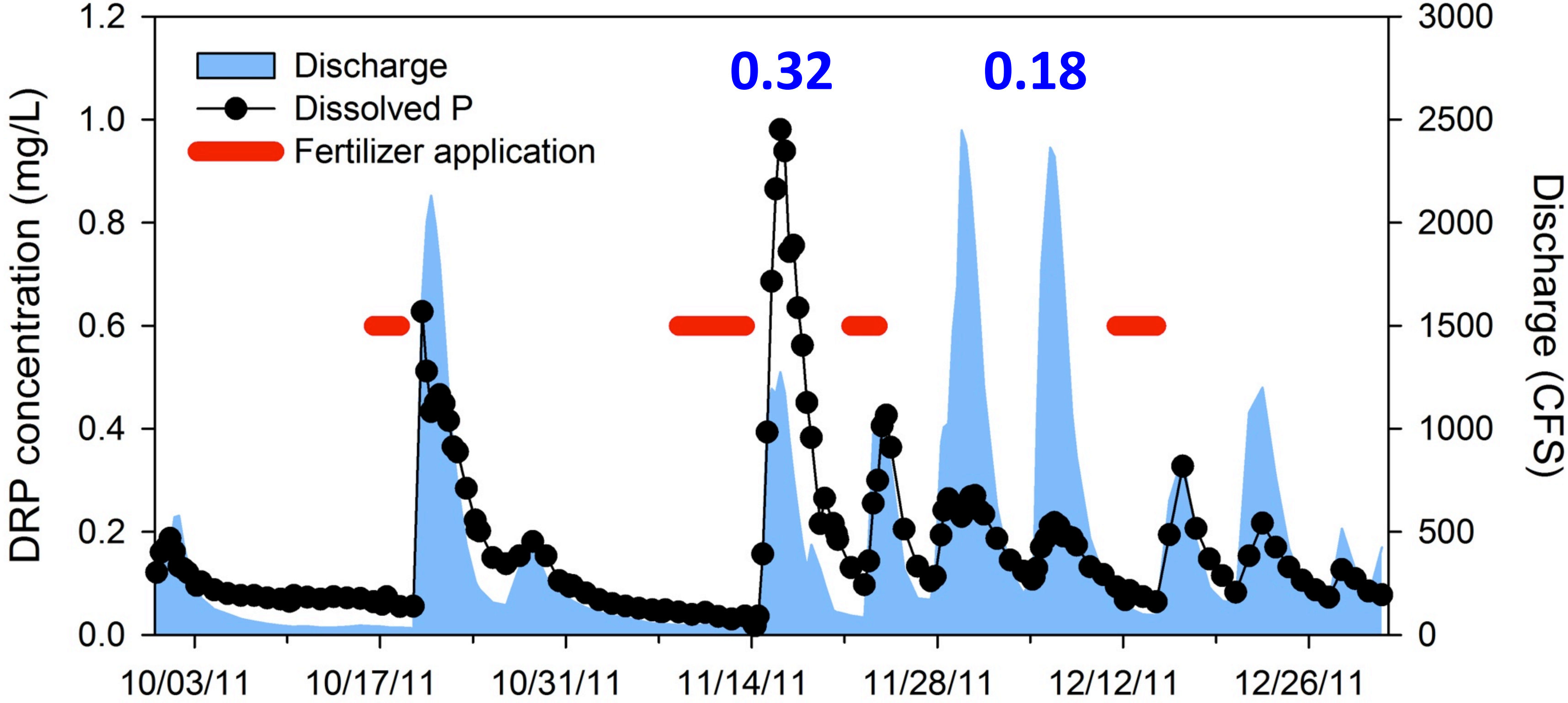
- **Greatest potential for surface and tile losses occurs with fall and winter application**
- **Applying P in spring or after wheat harvest seems to minimize surface and tile losses**

Soil Drainage Research Unit

*Kevin King, USDA-ARS, Columbus, Ohio*

# Right Time

## DRP load in lb of $P_2O_5$ per acre of watershed




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.

*David Baker and Laura Johnson, Heidelberg University*


**Broadcast? at the right time to avoid runoff**

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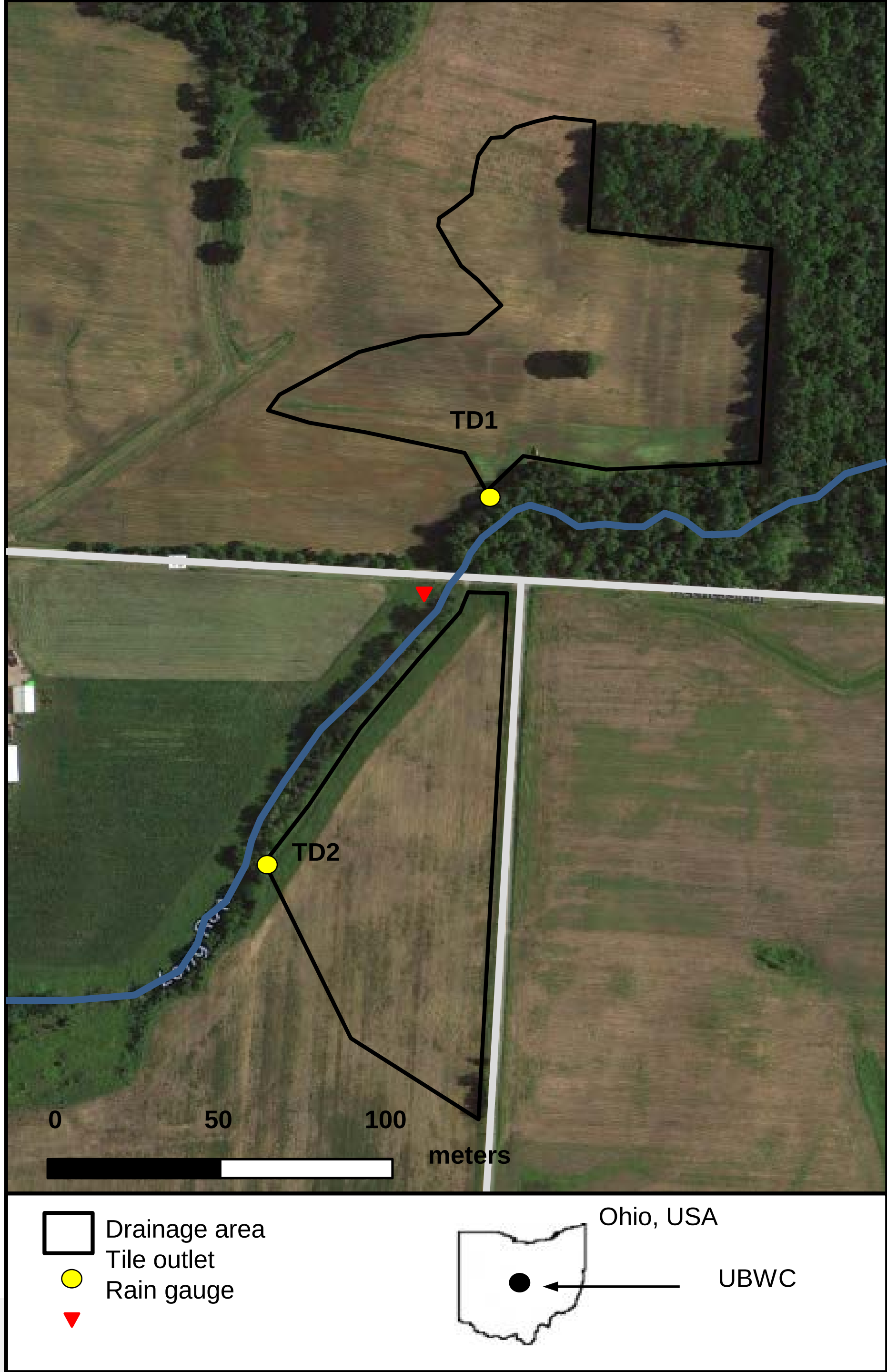
# Right Place – in the soil, not on the soil

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

**<u>2014 management</u>**
May 6$^{th}$ – Applied MAP @ 45 kg P/ha
May 8$^{th}$ – Tilled field TD1 (disc)
(TD2 remained no-till)

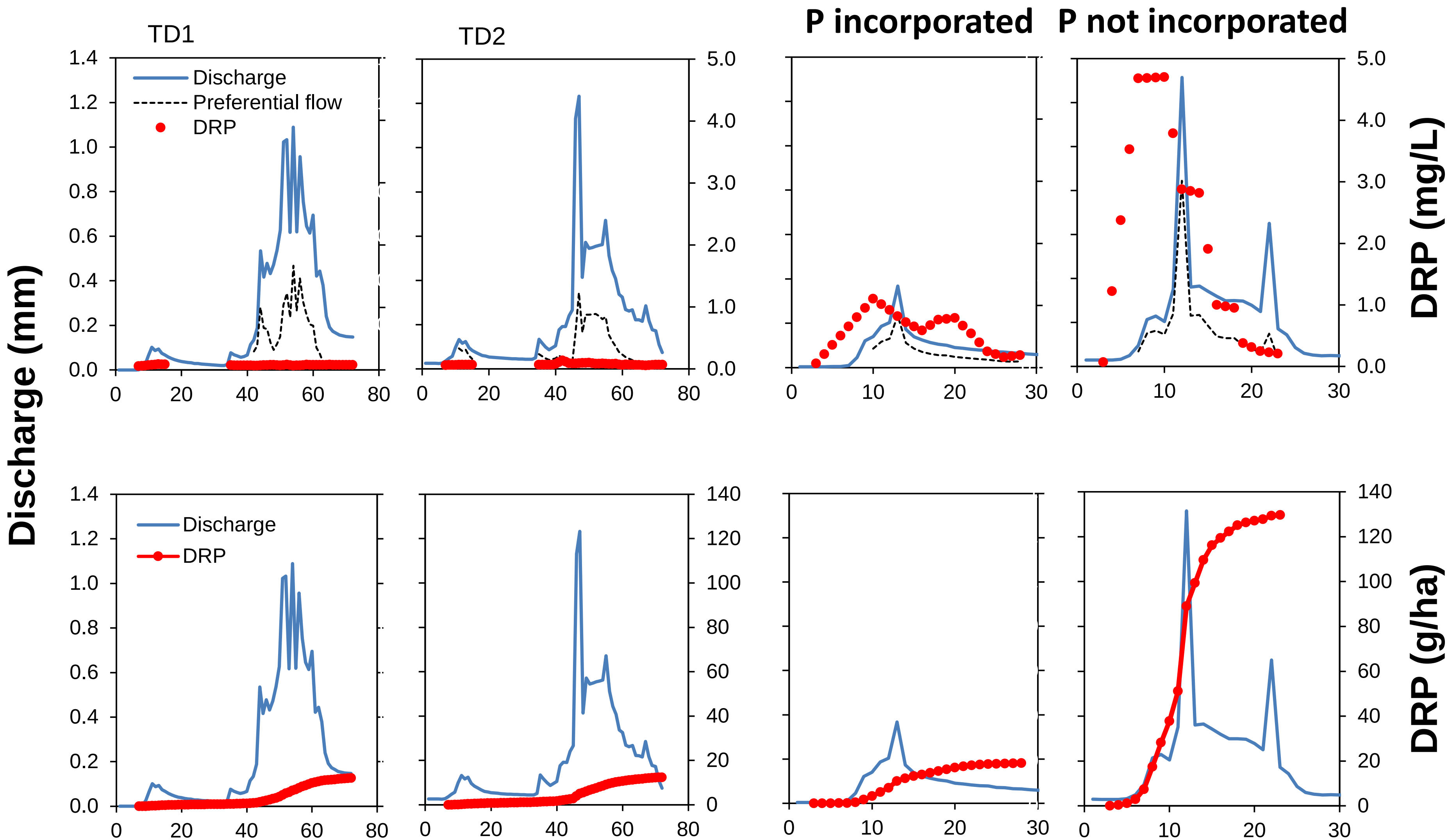
Compared P transport out of the tile drains
1. Broadcast P incorporated versus
2. Broadcast P not incorporated




*Williams and King, USDA-ARS, Columbus, Ohio*

## Before P application & tillage (April 28th)

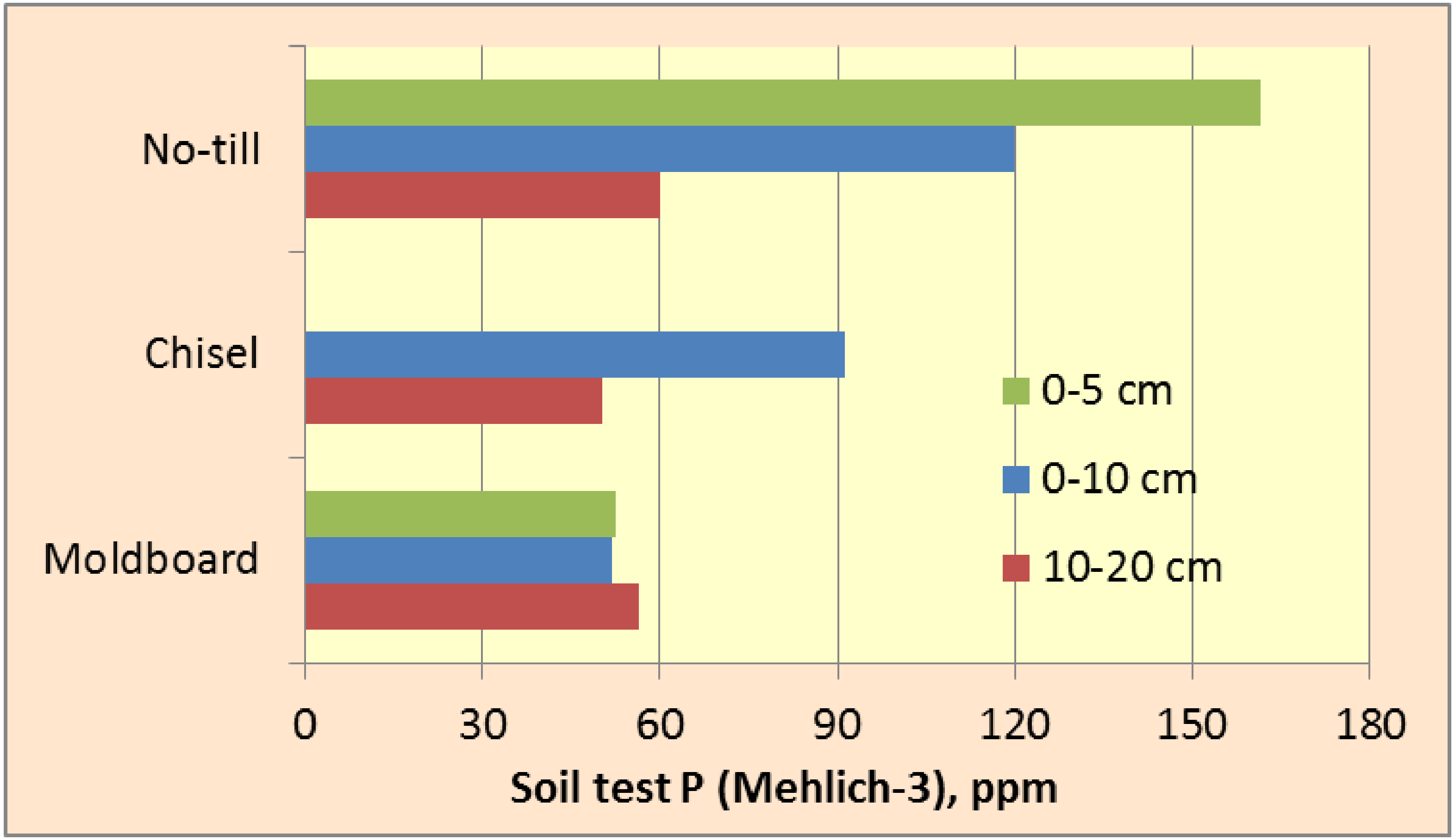
## After P application & tillage (May 12th)




**Incorporating reduced DRP loss from 0.27 to 0.04 lb $P_2O_5$ per acre**

*Williams and King, USDA-ARS, Columbus, Ohio*

# Soil test P stratifies when moldboard plowing stops




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.

**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*

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**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

| Practice | Dissolved P | Particulate P |
|---|---|---|
| Source | --- | --- |
| Rate | 60 to 88% | negligible |
| Time | 41 to 42% | negligible |
| Place | 20 to 98% | -60% to NS |
| Soil inversion | NS to 92% | -59% to NS |
| Conservation tillage | -308 to -40% | -33 to 96% |

Dodd & Sharpley, 2015. Nutrient Cycling in Agroecosystems.

1. **Wide range of efficacies demands more site-specific focus.**
2. **Trade-off between dissolved and particulate is important.**

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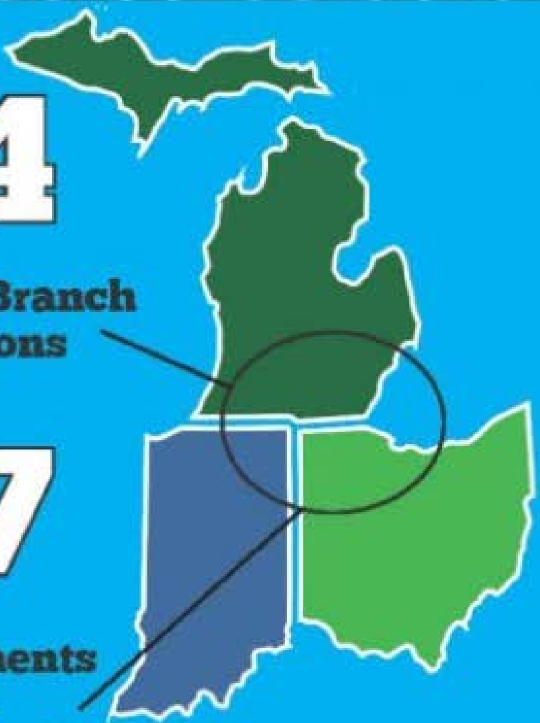
# 4R NUTRIENT STEWARDSHIP CERTIFICATION PROGRAM

**Western Lake Erie Basin - Ohio, Michigan, and Indiana**

**34** Certified Branch Locations

**37** Commitments From Other Branches



| | |
|---|---|
| Acres serviced or applied in WLEB | 1,900,000 |
| Acres outside WLEB serviced or applied | 800,000 |
| Total | 2,700,000 |
| Number of Clients Serviced in WLEB | 4,000 |
| Clients Serviced Outside WLEB | 1,500 |
| Total | 5,500 |

NUTRIENT STEWARDSHIP CERTIFICATION

## 2.7M acres in OH-IN-MI

extending to all of Ohio

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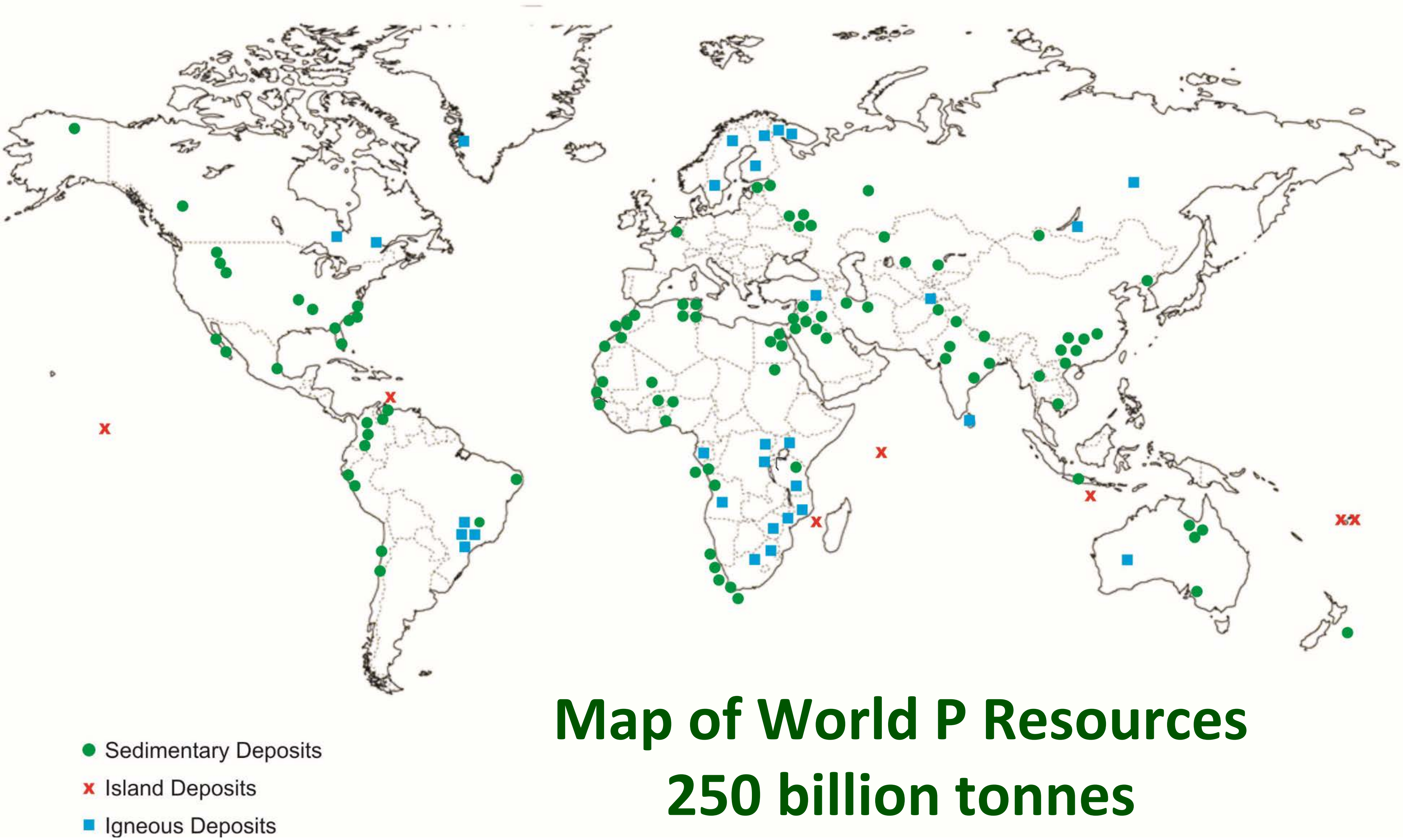
# Phosphate Rock Reserves and Quality

- Grade
- $P_2O_5$ content
- Trace elements – Cd, etc.
- Phosphogypsum – 5 tons per ton of phosphoric acid

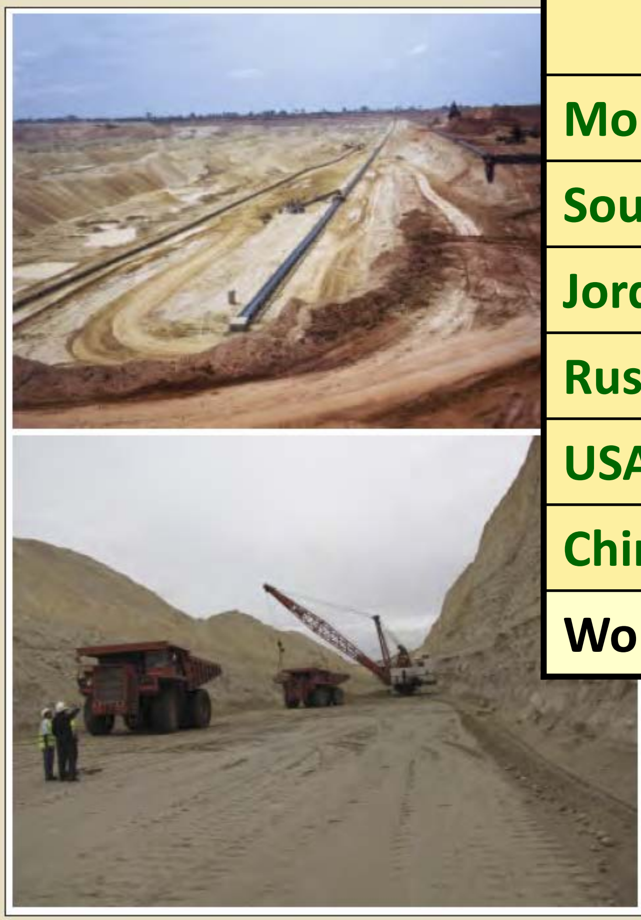



# Map of World P Resources
# 250 billion tonnes
# in >100 countries

*Sources: IFDC; USGS (2002, 2013)*

IFDC

World Phosphate Rock Reserves and Resources



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

Source: USGS, 2016

"No matter how much phosphate rock exists, it is a non-renewable resource"
IFDC, 2010

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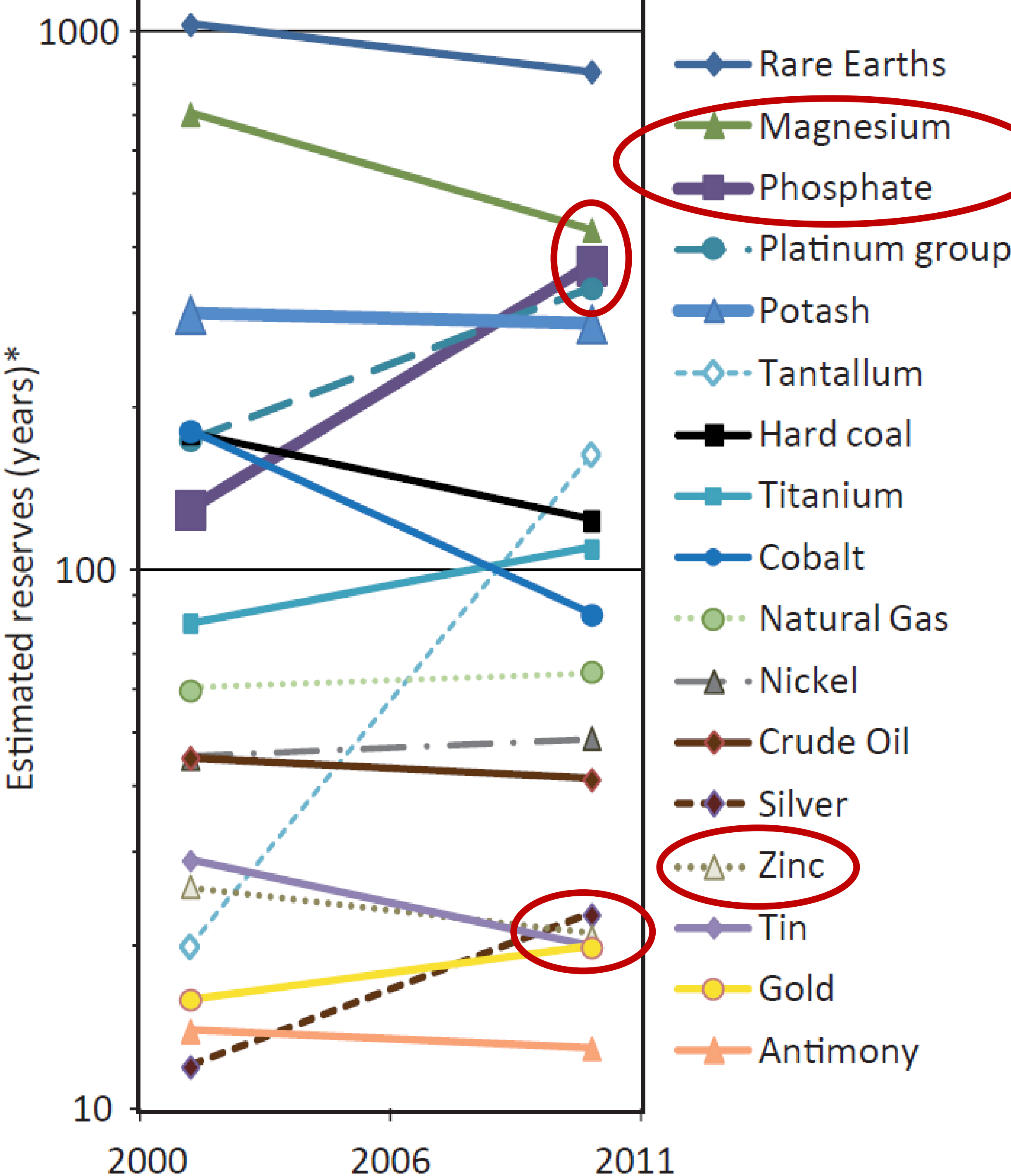
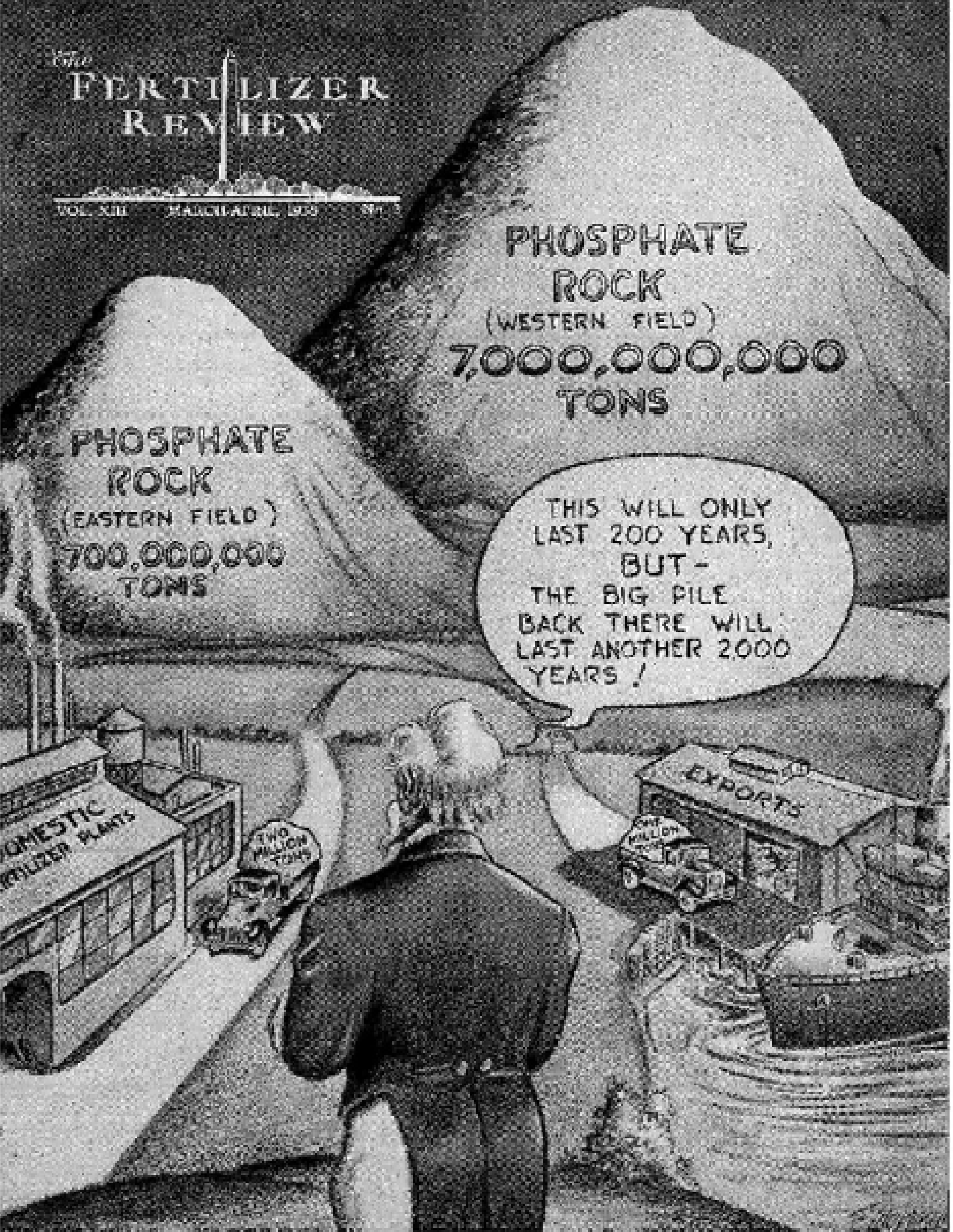



Putting phosphorus reserves into context: Changes in estimated reserves of different commodities as estimated in 2002/2003 and 2010 (Based on Scholz & Wellmer, 2013; U.S. Geological Survey, 2012a; U.S. Geological Survey, 2012c). *Ratio of estimated reserve to annual mine production.

*Sutton et al. 2013. Our Nutrient World. Global Partnership on Nutrient Management.*

IPNI




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.**

*Andrea E. Ulrich. 2016. Science of The Total Environment 542(B):1005-1168*

**Global ore tonnage and grade:**

1983: 513 Mt @ 14.3% $P_2O_5$

2013: 661 Mt @ 17.5% $P_2O_5$

*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.