

# Phosphorus in a global context

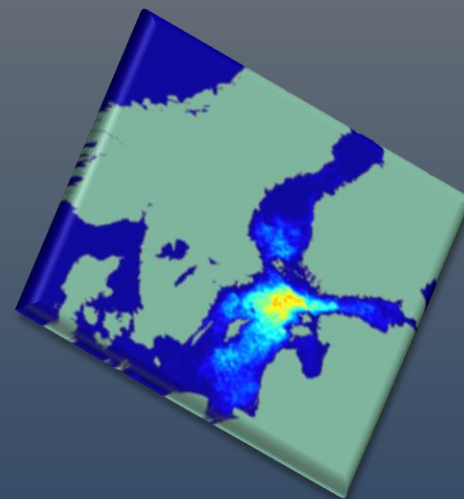
*Persistent issues in research and management*



Peter Kleinman

*U.S. Department of Agriculture*

*Agricultural Research Service*



*Understanding Algal Blooms: State of the Science*

*September 13, 2018. Toledo, OH.*

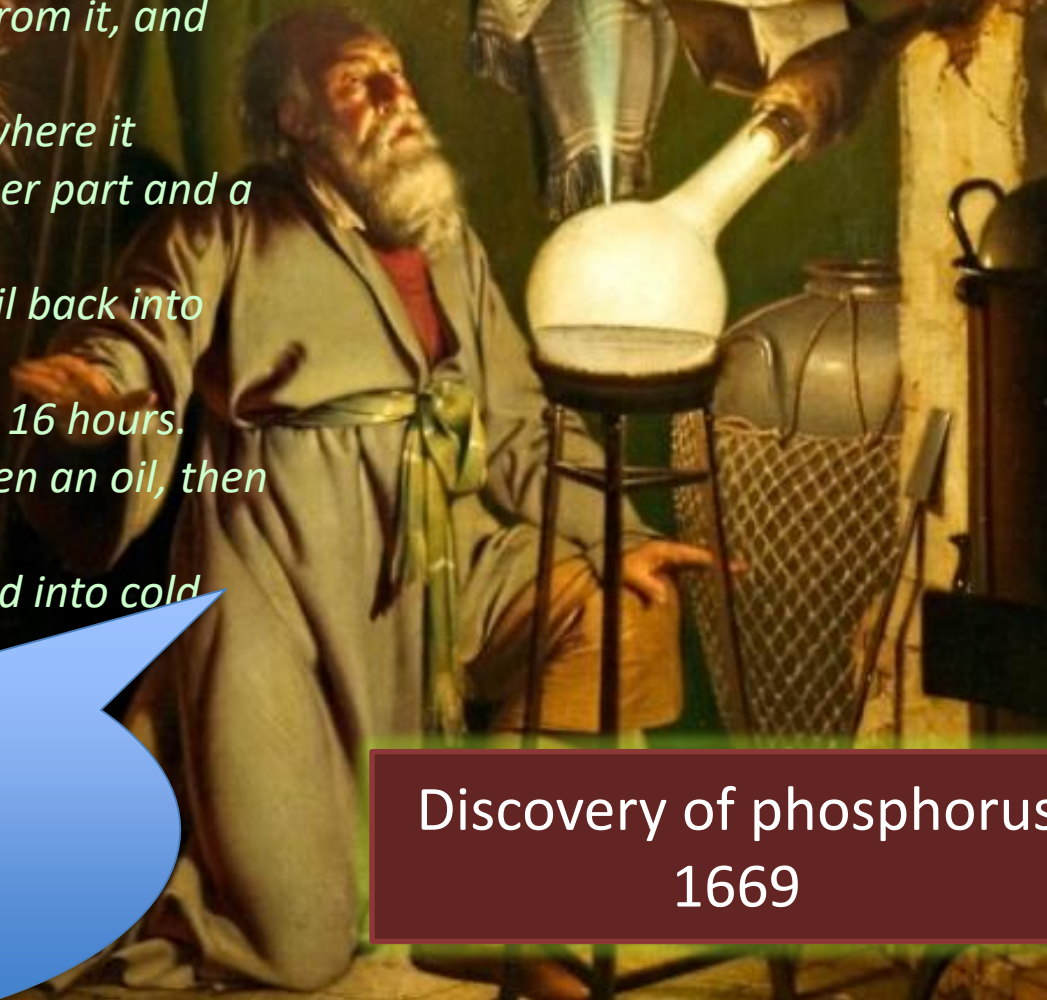
# Hennig Brand and the Philosopher's Stone

## 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

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

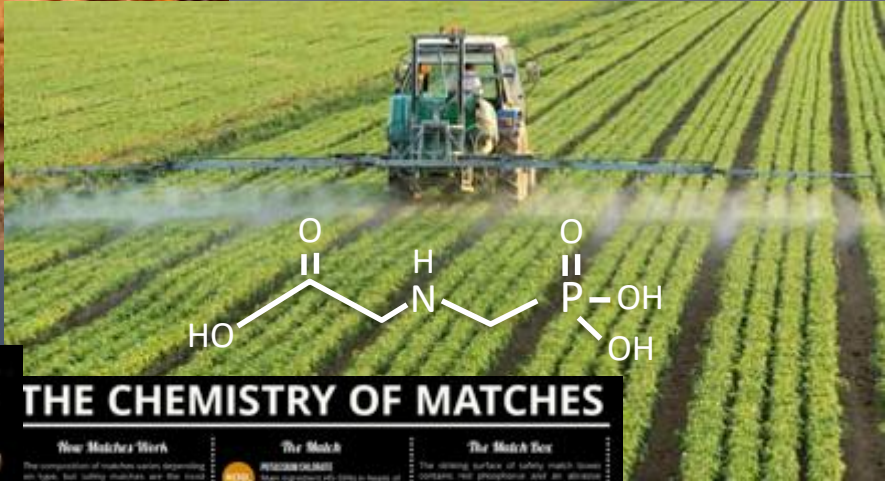
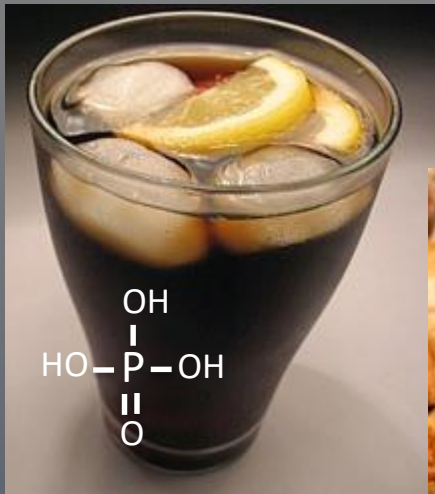
Discovery of phosphorus  
1669





# Devilishly useful

INGREDIENTS: CHEDDAR CHEESE (MILK, CHEESE CULTURE, SALT, ENZYMES), WHEY, WATER, MILK PROTEIN CONCENTRATE, MILK, SODIUM CITRATE, CONTAINS LESS THAN 2% OF CALCIUM PHOSPHATE, MILKFAT, GELATIN, SALT, SODIUM PHOSPHATE, LACTIC ACID, SORBIC ACID AS A PRESERVATIVE, ANNATTO AND PAPRIKA EXTRACT (COLOR), ENZYMES, VITAMIN A PALMITATE, CHEESE CULTURE, VITAMIN D3  
CONTAINS: MILK.



## THE CHEMISTRY OF MATCHES

### New Matchstick Work

The composition of matchsticks varies depending on type, but safety matches are the most commonly used. They contain a strong oxidizing agent in the match head and red phosphorus on the striking surface. Striking the match causes small amounts of the oxidizer and phosphorus to combine, and the heat generated by this reaction of the striking causes them to ignite.

Prior to the 1930s, white phosphorus was the oxidizer, regardless of match variety, but this could cause "phosphenia" and bone disorders, and was also toxic, so was replaced.

### The Match

**REDUCING COMPOUND**  
More significant redox takes place in the head of safety matches.

**PHOSPHORUS COMPOUNDS**  
Longer in the head of most traditional matches.

**ANTIMONY (III) SULFIDE**  
Added to some matches to make them burn more vigorously.

Traditionally, the matches contain ammonium phosphates to prevent "afterglow", due to total oxidation, and to prevent the loss of burning.

### The Match Box

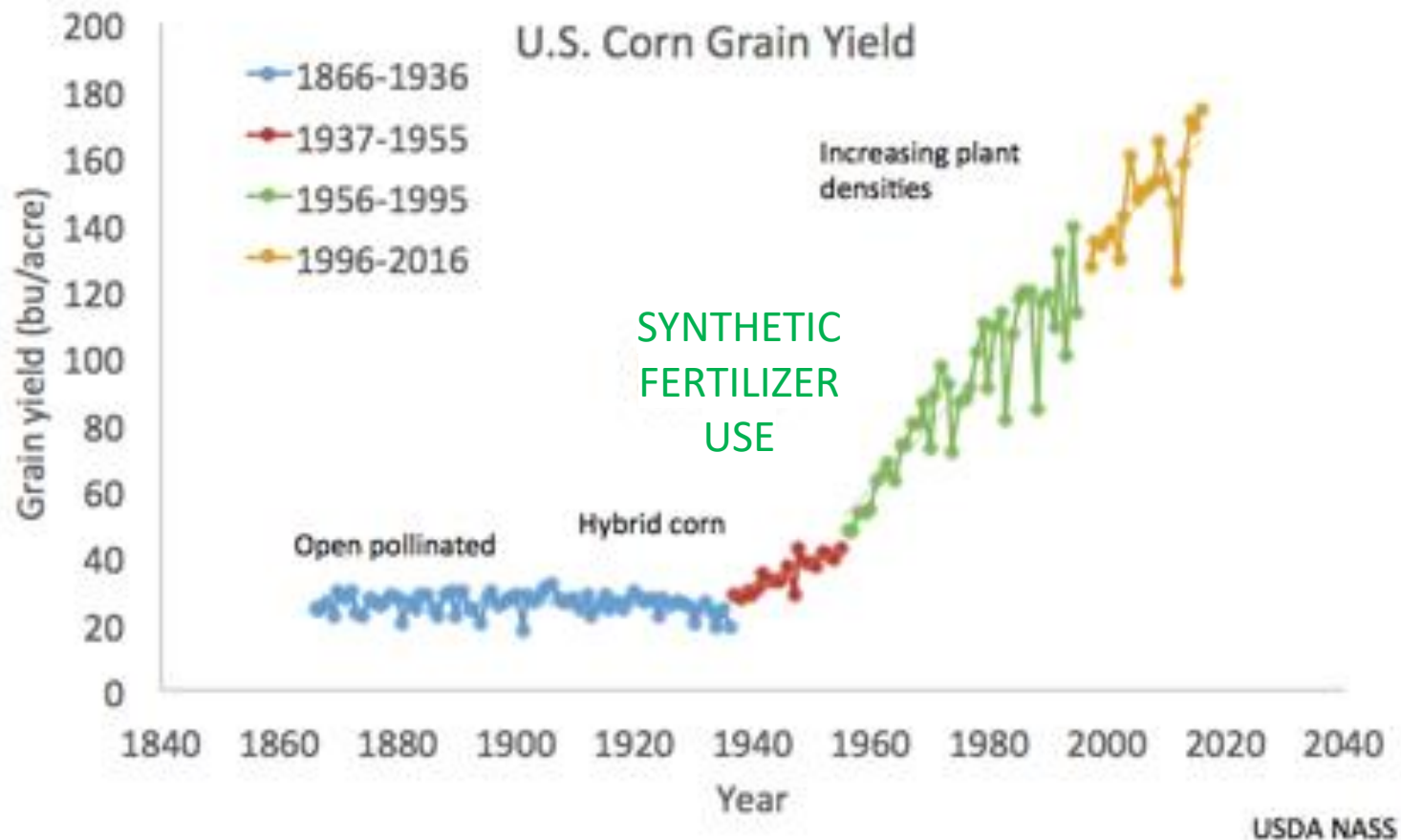
The striking surface of safety match boxes contains red phosphorus and an oxidizing substance. When struck, a small amount of white phosphorus is produced, which ignites.

Red Phosphorus (left) White Phosphorus (right)

© Copyright 2010 by The Matchstick Company. All rights reserved. This document is for informational purposes only. It is not intended to be used as a substitute for professional advice. Printed under a Creative Commons Attribution-NonCommercial-ShareAlike license.

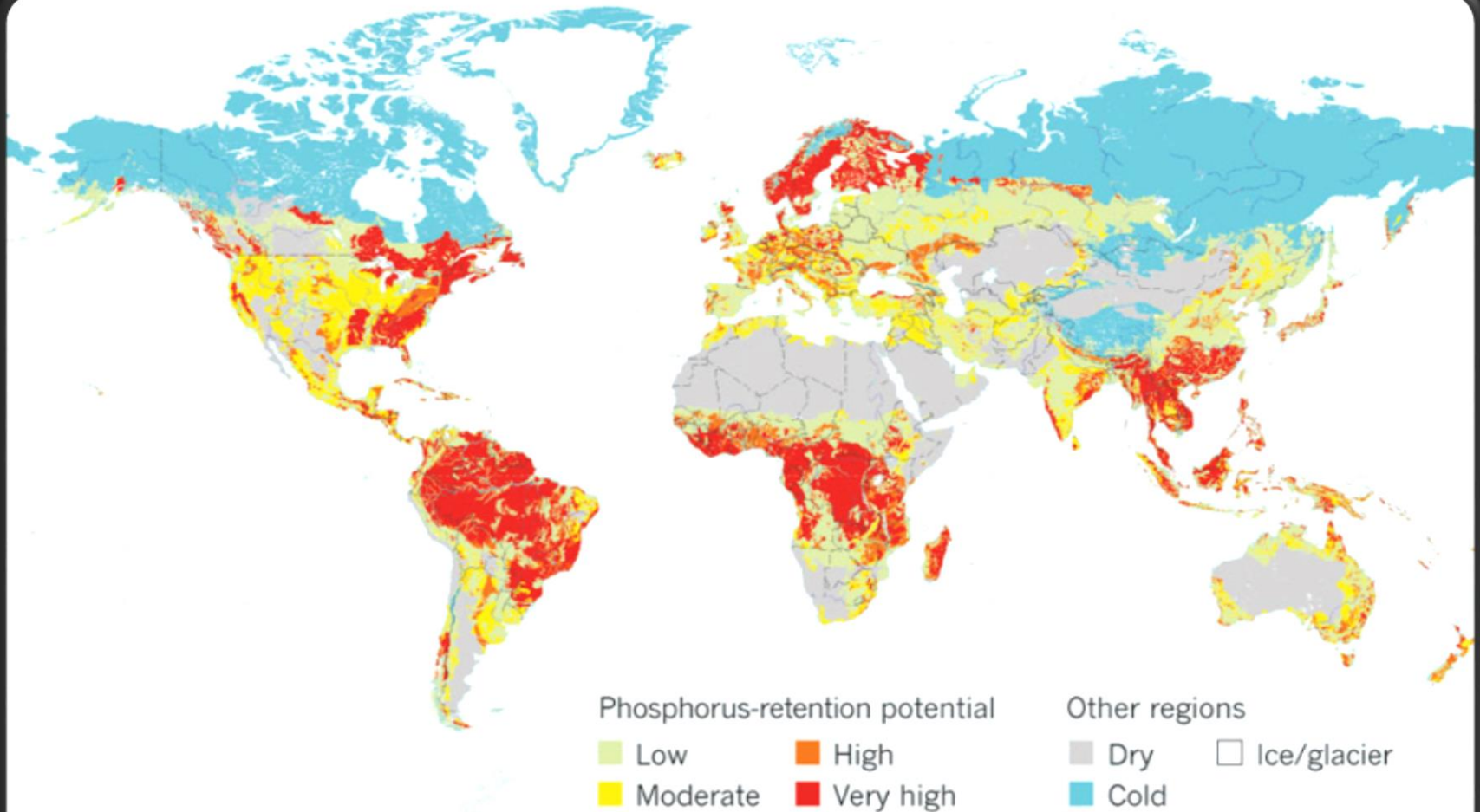
# Phosphorus as a crop nutrient

## *A pillar of modern crop production*



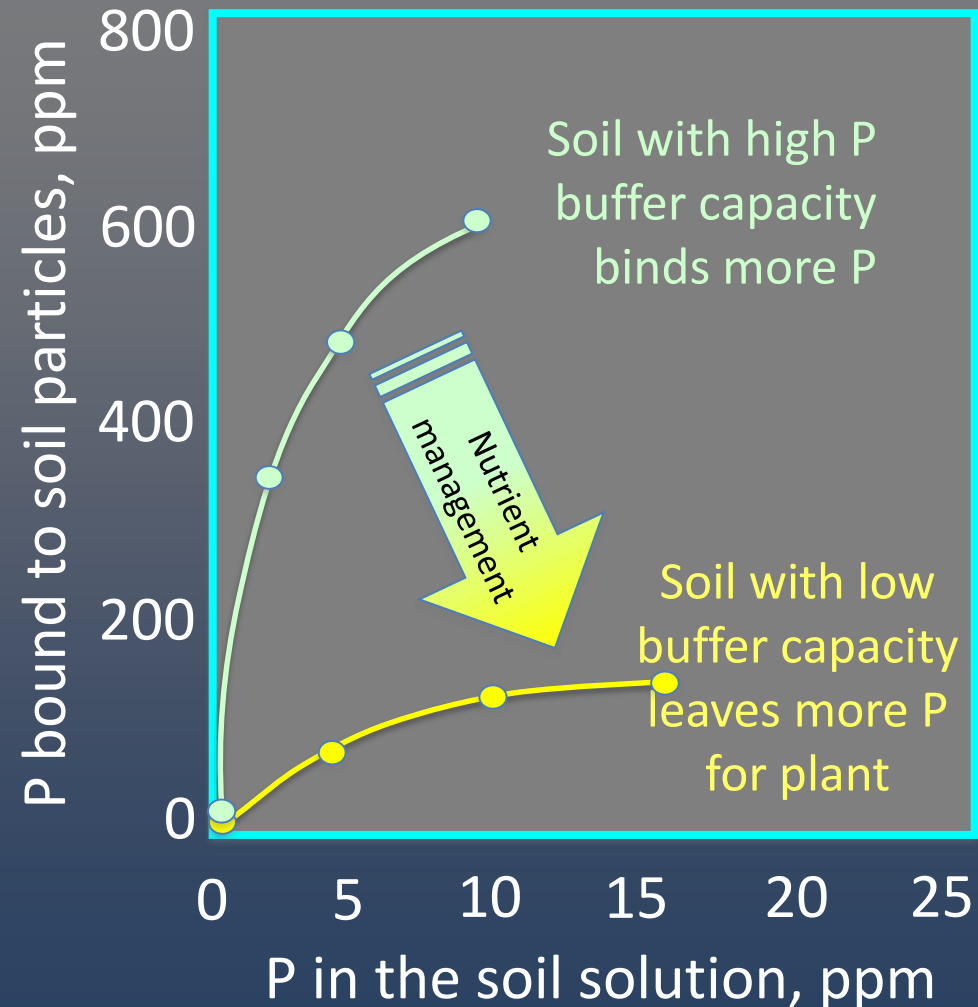
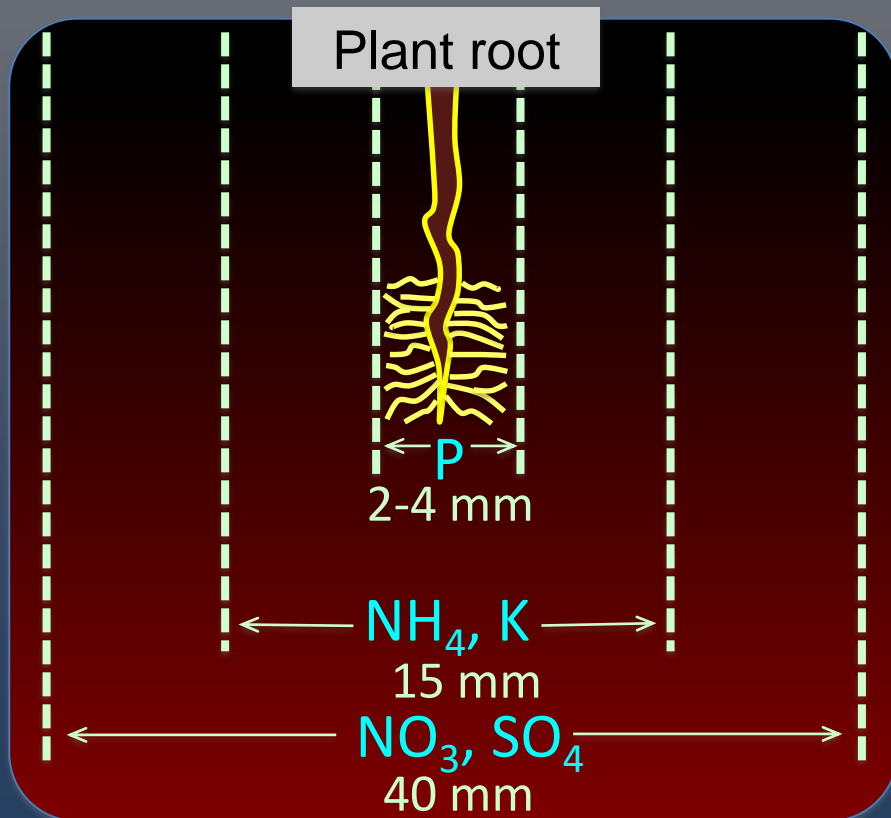
# Challenge: the inequity of resource distribution

## *Overcoming soil P buffering*



# Phosphorus fertility - historical priority

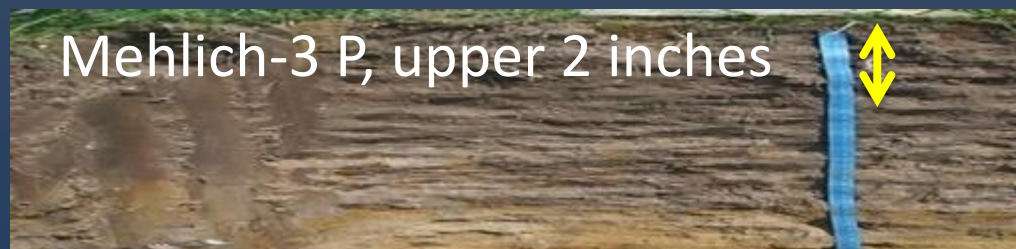
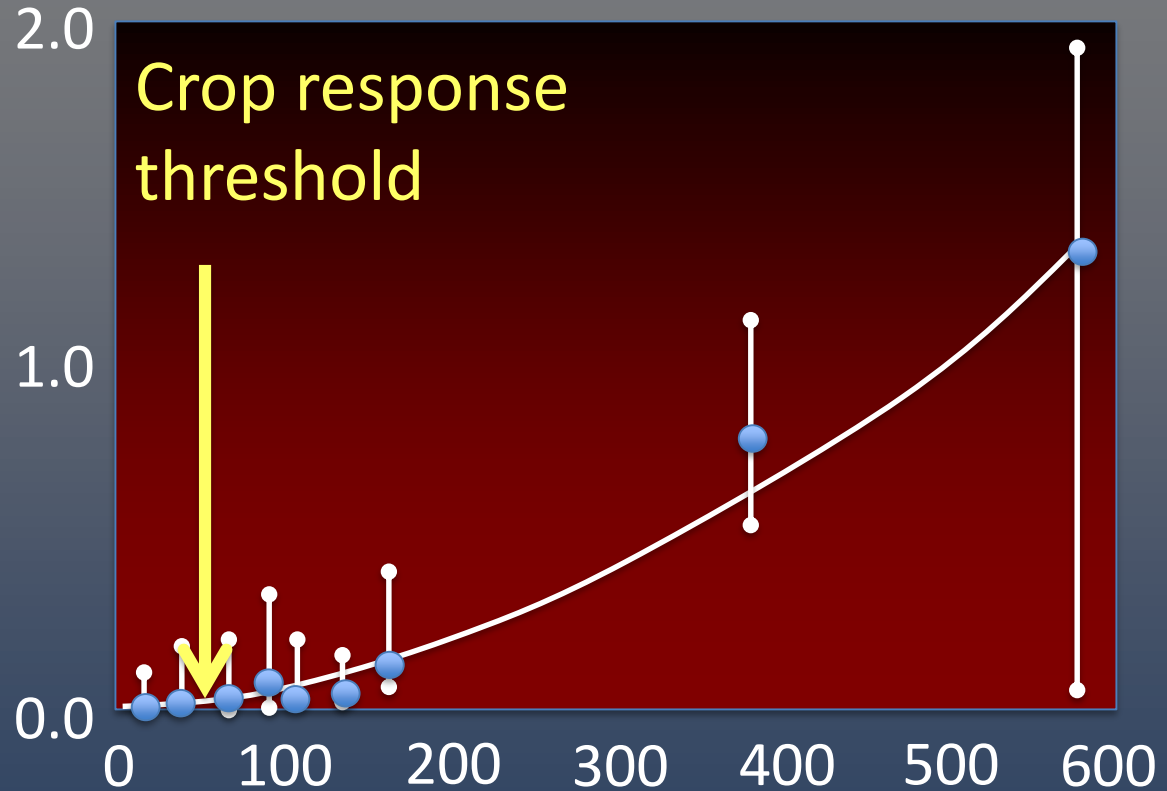
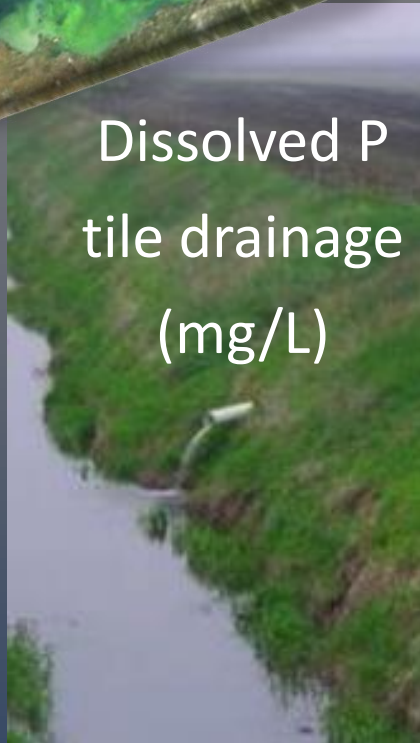
*Fertilizing the soil to get to the crop*



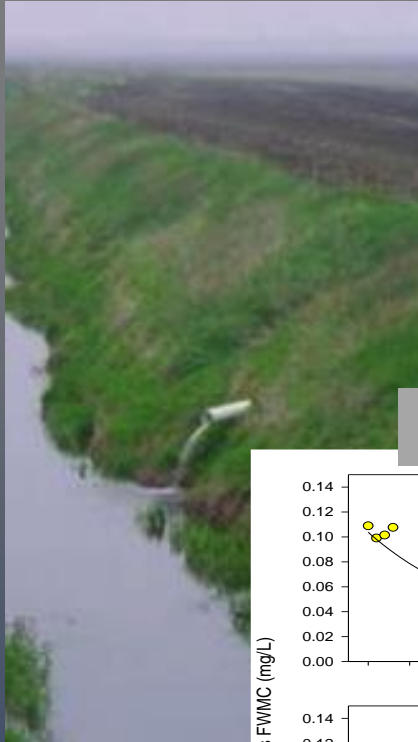




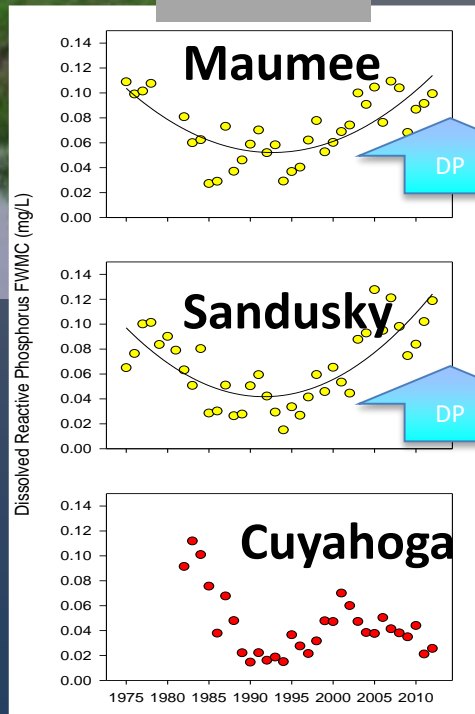
# Inherently inefficient *P* loss to water



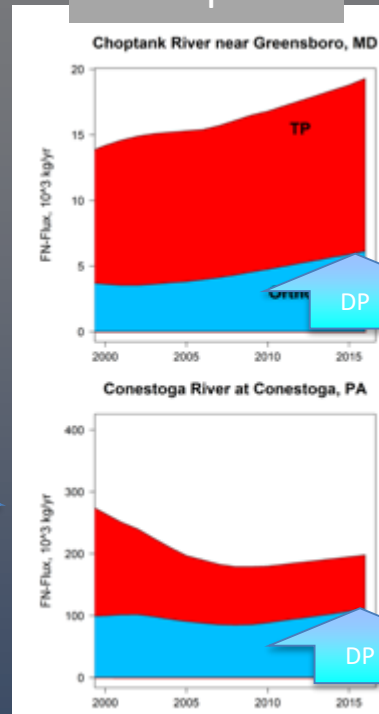
# Dissolved P - the universal headache aka “soluble P”



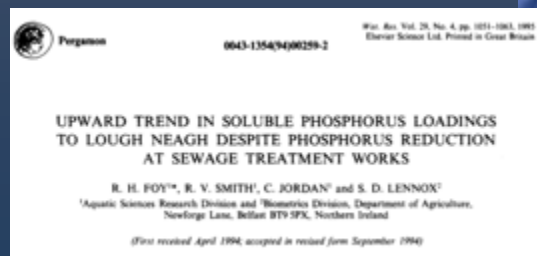
Lake Erie



Chesapeake

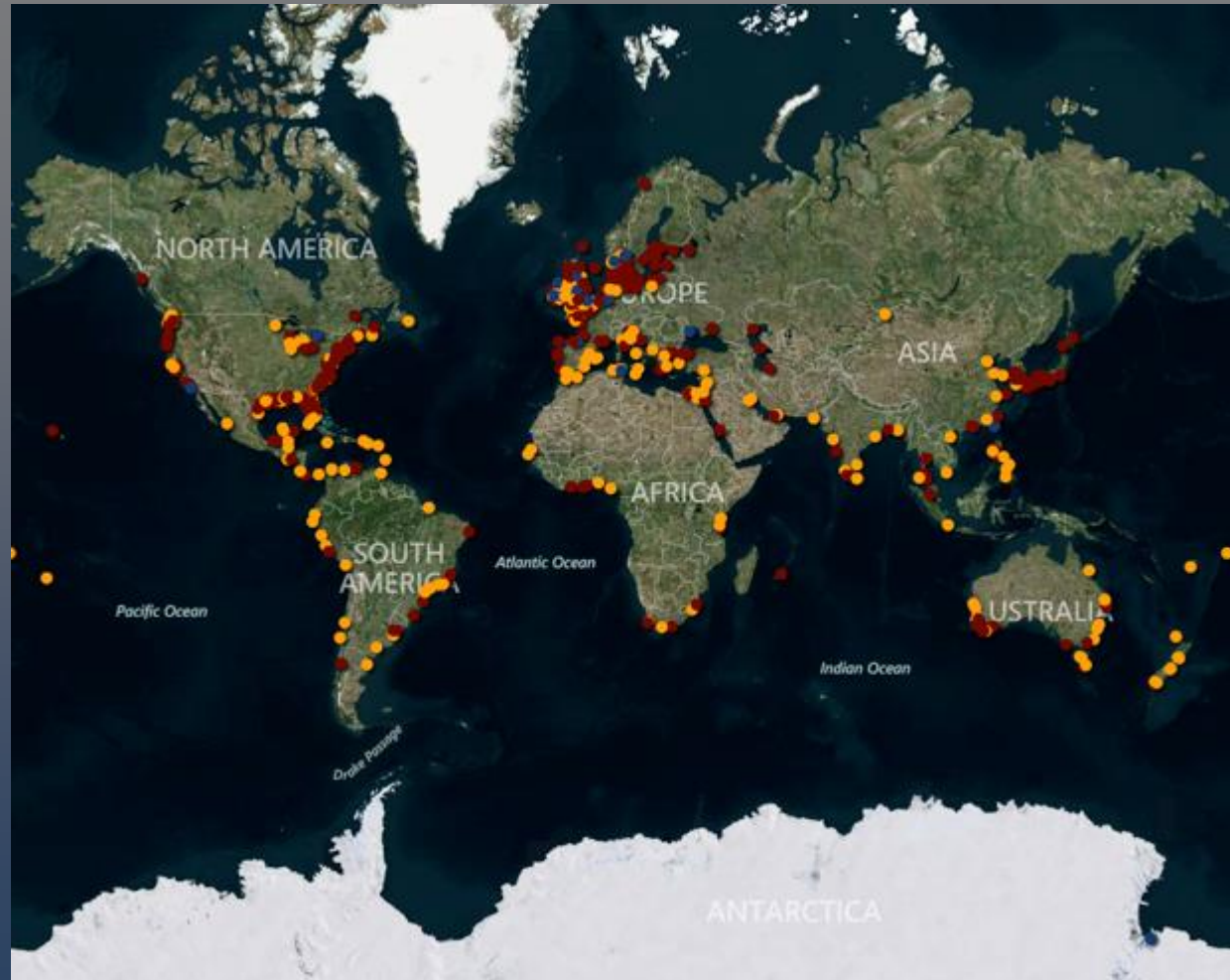


Baltic Sea





# Eutrophication persists despite decades of watershed mitigation efforts





Crop Dairy Swine

P imported (kg/ha)

fertilizer	18	11	0
feed	0	30	104

P exported (kg/ha)

milk/animals	0	12	20
crops	16	1	0

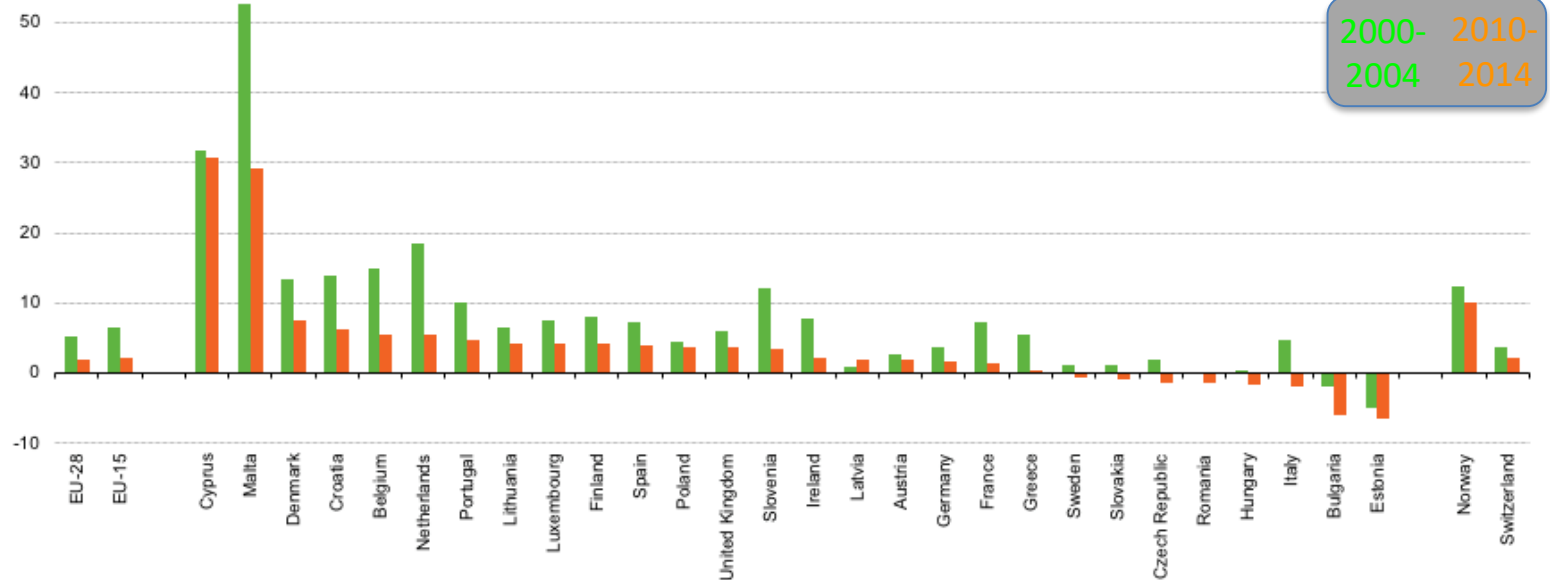
P balance (kg/ha)

2 29 84

Source: Lanyon (1999)

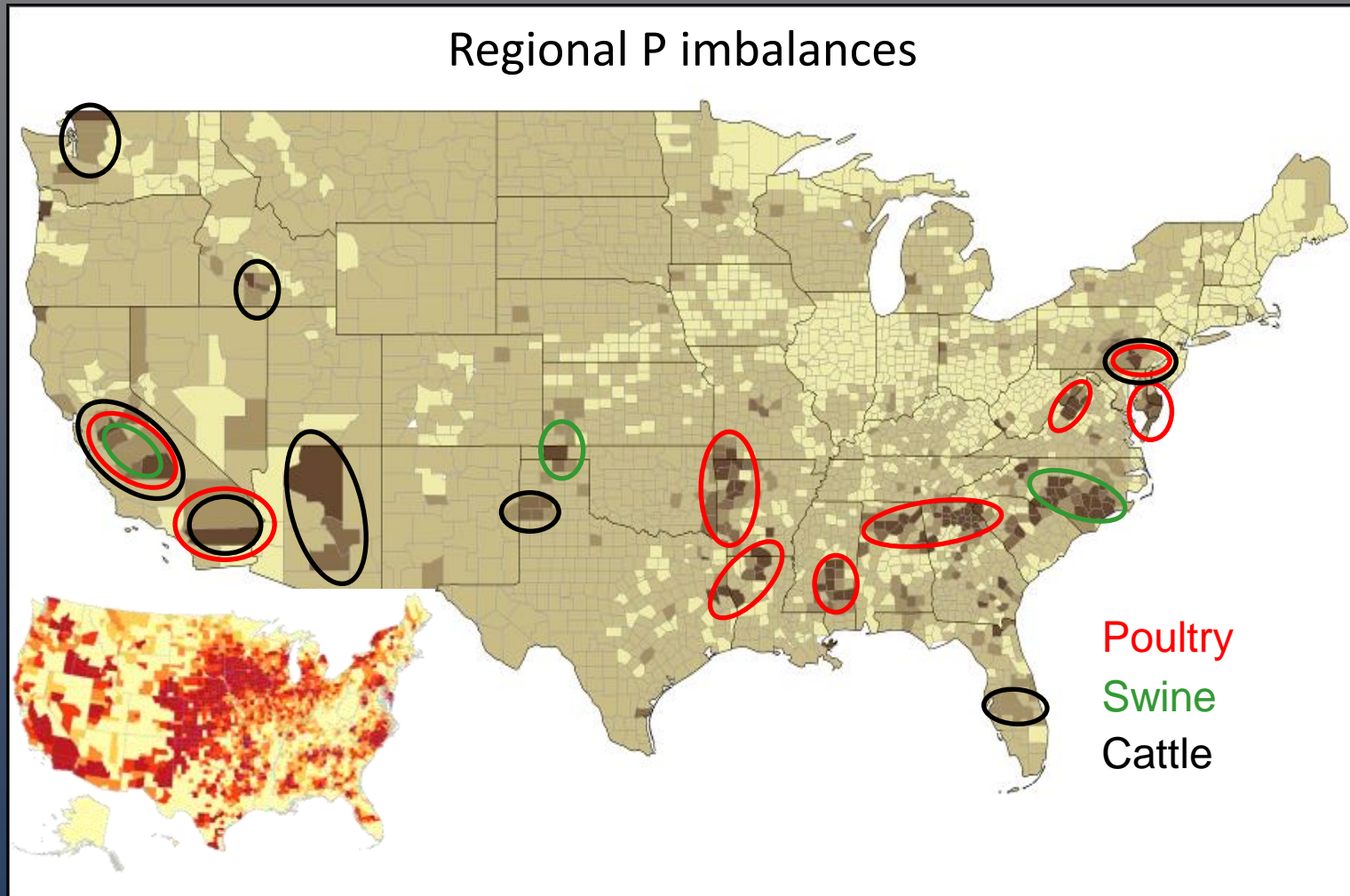
Thinking of P as a  
resource

*a matter of budgets*



# “Legacy P” and animal agriculture

*intensification and specialization of farming systems*

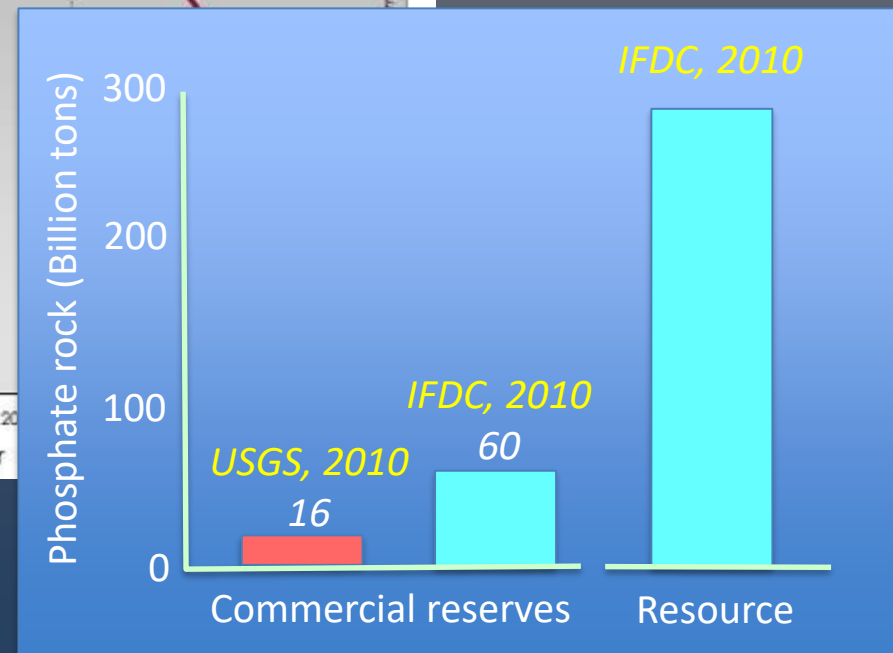
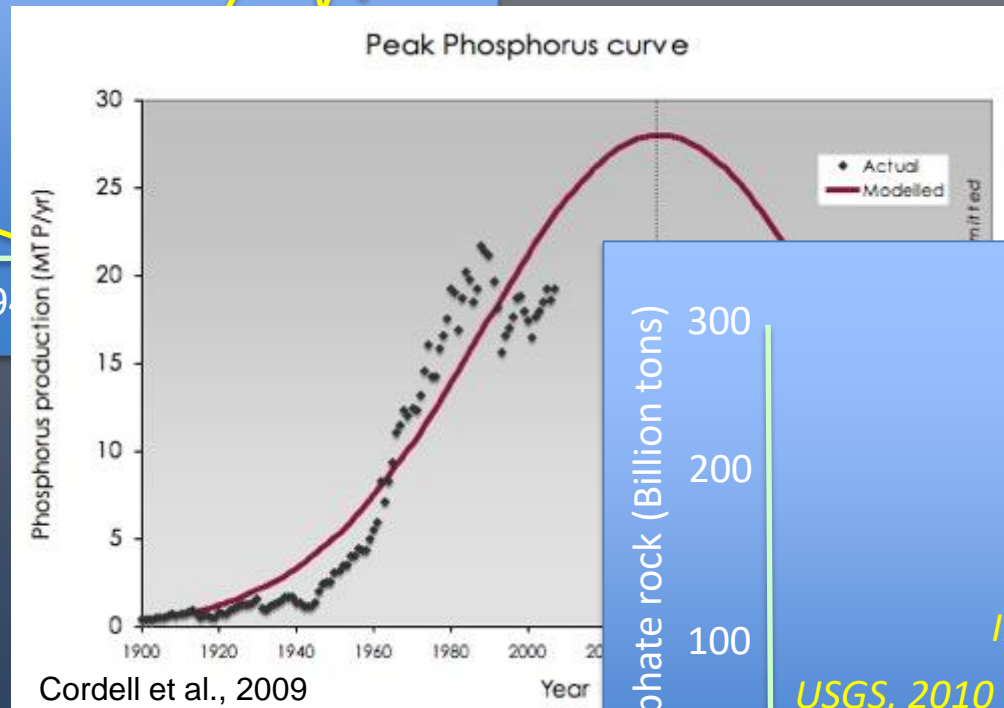
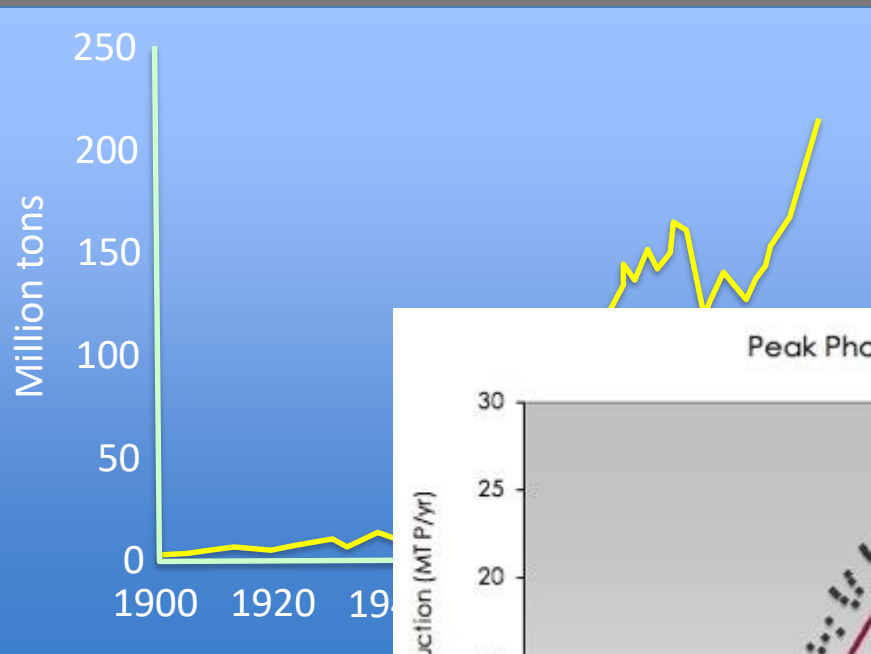




# Phosphorus: circular economy poster child

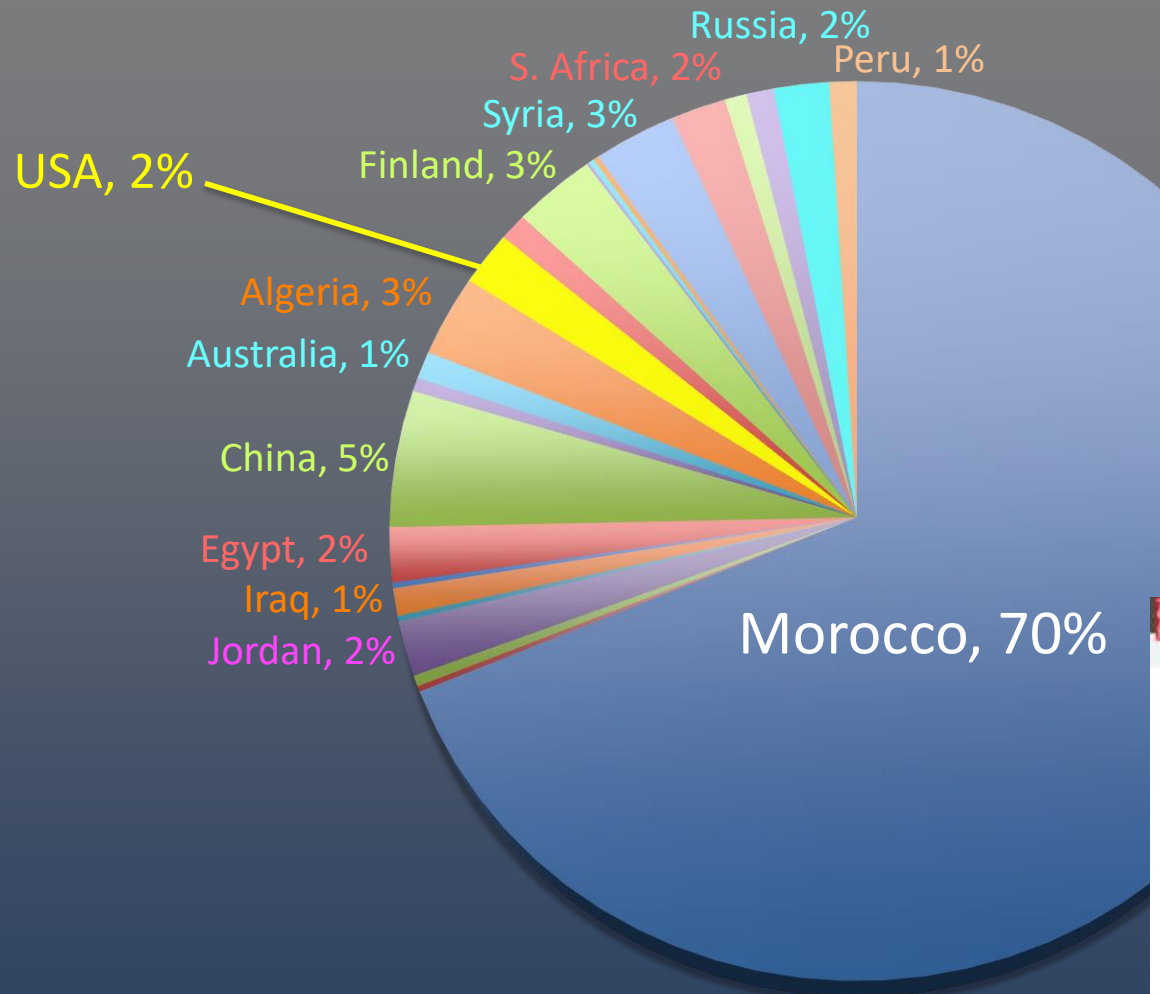


# Phosphorus: more valuable than oil?



# Commercial reserves of rock phosphate – 2016

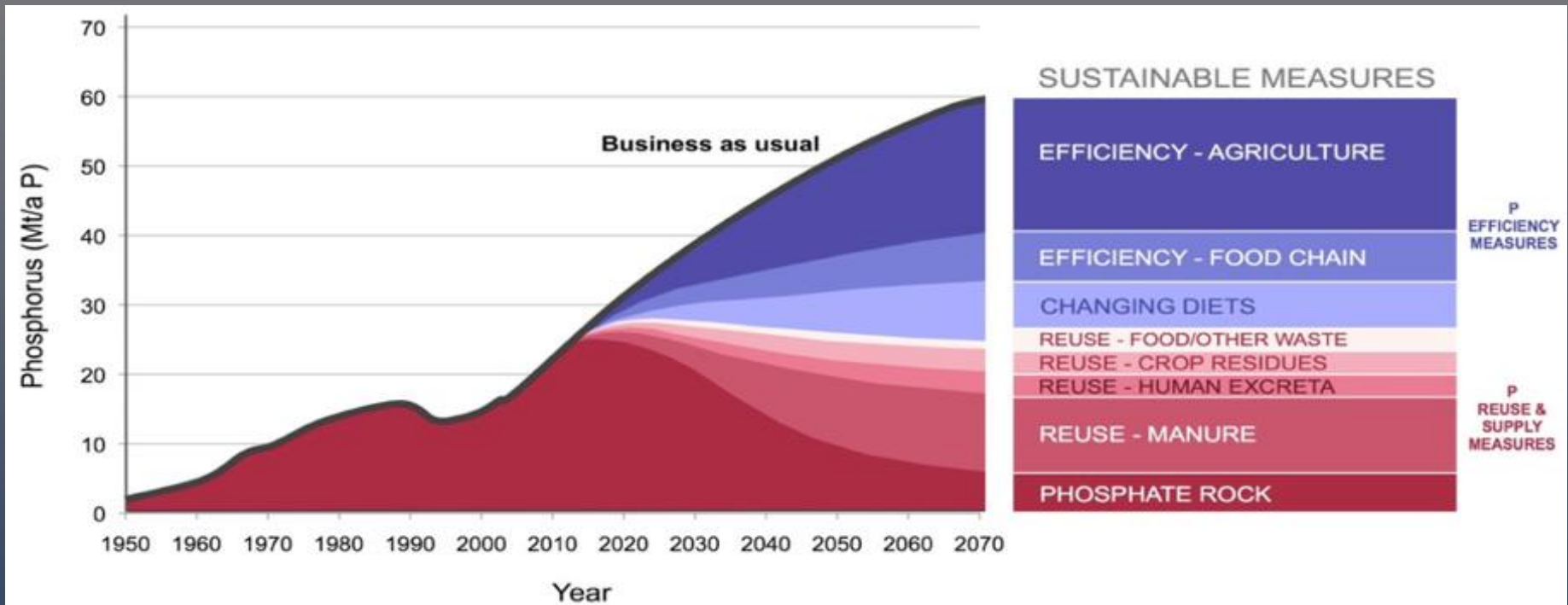
## *National case for food security*





# Opportunities for improvement

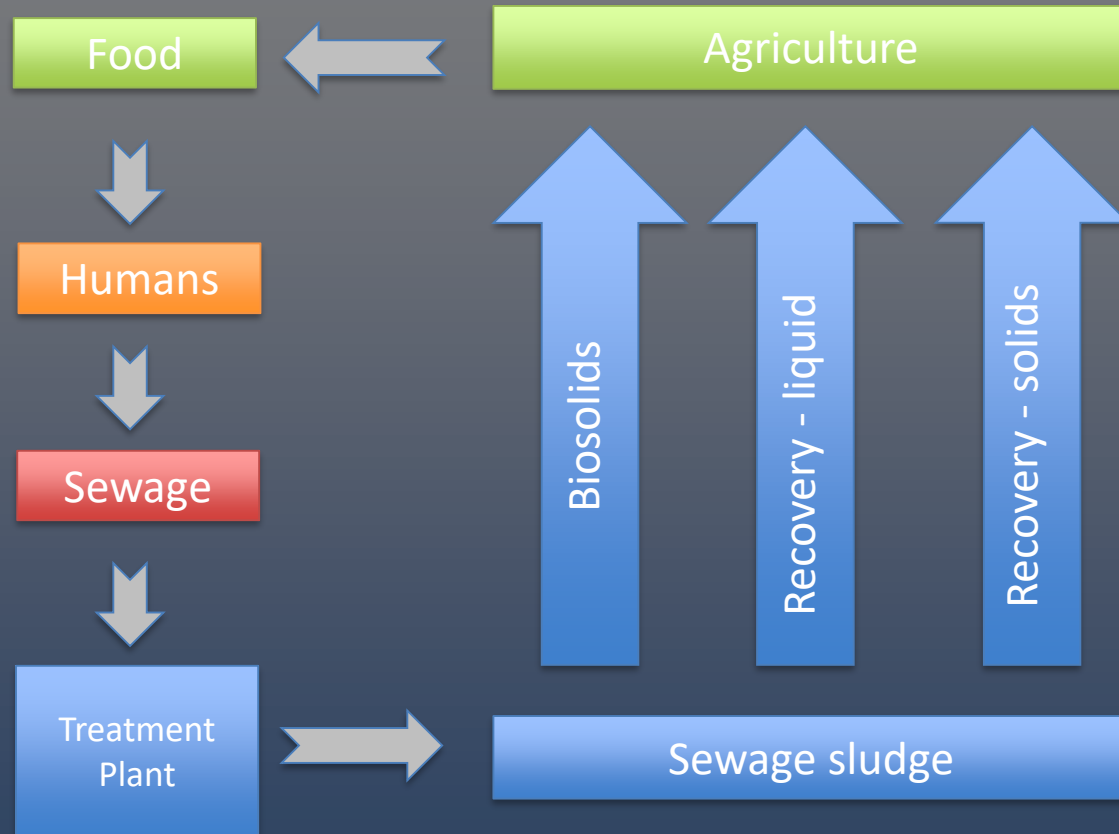
## *P Use Efficiency, Consumption, Recovery*



Source: Cordell, D.; White, S. Sustainable Phosphorus Measures: Strategies and Technologies for Achieving Phosphorus Security. *Agronomy* 2013, 3, 86-116. (Copied from <https://phosphorusalliance.org/about/>)

# RECOVERY

*a wastewater centric perspective*



# Biosolids Land Application

## *Increasingly Challenged*

## Conclusions

- It would be a devastating step backwards to lose sludge as a source of nutrients.
- Cooperation when examining
- Kåppala can be an efficient way
- Working with high quality, contributes



# Struvite Recovery



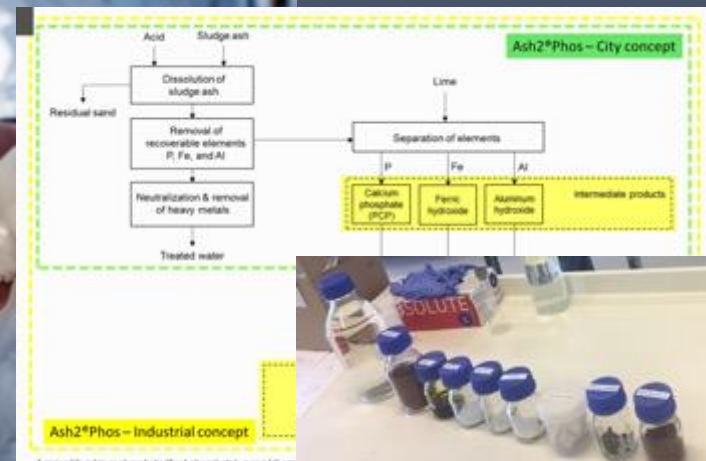
### Phosphorus recovery from water phase



# HSY – New Research

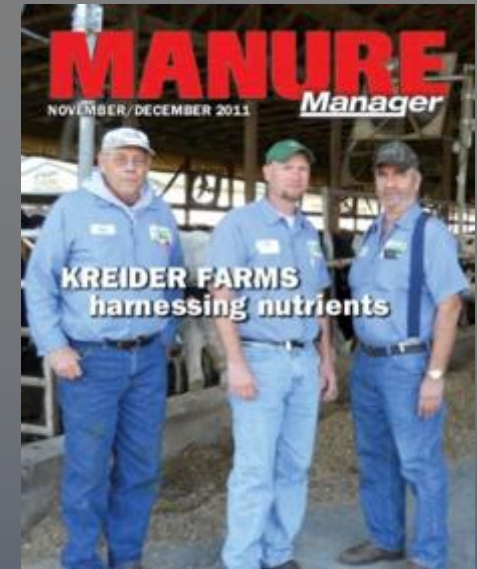


# Ash2Phos





# Nutrient recovery systems for CAFOs



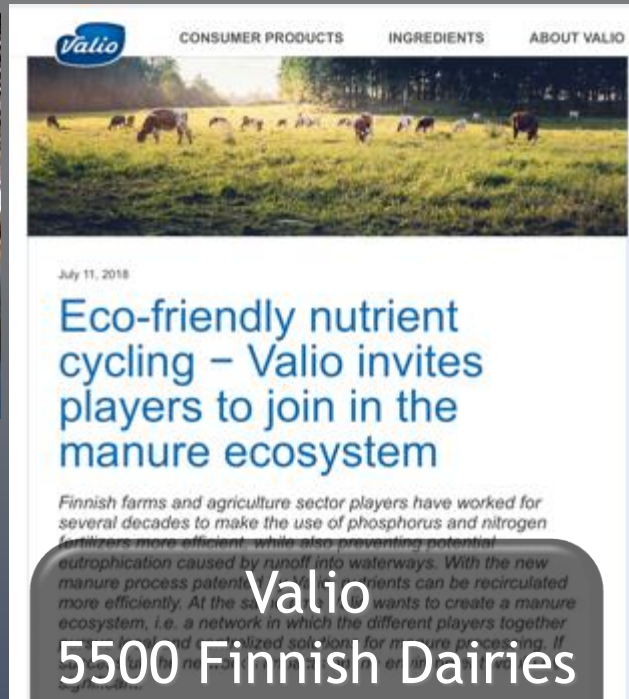


# Implementation challenges

*Policies, markets, scale, incentives*



Purdue litter  
pelletizing plant



Valio  
5500 Finnish Dairies  
N and P  
recovery system



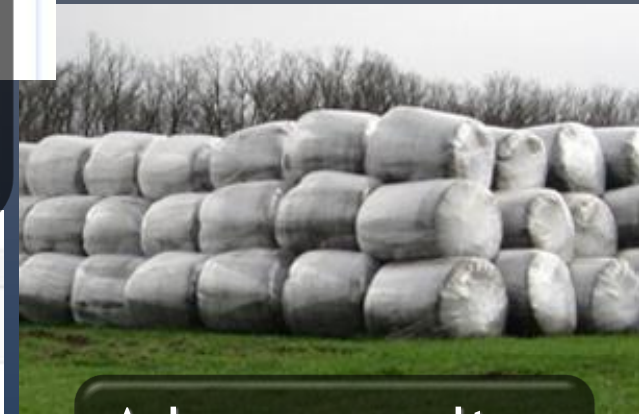
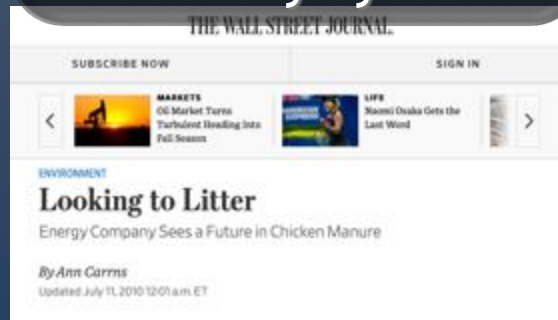
Dane County  
Wisconsin  
manure digester



Fibrominn turkey  
litter power plant



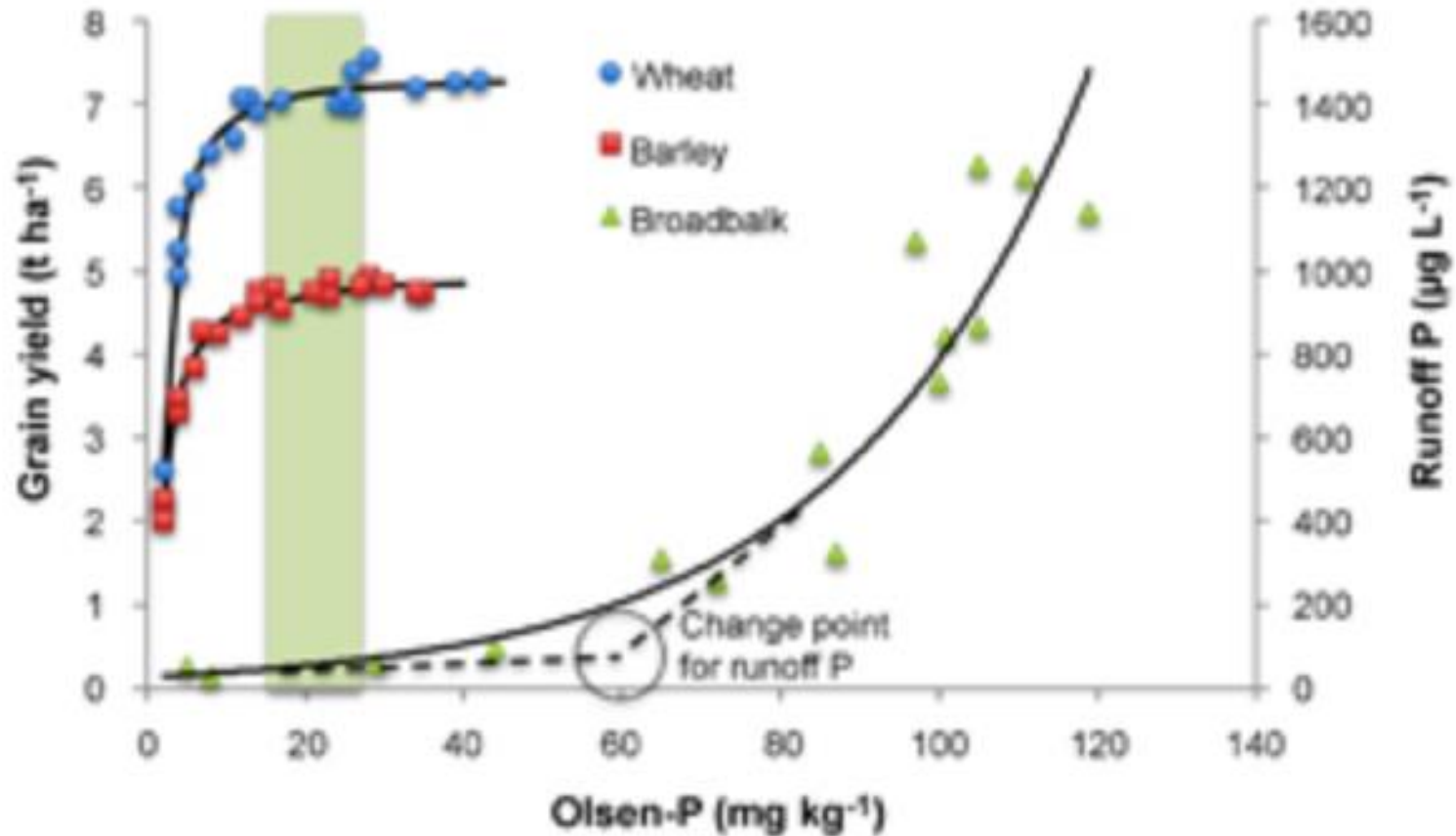
Minn. power plant that burns turkey poop faces closure



Arkansas poultry  
litter baling

# Food production and environmental health

## *Moving beyond win-win assumptions*

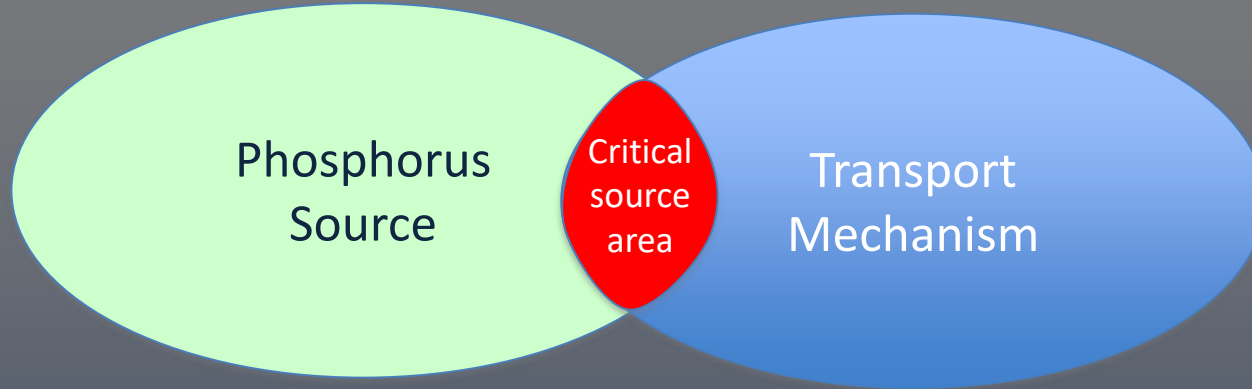


Obtained from Withers et al., 2017, displaying relationships of Poulton et al. (2013) and Heckrath et al. (1998)

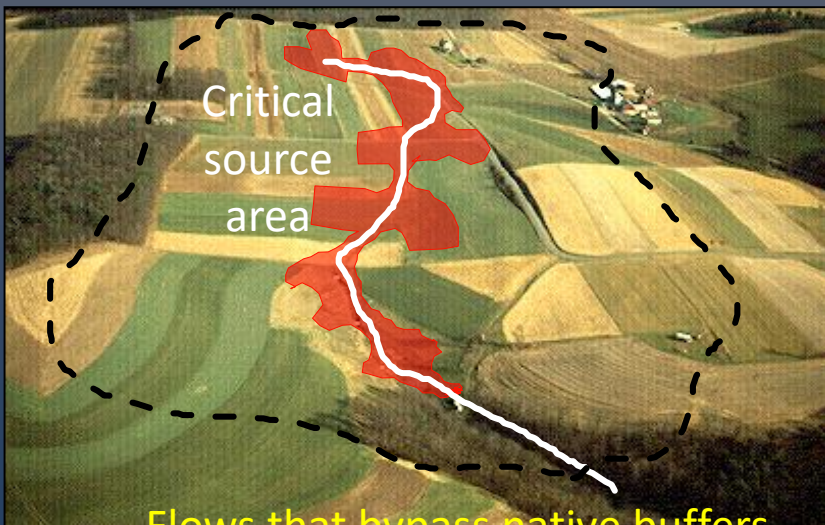


# Critical Source Area Management

*Managing sources and transport pathways*

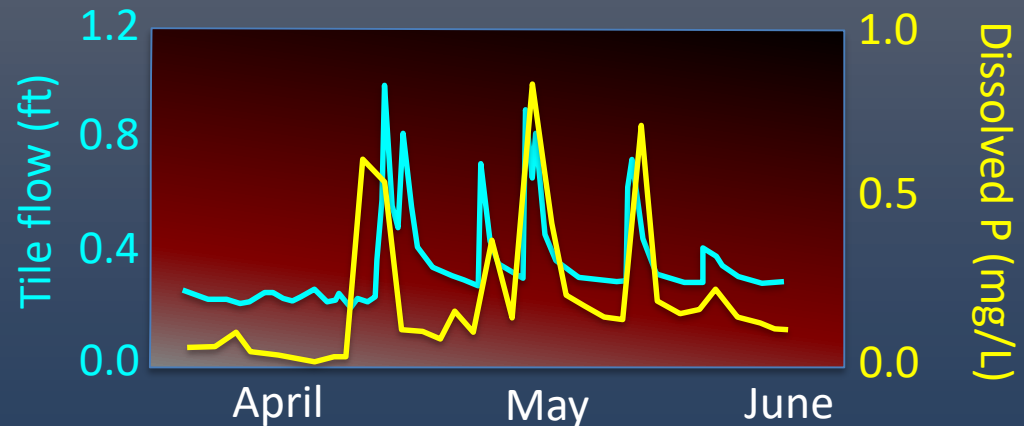


## HOT SPOTS



Flows that bypass native buffers

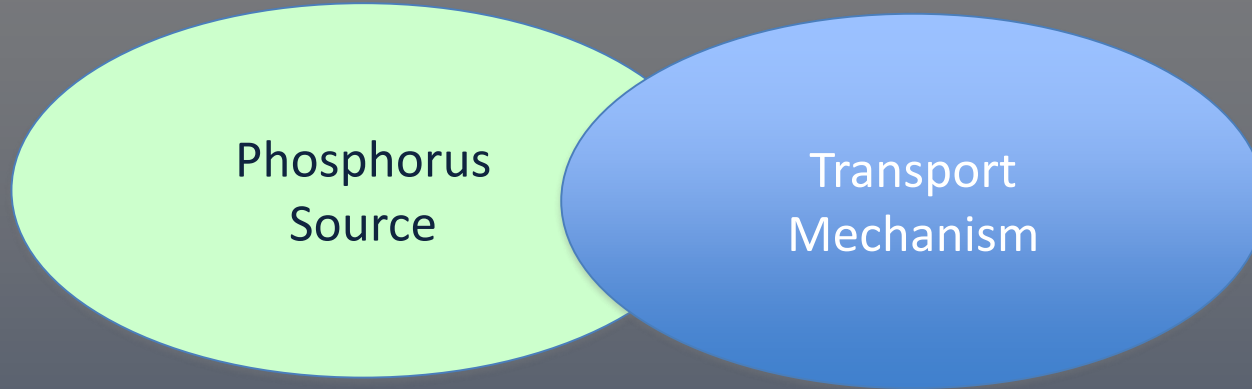
## HOT MOMENTS



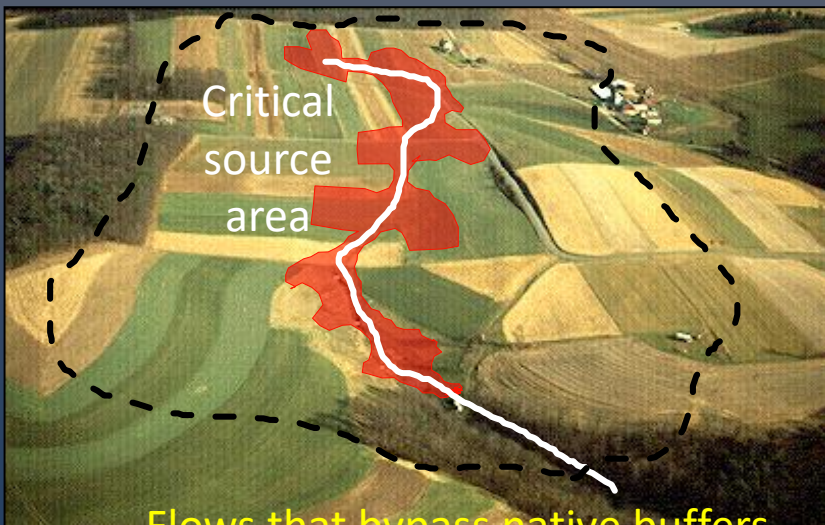
Source: King, USDA-ARS

# Critical Source Area Management

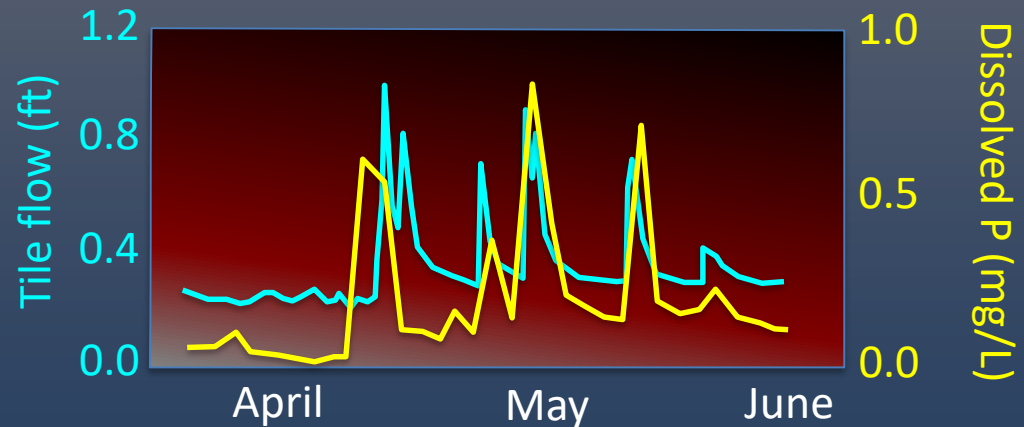
*Disconnecting sources and transport pathways*



## HOT SPOTS



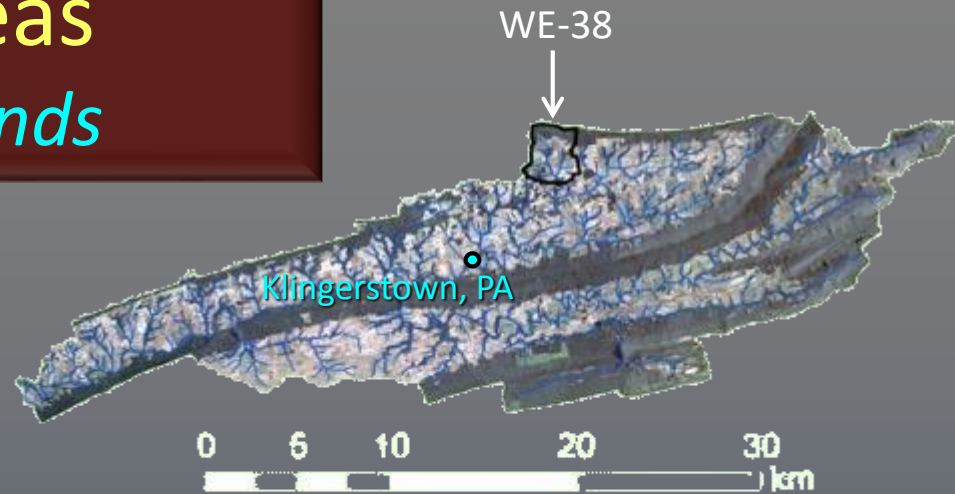
## HOT MOMENTS



Source: King, USDA-ARS

# Critical source areas

## *Chesapeake Bay uplands*



WE-38 Watershed (7.3 km<sup>2</sup>)

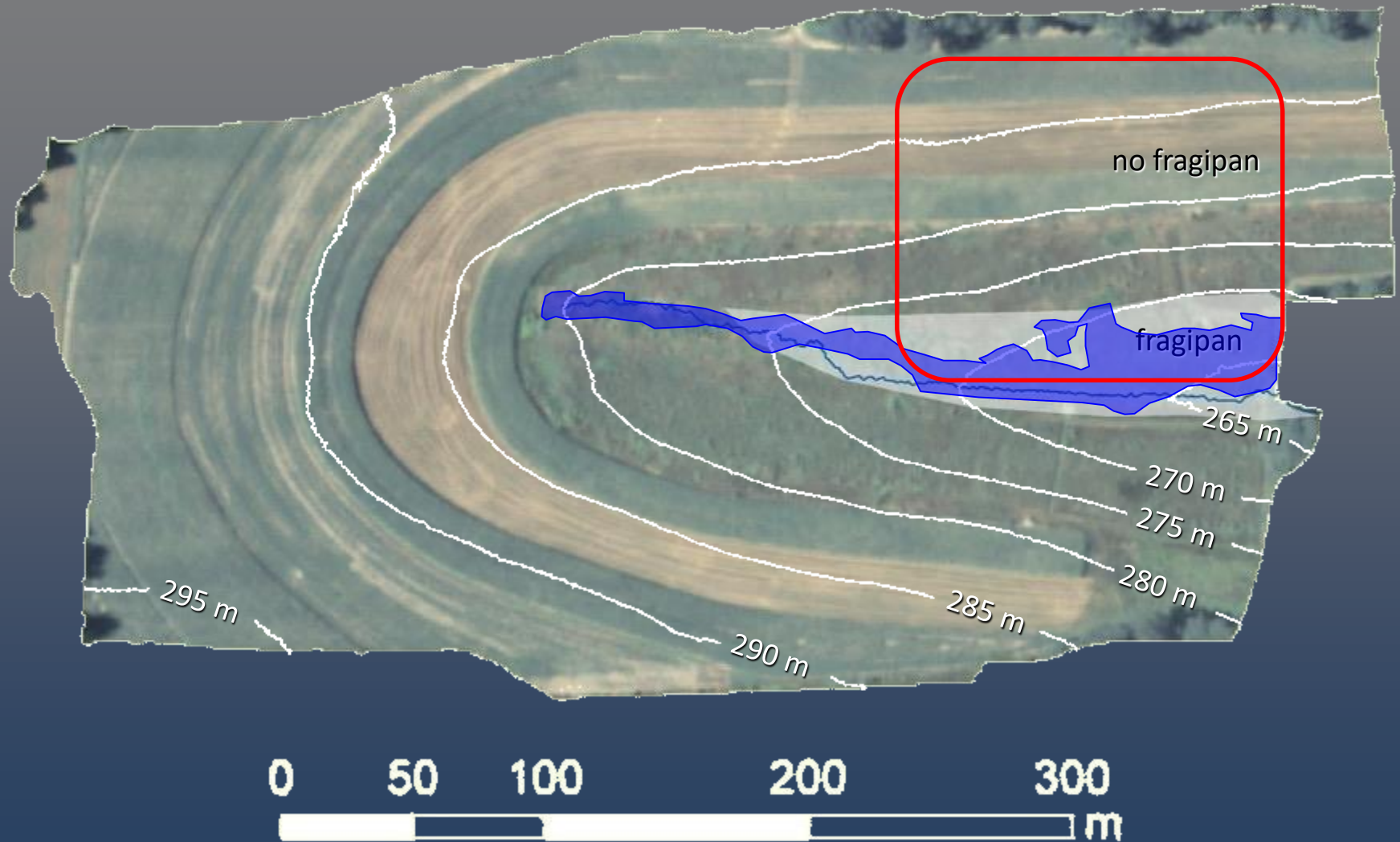
Mattern  
(11 ha)



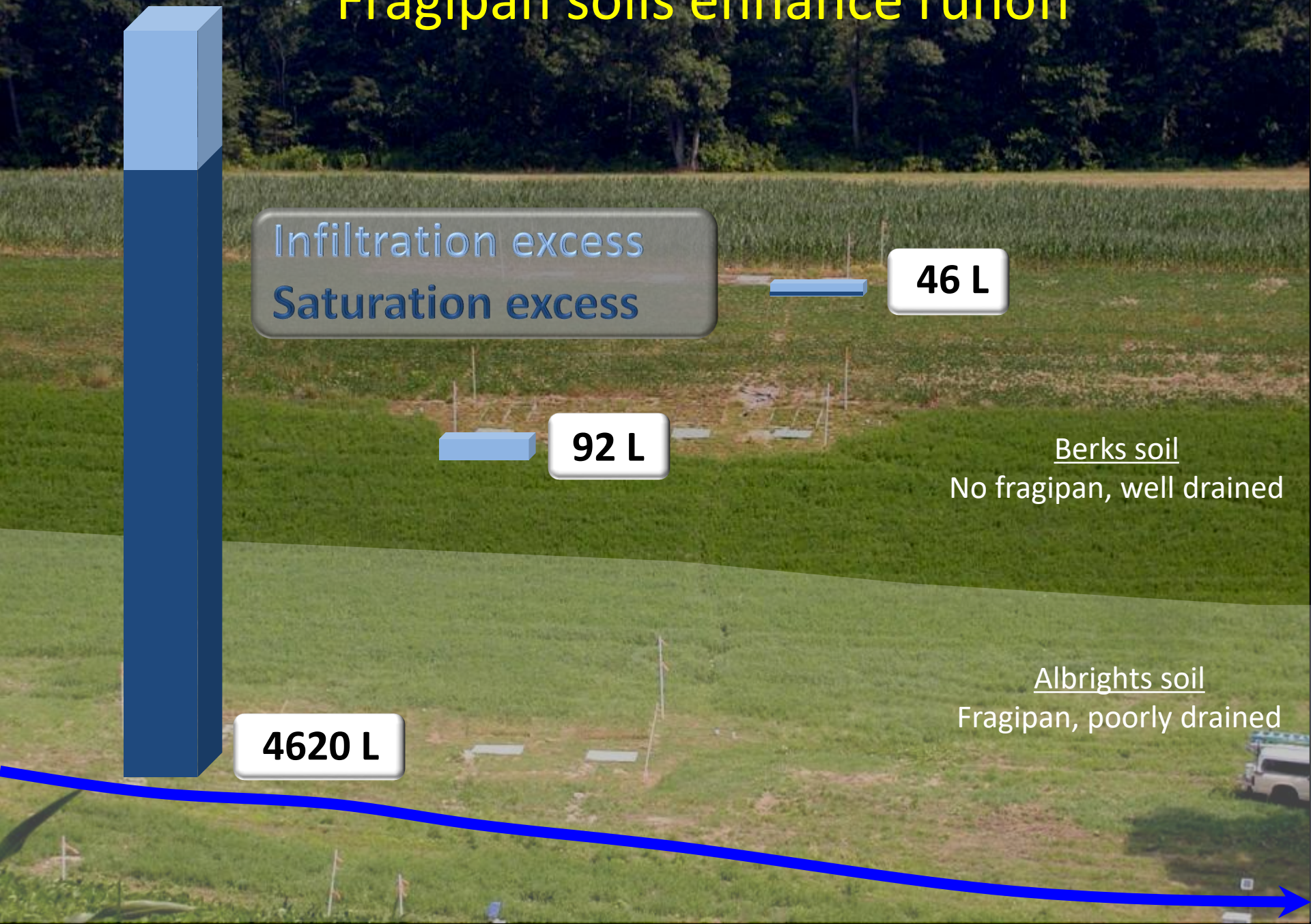


# Fragipan soils and zones of saturation

*Late October 2003*



# Fragipan soils enhance runoff





# Even modest sources can create large loads when they are hydrologically active

Total P

6 kg/ha/yr

1 kg/ha/yr

<1 kg/ha/yr

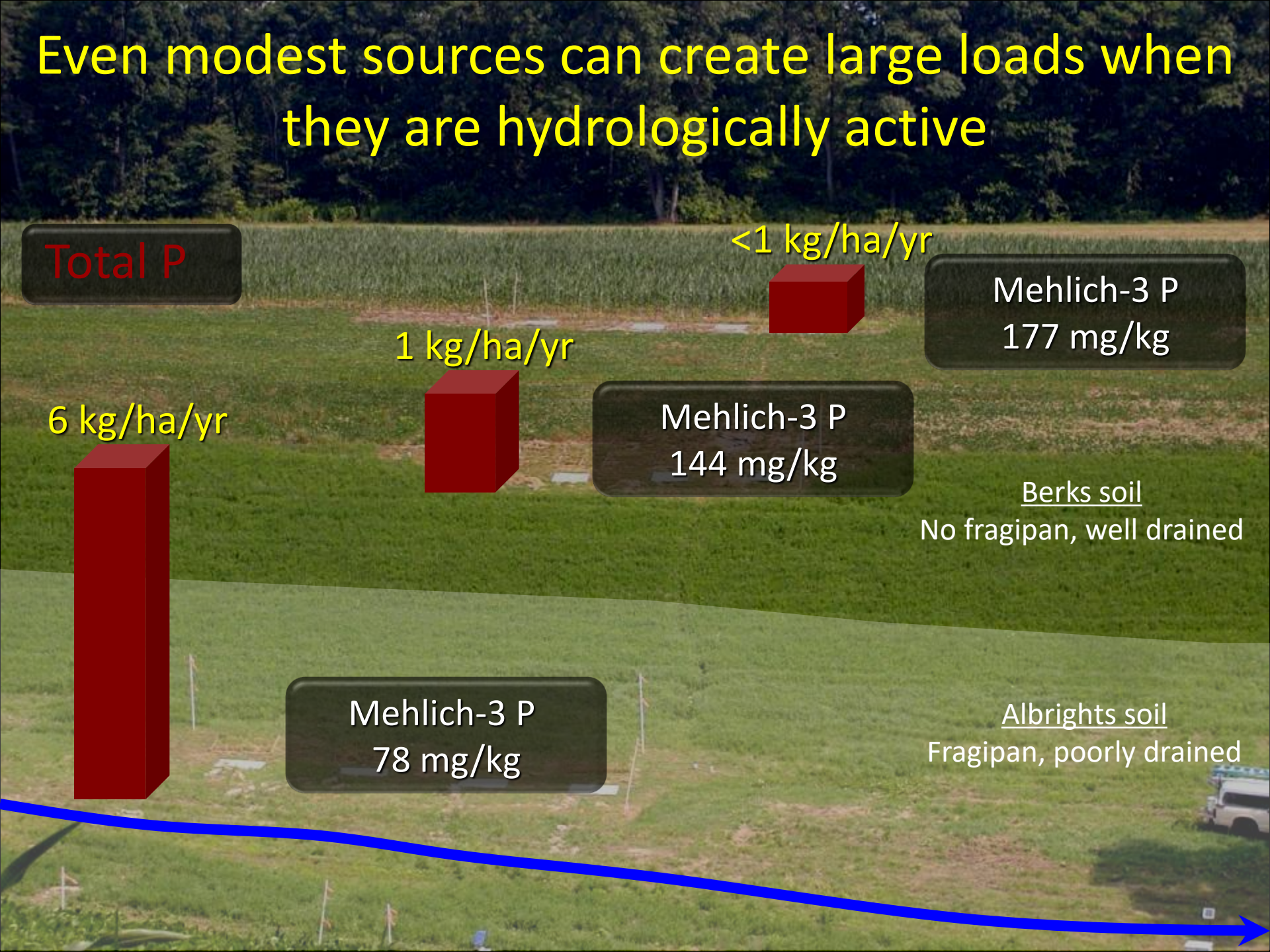
Mehlich-3 P  
177 mg/kg

Mehlich-3 P  
144 mg/kg

Mehlich-3 P  
78 mg/kg

Berks soil  
No fragipan, well drained

Albrights soil  
Fragipan, poorly drained





# Field drainage – ditches and tiles

*lower water tables, faster travel times, increased connectivity*

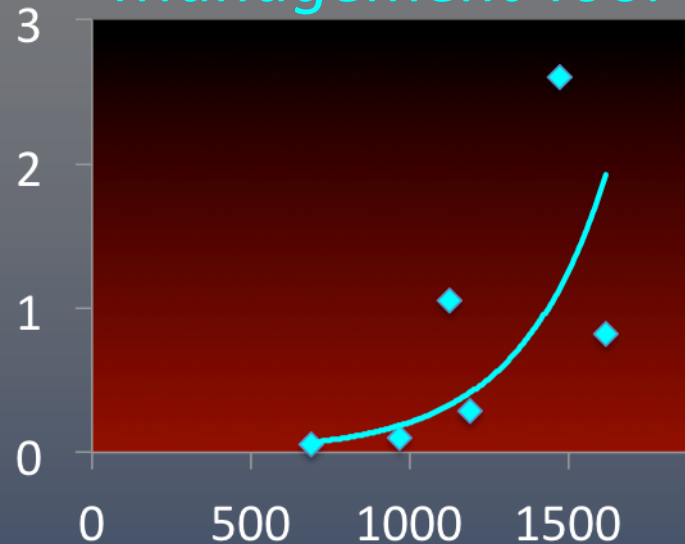




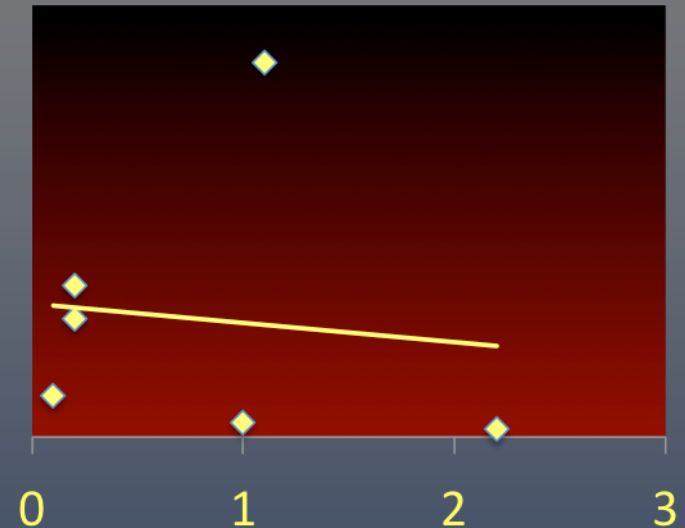
# Drainage in the P Index

*Comparison with ditch P loadings*

*Maryland's P  
Management Tool*



*North Carolina's  
P Loss Assessment Tool*



PMT  
Subsurface  
Score

PLAT's Subsurface  
Score

# BMPs for P





# The allure of magic dust *structured liming and gypsum*



Taylor & Francis Online

Journal  
**Acta Agriculturae Scandinavica, Section B — Soil & Plant Science**  
Volume 64, 2014 - Issue 5

2303 1  
Views CrossRef citations, etc.

ORIGINAL ARTICLES

## Phosphorus leaching from clay soils can be counteracted by structure liming

Barbro Ulén & Ararso Etana  
Pages 425-433 | Received 25 Feb 2014, Accepted 25 Apr 2014, Published online: 12 Jun 2014

Download citation | <https://doi.org/10.1080/09064710.2014.920043>

## Gypsum treatment of fields enhances water protection in agriculture

28.3.2018 | LIFE SCIENCE NEWS

PRESS RELEASE

AUTHOR: COMUS-VIKKO@HELUNI.FI



Gypsum treatment has been piloted as an innovative protection method under the NutriTrade project funded by the EU Interreg Central Baltic programme. The suitability of gypsum treatment for improving the state of the Archipelago Sea is being studied under the SAVI project funded by the Ministry of the Environment.

Gypsum treatment of agricultural fields has proven to be a safe and effective method, approved by farmers, in reducing phosphorus load originating from agriculture to the Baltic Sea. The results are based on a large-scale pilot project testing the application of gypsum to agricultural fields in Southwest Finland. Large-scale use of gypsum would enable Finland to meet the goals set by the Baltic Marine Environment Protection Commission (HELCOM) for reducing the phosphorus load entering the Baltic Sea. Gypsum treatment would have extensive potential throughout the Baltic Sea area.



# Reactors





# 4R Nutrient Stewardship

*A framework for strategic management*

Analysis



Formulation



Soil testing

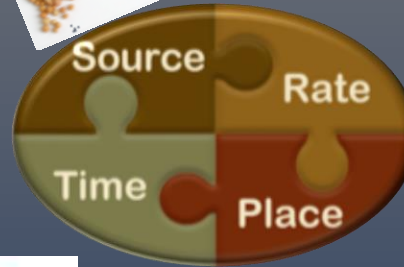


Source

Rate

Time

Place



Calendar



To growing  
crops when  
risks are low



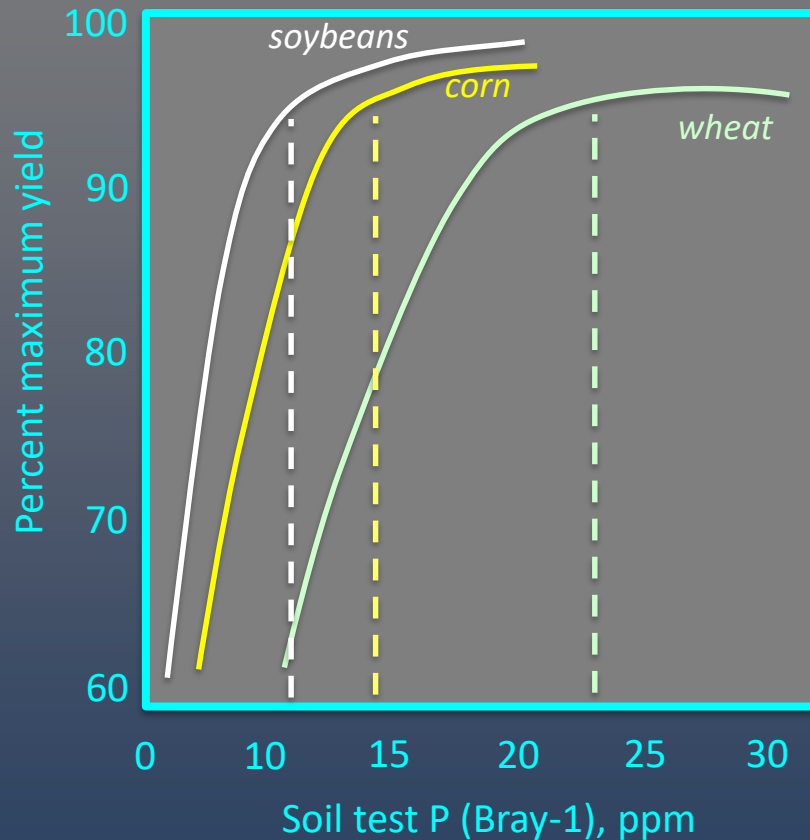
Field  
Assessment



Delivery technologies

# 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

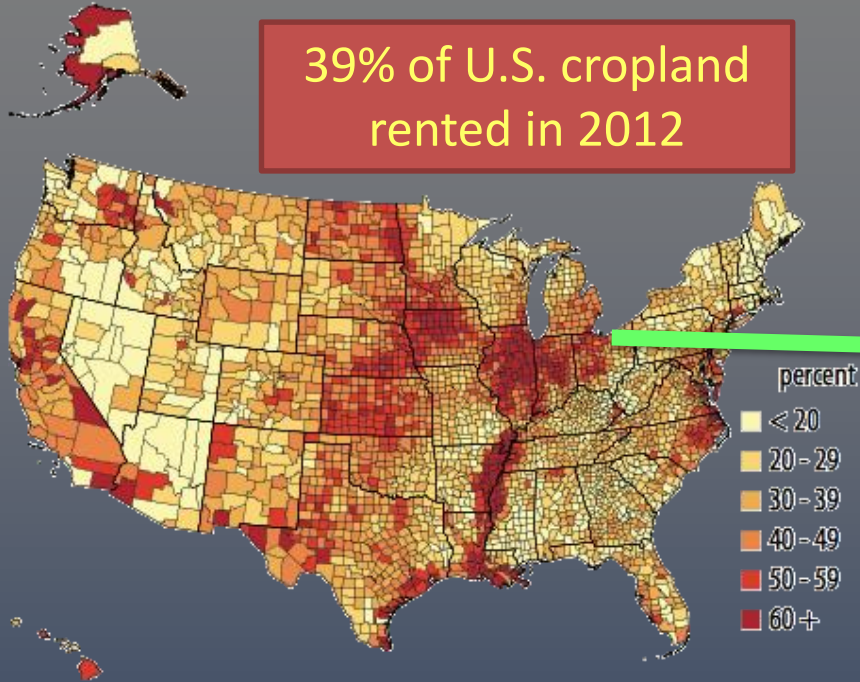
### Proposed Tests

Fe-oxide strip  
Resin  
Haney soil health test?

# Soil P maintenance and land rental

## *Contractual obligations*

39% of U.S. cropland  
rented in 2012



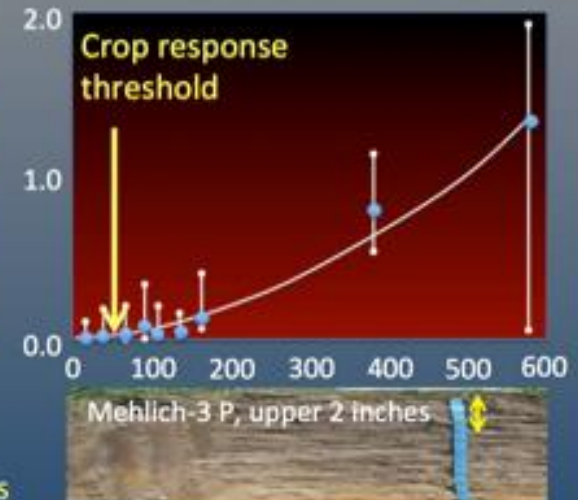
More than 50% of  
cropland in Western  
Lake Erie is rented



Soil P maintenance  
required in rental  
agreement



Source: King, USDA-ARS





# Revisiting P fertilizer recommendations

*How low can you go?*

Early season signs of deficiency are not the same as yield decline

Corn



Grapes



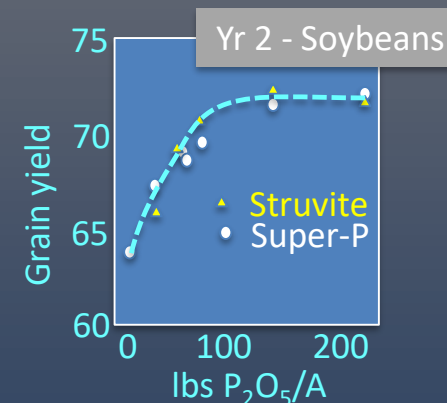
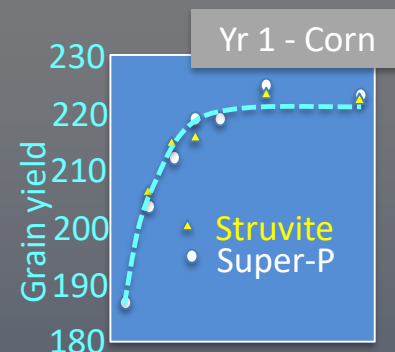
# Struvite – slow release fertilizer

*generally substitutes for high solubility fertilizers*

Table 4. List of experiments reporting the fertilizer value of struvite

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

\* 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.

# Better Fertilizer Decisions for Cropping Systems

## *Australia's model program*

MAKING **BETTER FERTILISER DECISIONS** FOR CROPPING SYSTEMS IN AUSTRALIA



Home  
Background  
BFDC Interrogator  
Included data  
Calibrations  
Publications  
Contact us  
Acknowledgements  
Disclaimer

MAKING BETTER FERTILISER  
DECISIONS FOR CROPPING  
SYSTEMS IN AUSTRALIA

 Department of  
Primary Industries

 **GRDC** Grains Research &  
Development Corporation  
Your GRDC working with you

 **EITF**

*Laboratories  
Consultants*

New South Wales Department of Primary Industries

**GEOGRAPHIC WEB  
SOLUTIONS** 

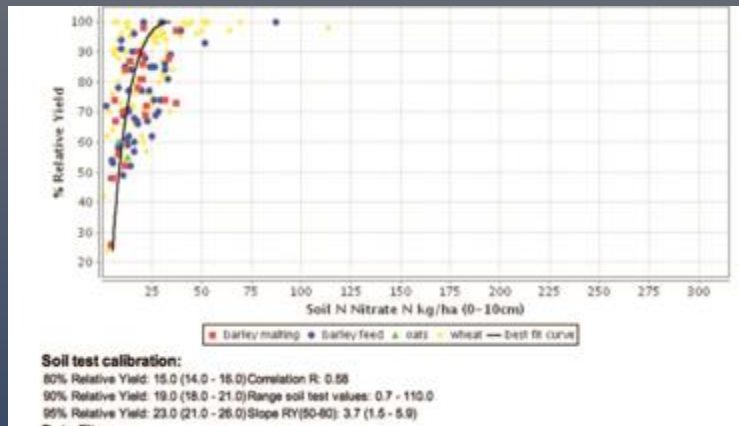


# Better Fertilizer Decisions for Cropping Systems

## *Australia's model program*

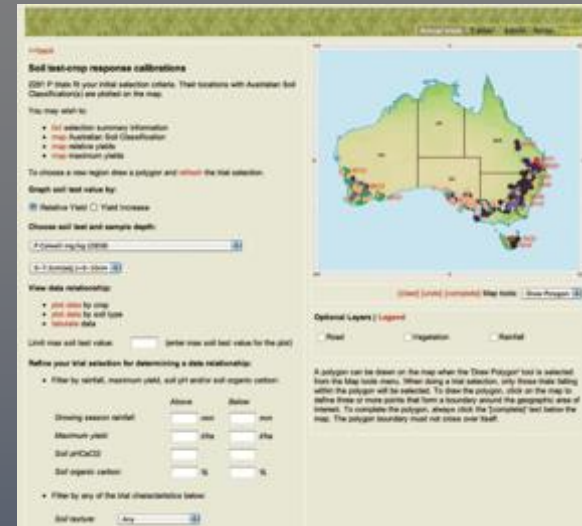
### BFDC Database

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

## 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.
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Discovery of phosphorus  
1669