Importance of Phosphorus in Plant and Human Nutrition

The Role of Fertilizer in Global Food Security
and
"World Phosphate Reserves and Resources"
Report Release

Terry Roberts, PhD
President, IPNI

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Center for Strategic & International Studies

Better Crops, Better Environment … through Science

International Plant Nutrition Institute

- IPNI is a not-for-profit, scientific organization
  - established in 2007 from the Potash Phosphate Institute (PPI)
  - Agronomic programs in Africa, China, India, Eastern Europe & Central Asia, Middle East, Oceania, North and South America
- We provide a unified, scientific voice for the world's fertilizer industry; independent, but scientifically credible

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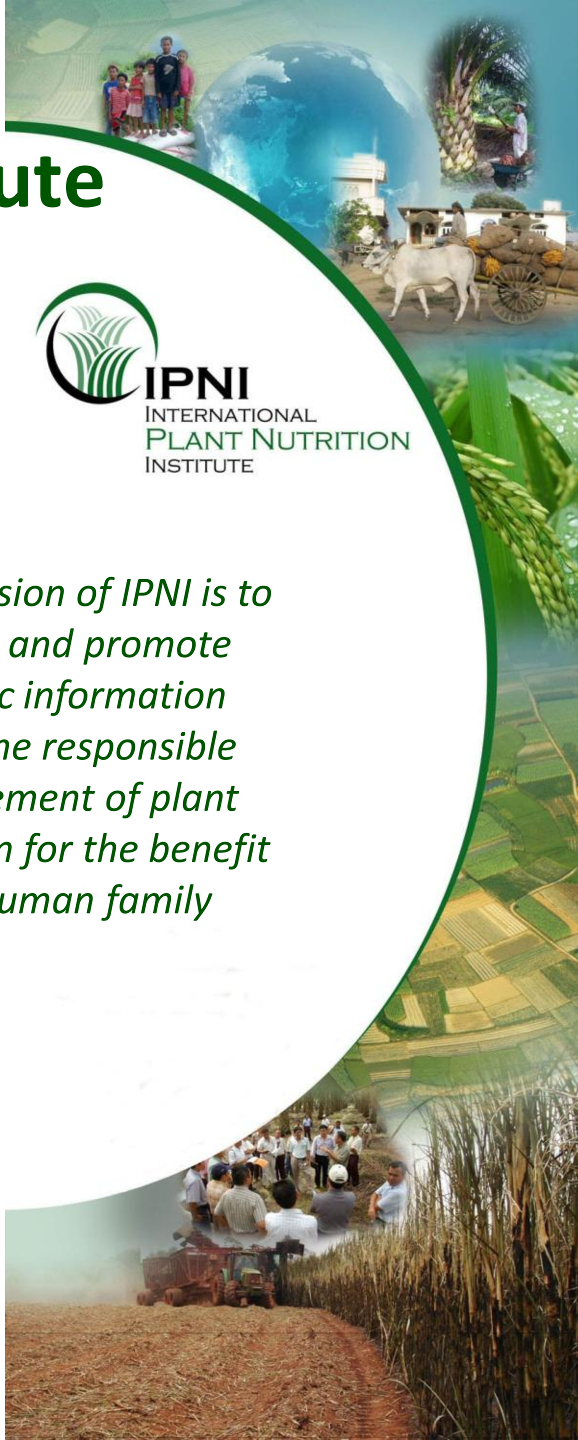
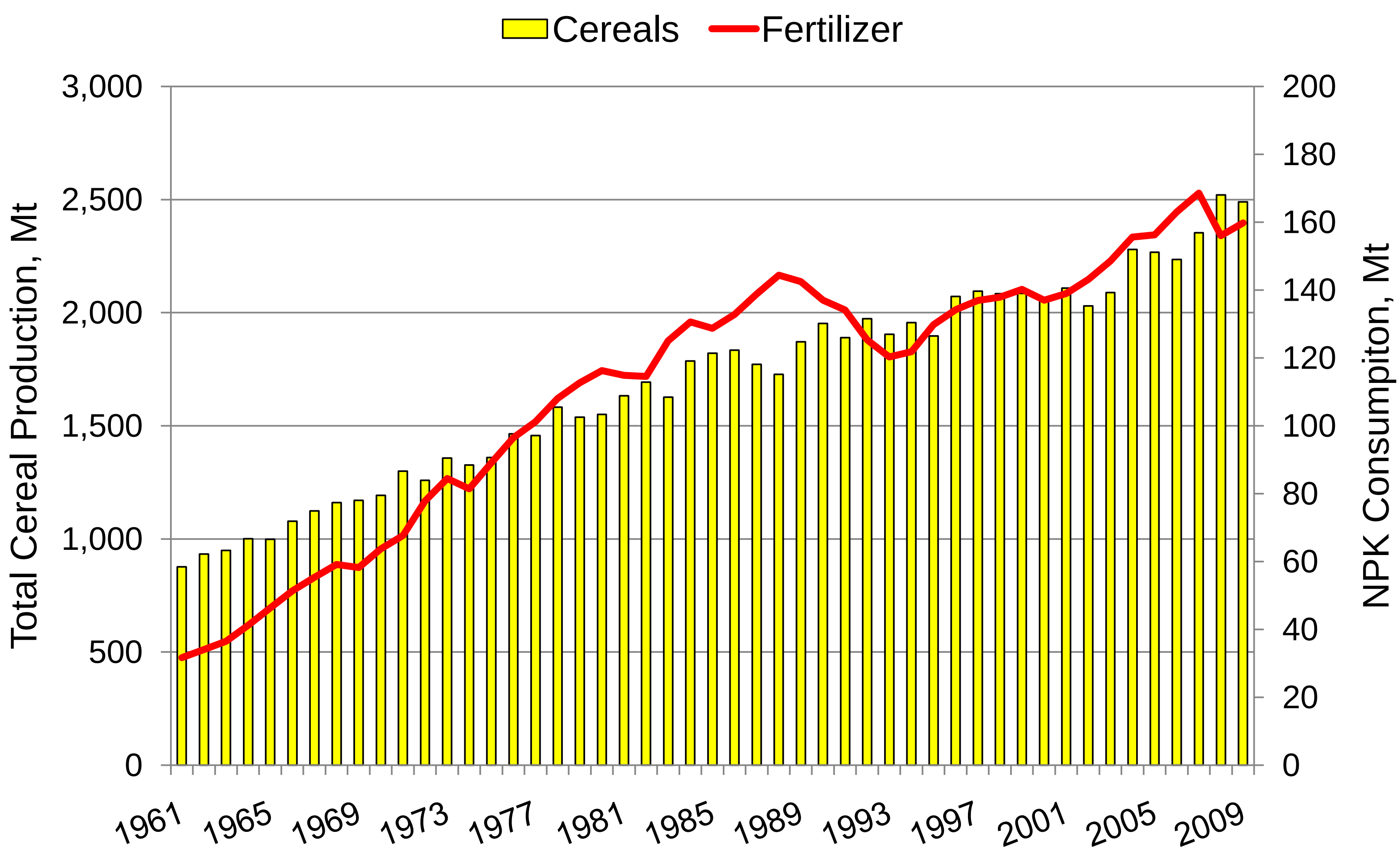
The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family

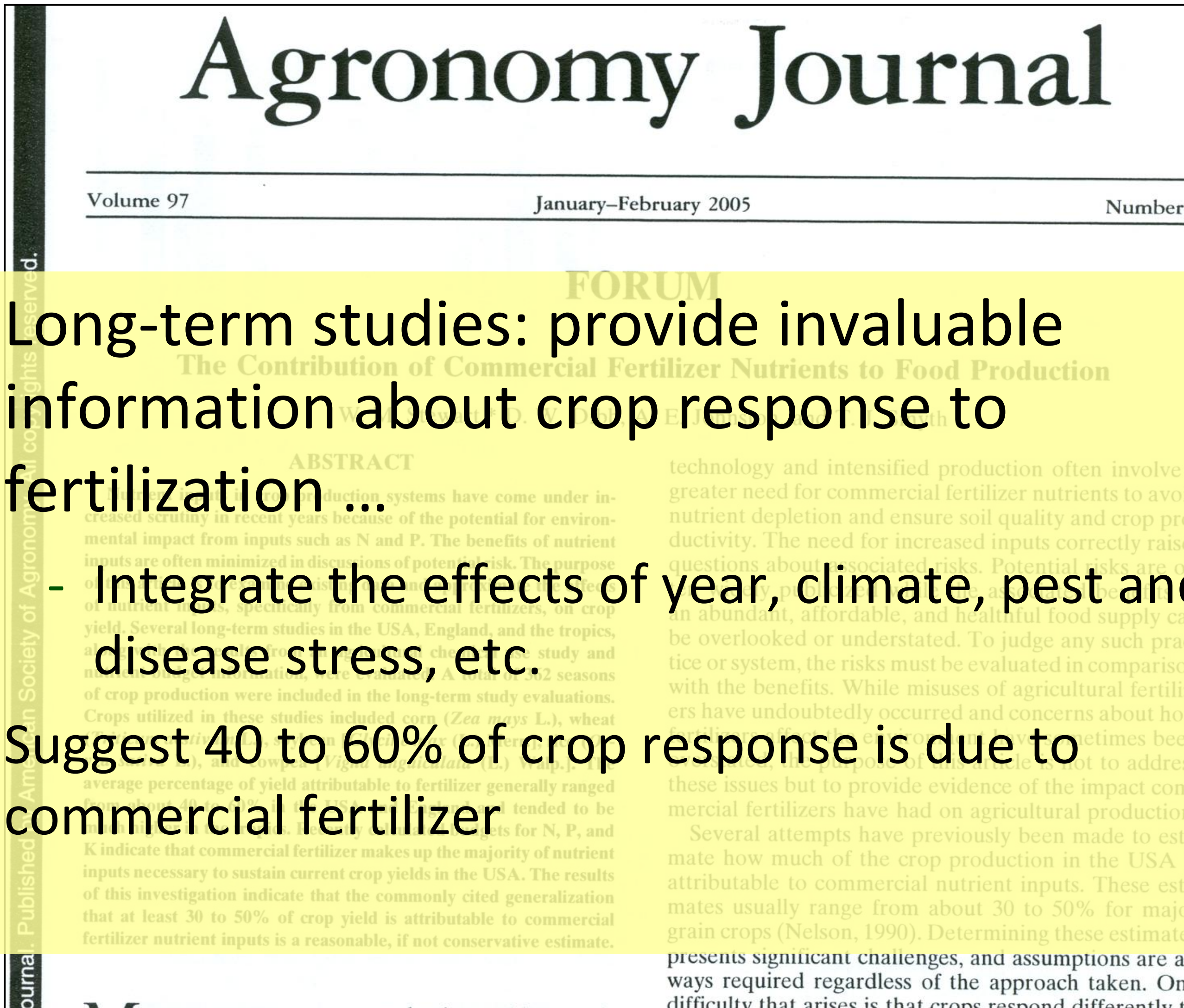


World cereal production and fertilizer consumption, million metric tons



Source: FAO and IFA

How much crop yield is attributable to fertilization?



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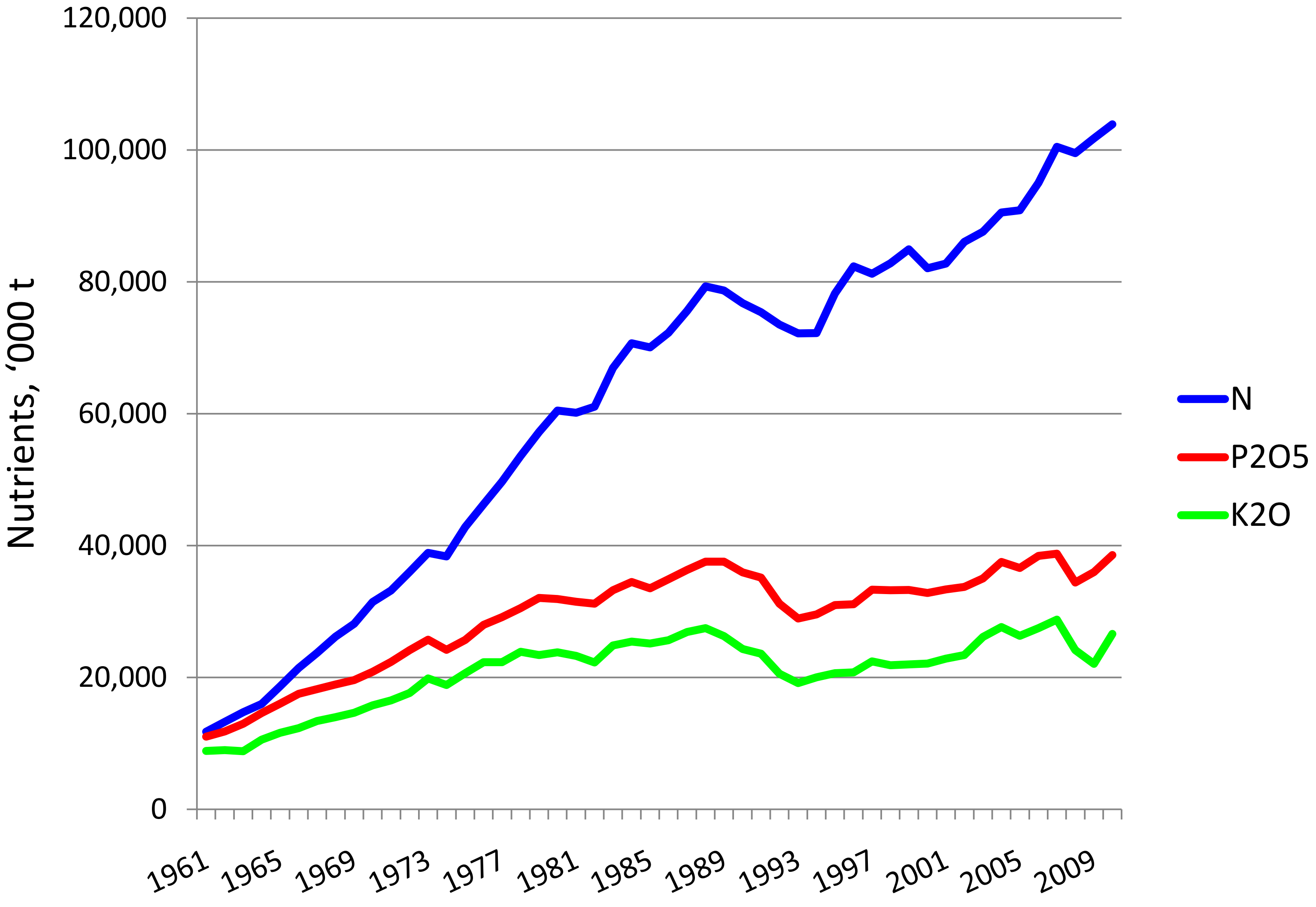
FORUM

The Contribution of Commercial Fertilizer Nutrients to Food Production

ABSTRACT

- Long-term studies: provide invaluable information about crop response to fertilization …
  - Integrate the effects of year, climate, pest and disease stress, etc.
- Suggest 40 to 60% of crop response is due to commercial fertilizer

World fertilizer consumption (1961-2010)



Source: IFA

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World Fertilizer Consumption Forecast (Mt nutrients)

	2009	2010 (f)	2014 (f)	2009/14 variation
N	101.8	103.9	111.7	2.0%
P_2O_5	36.0	38.6	43.7	4.5%
K_2O	22.1	26.6	31.9	8.2%
Total	159.8	169.0	187.3	3.5%

Source: IFA

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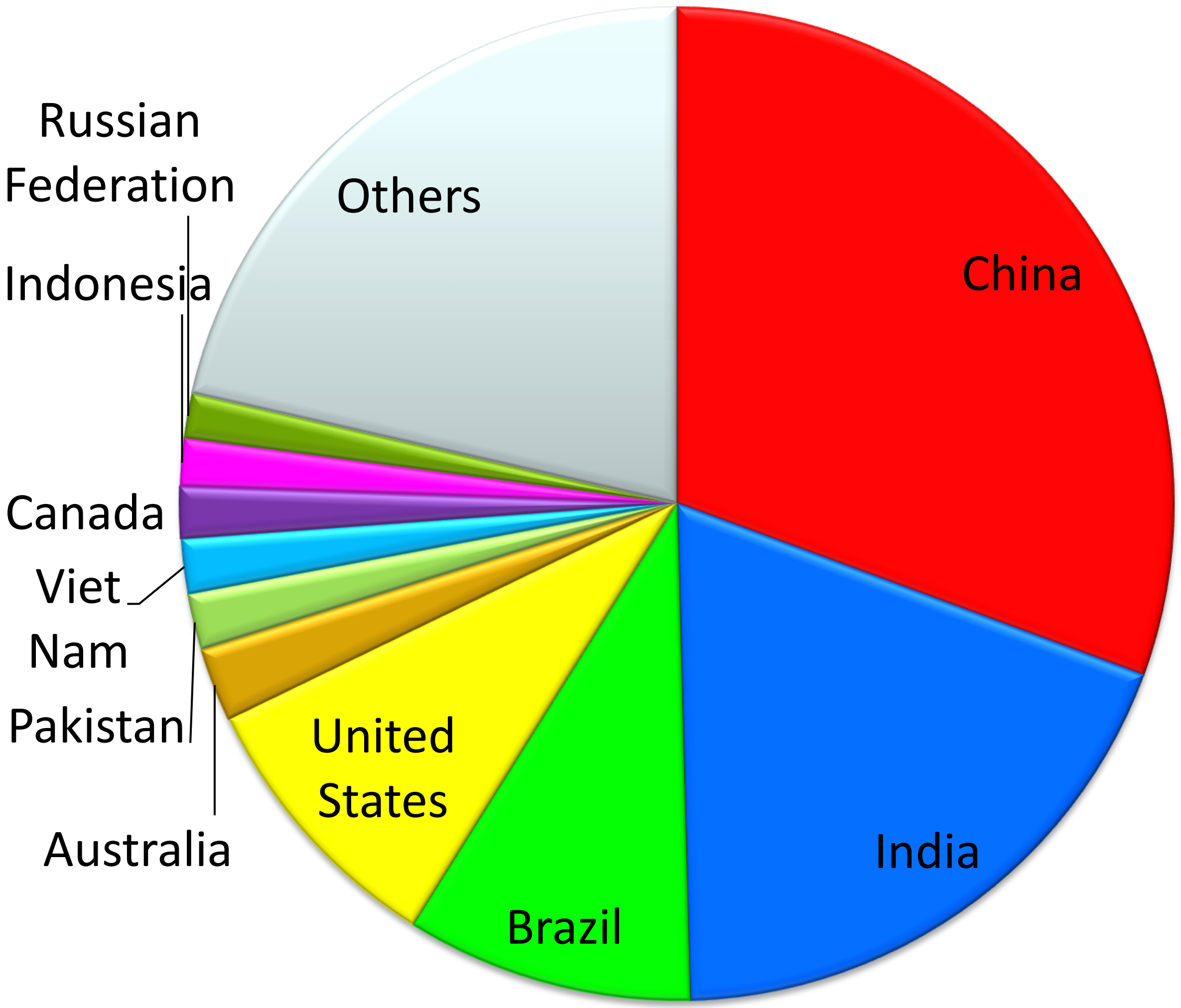
Top 10 Phosphate Using Countries, % of total consumption



Source: IFA

P is essential for plant and animal nutrition

- In plants:
  - involved in photosynthesis, energy transfer, cell division & enlargement
  - root formation and growth
  - improves fruit & vegetable quality
  - vital to seed formation
  - improves water use
  - helps hasten maturity
- In animals:
  - major component of bones and teeth
  - important for lactating animals
  - P and calcium are closely associated in animal nutrition
  - essential for energy transfer and utilization

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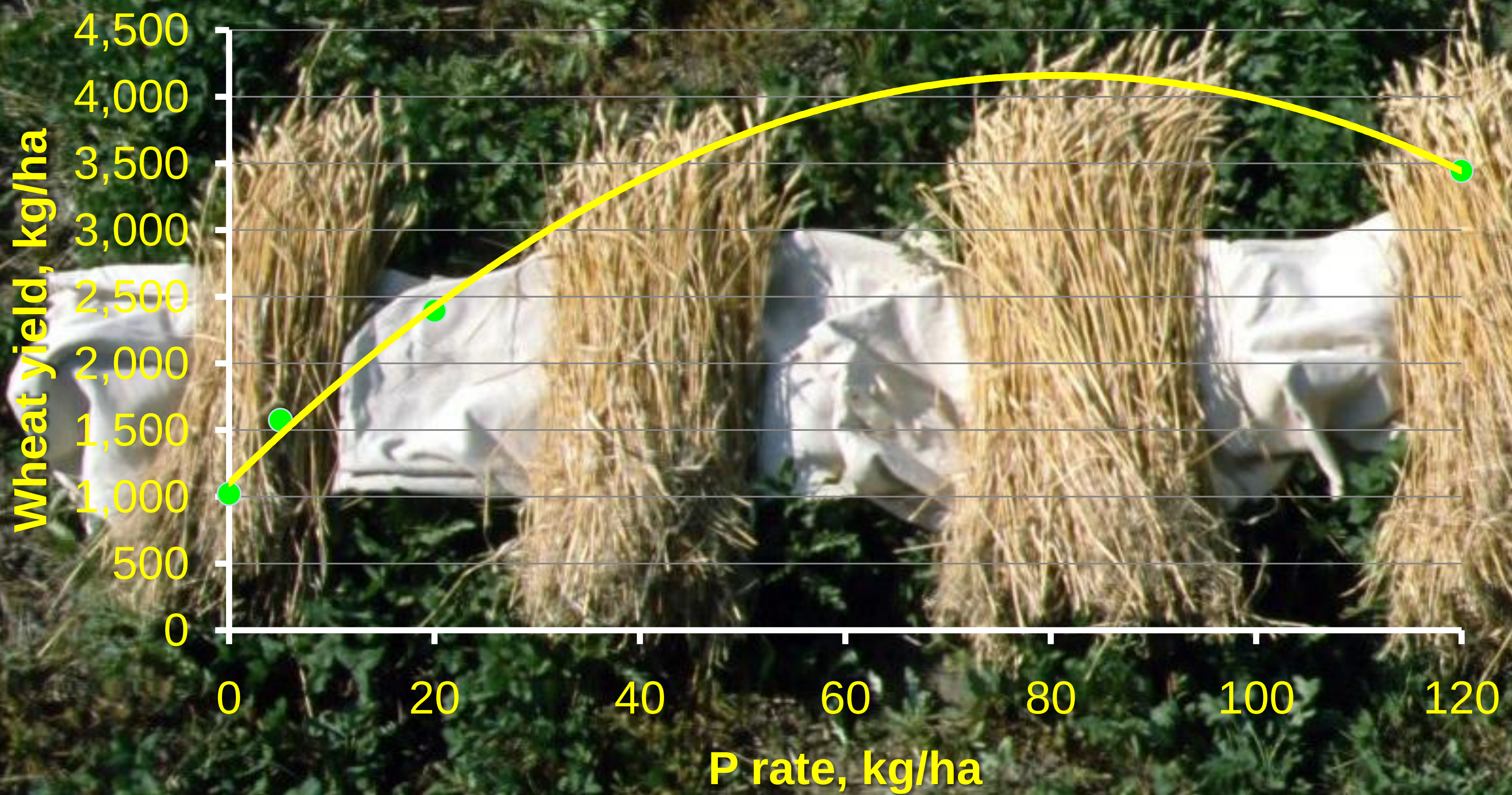
Wheat response to P fertilizer on a P deficient soil in Manitoba



Source: Tomasiewicz, 1992

Seeds Contain More Phosphorus than Other Plant Parts

Crop	Plant part	Yield level, t/ha	P content, %	P removal, kg/ha
Maize	Grain	9.4	0.22	21
	Stover	8.4	0.17	14
Wheat	Grain	4.0	0.42	17
	Straw	6.1	0.12	7
Rice	Grain	6.7	0.28	19
	Straw	7.8	0.09	7

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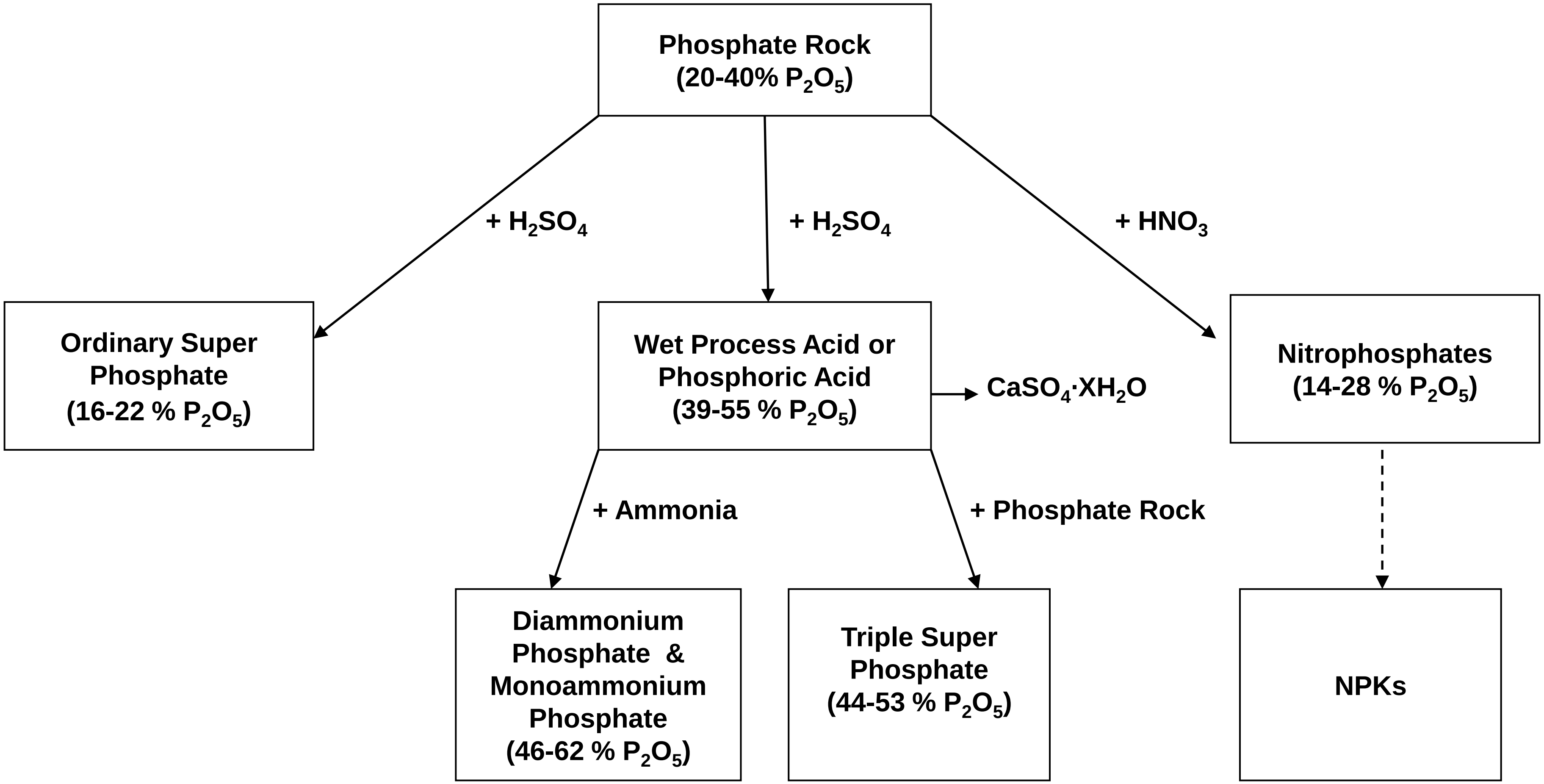
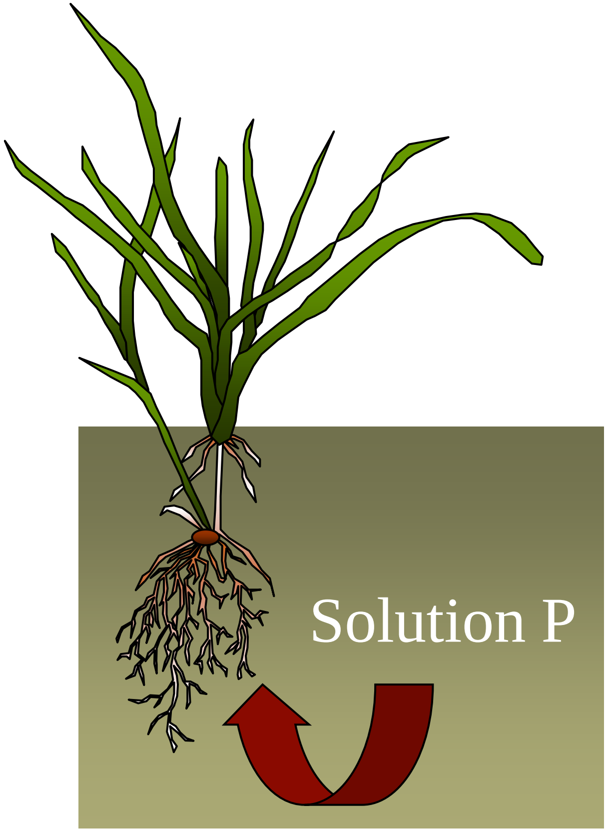
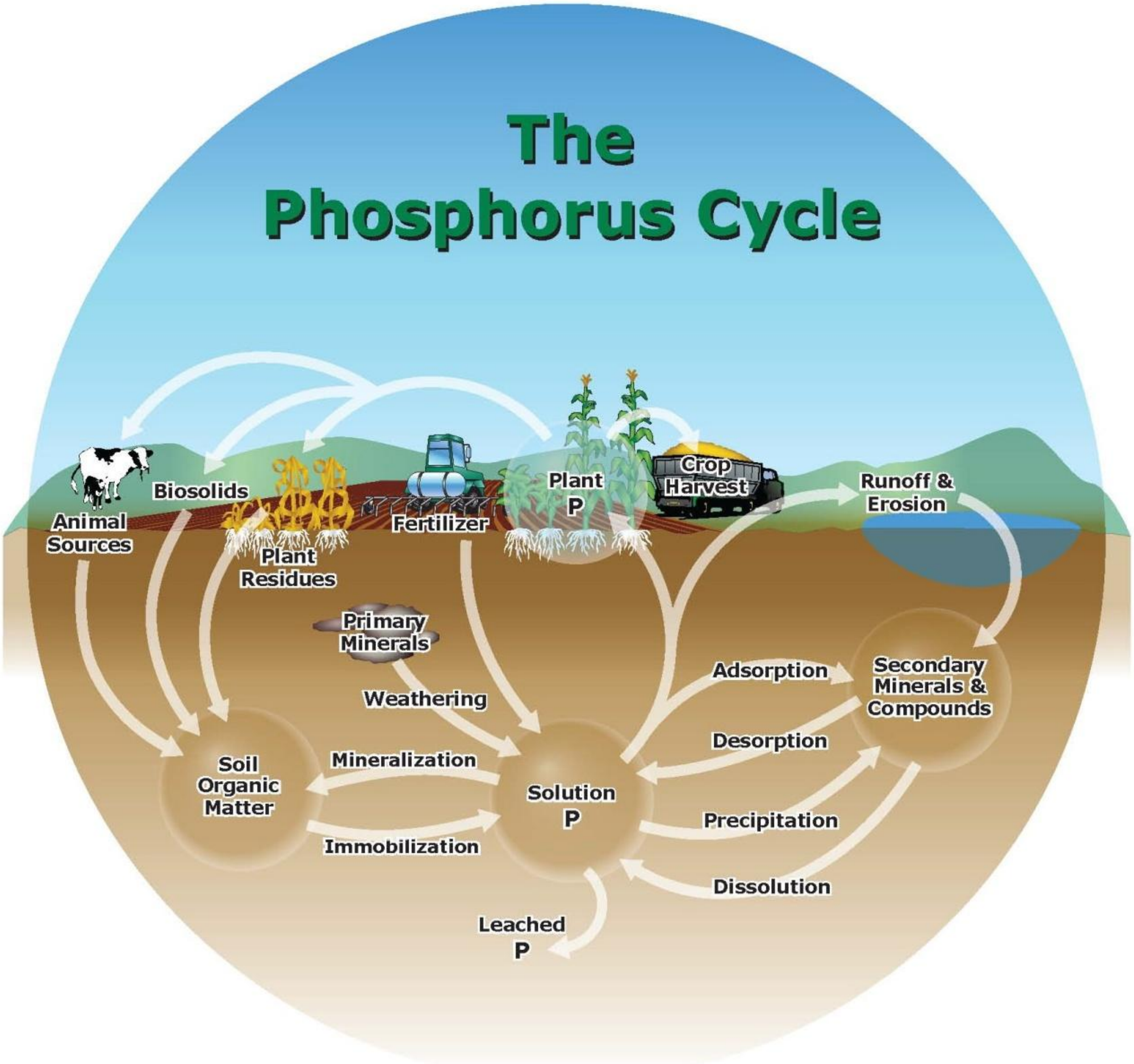
Primary raw material for P fertilizer is phosphate rock: $[Ca_3(PO_4)_2]_3 \cdot CaF_2$



Phosphorus fertilizer and the soil

- Common commercial P fertilizers are highly (≥90%) water soluble
- Once dissolved in soils orthophosphate ions are available for plant uptake
  - primary orthophosphate ion: $H_2PO_4^-$ (pH < 7.0) and secondary orthophosphate ion: $HPO_4^=$ (pH > 7.0)
- P chemistry in soils is complex — P may become sparingly available to plants in some soils due to formation of reversion products




The
Phosphorus Cycle
Animal
Sources
Biosolids
Plant
Residues
Fertilizer
Plant
P
Crop
Harvest
Runoff &
Erosion
Primary
Minerals
Weathering
Adsorption
Secondary
Minerals &
Compounds
Desorption
Soil
Organic
Matter
Mineralization
Solution
P
Immobilization
Precipitation
Dissolution
Leached
P
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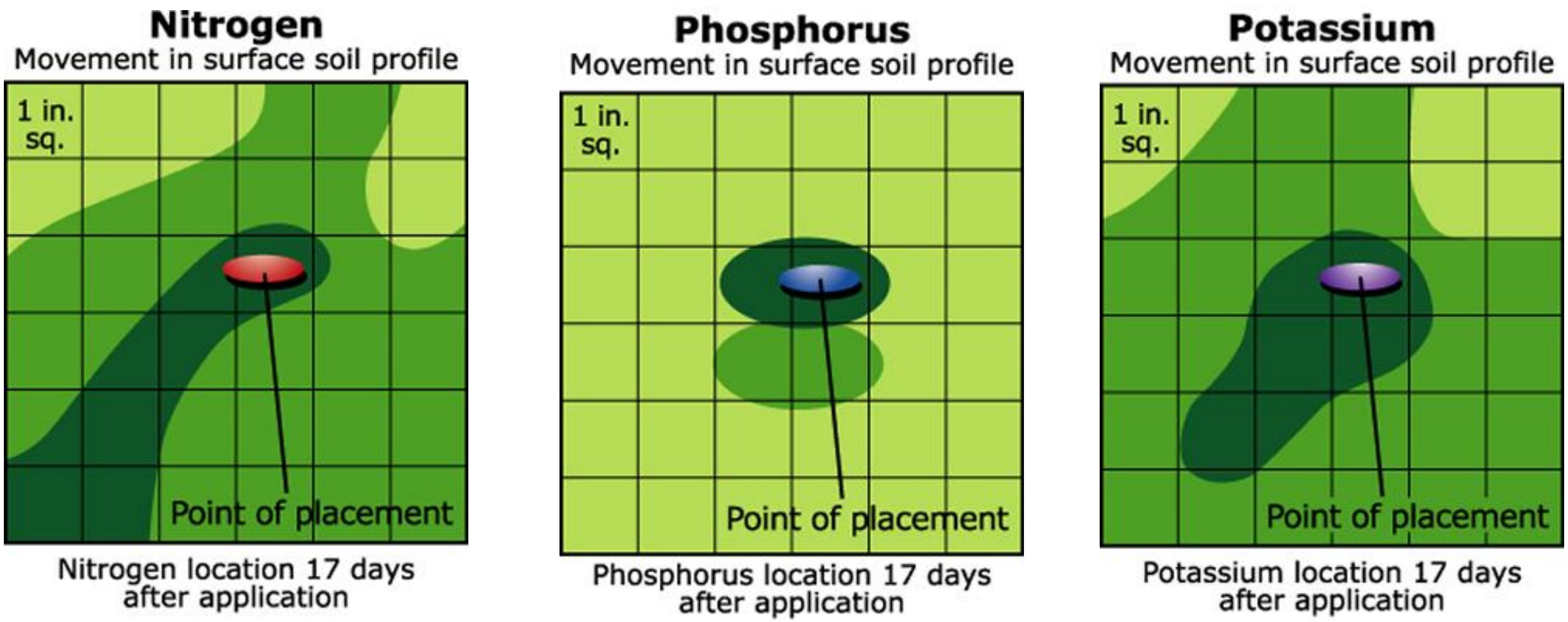
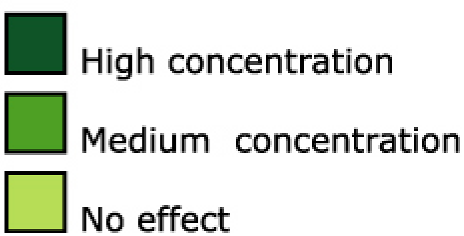
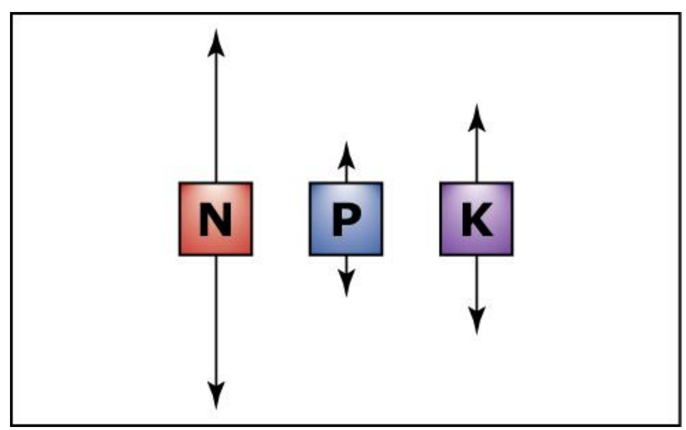
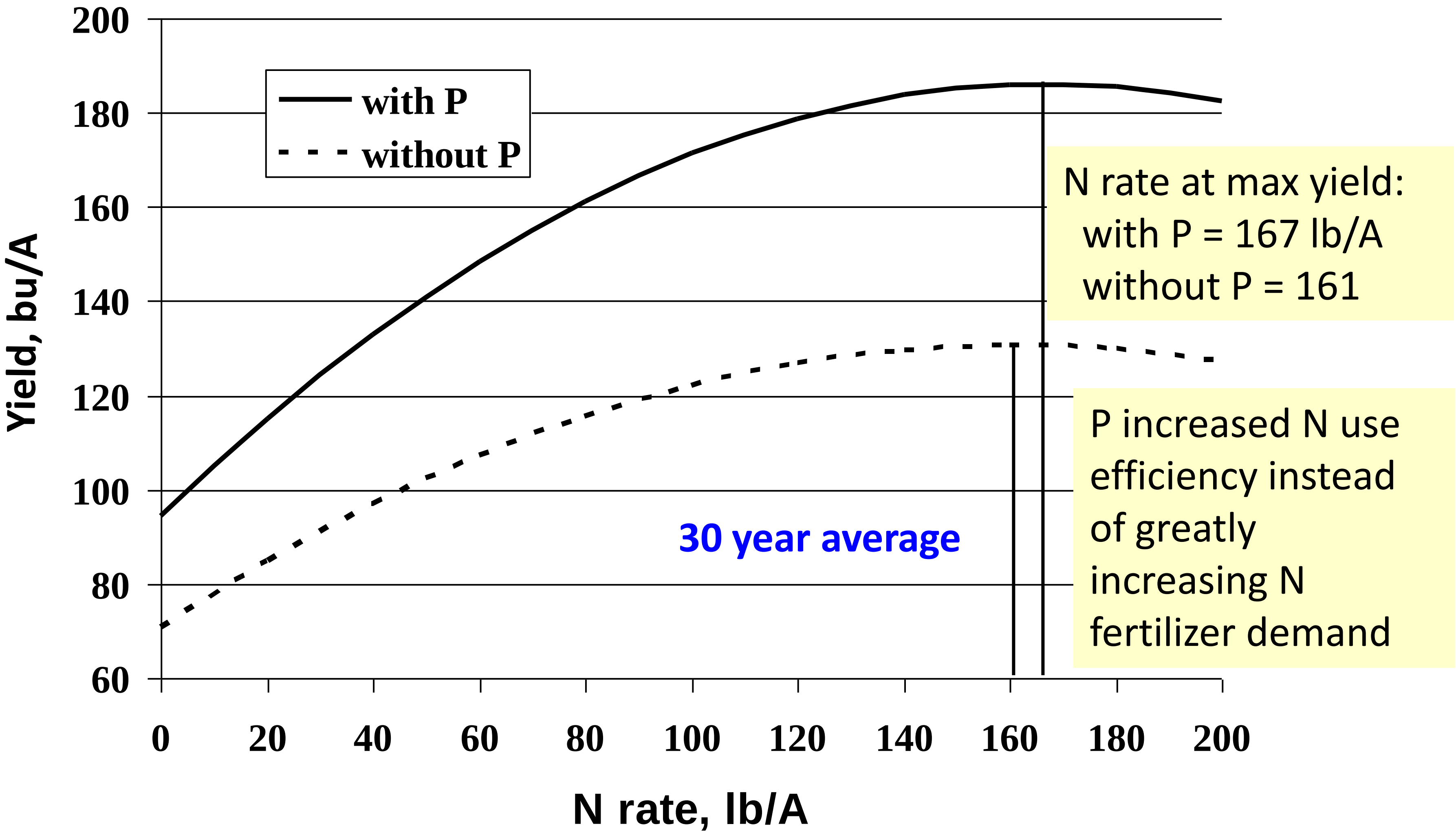
Relative Movement of N, P, K in the Soil







P interacts with other nutrients …
effect of N and P on Maize Yield



Schlegel, Dhuyvetter, and Havlin, 1996
J. Produc. Agric. 9:1

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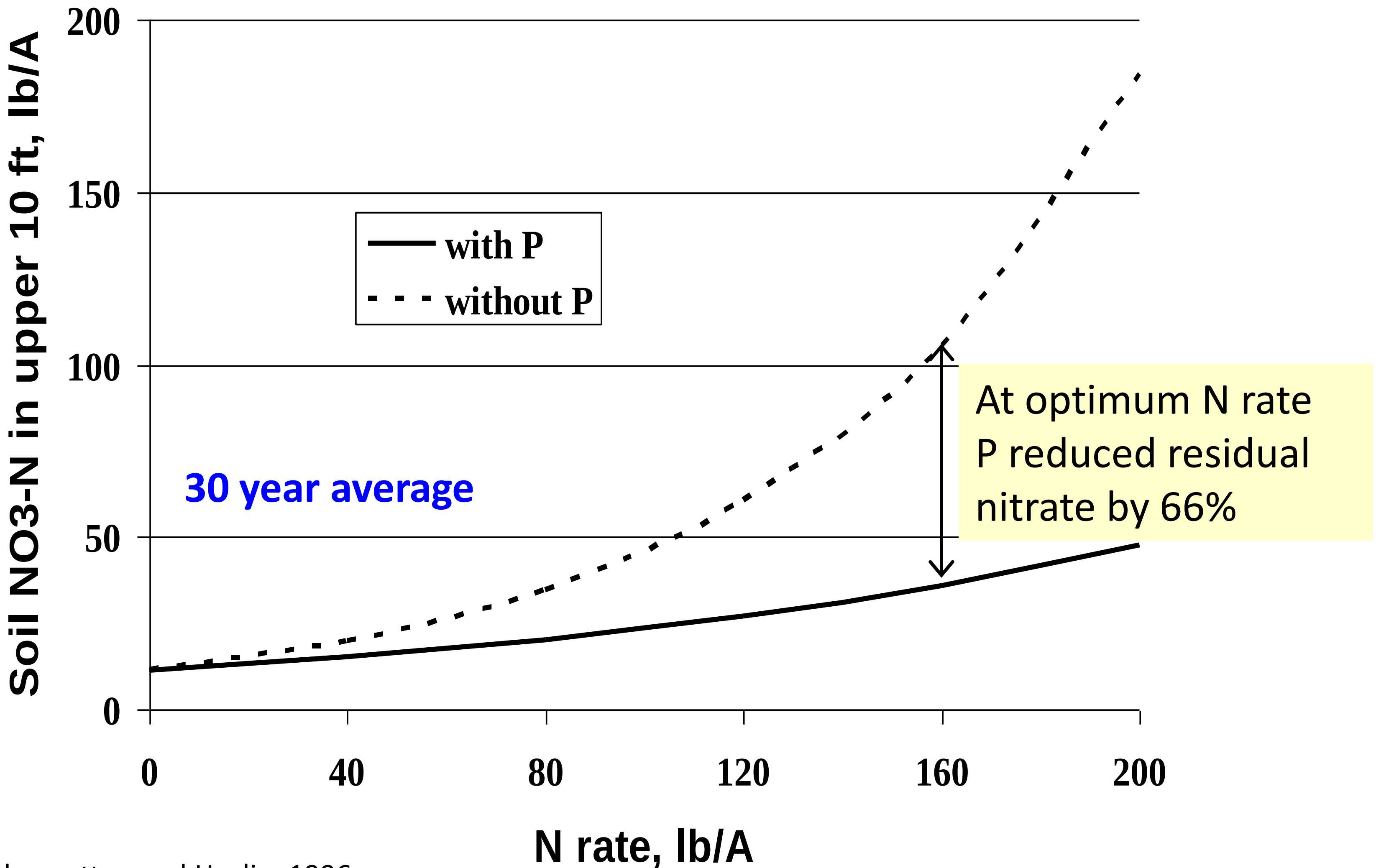
P Reduces Residual Soil Nitrate and Potential for Nitrate Leaching



Schlegel, Dhuyvetter, and Havlin, 1996
J. Produc. Agric. 9:1

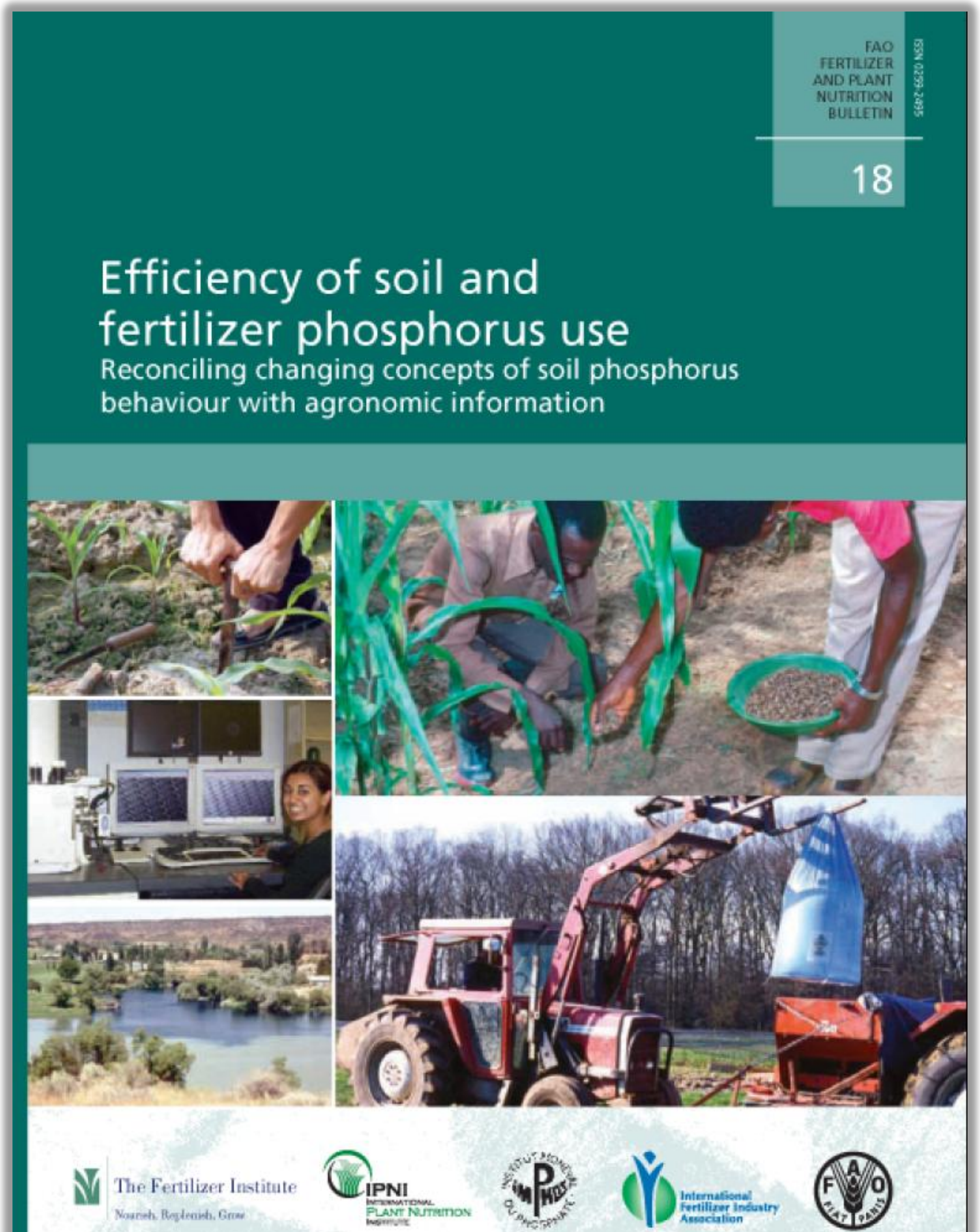
Efficiency of P Fertilizer

- Frequently stated that P is used inefficiently in agriculture
  - percent recovery of P applied in fertilizers usually between 10 and 25%

e.g. Crop fertilized with 25 kg/ha of P removes 18 kg of P from the soil and unfertilized crop removed 15 kg of P from the soil

$$\text{Percent recovery} = \frac{(18 - 15)}{25} \times 100 = 12\%$$

- This method is appropriate for N fertilizers, but of limited use for P. Why?
  - Because N fertilizer has little residual value. Nitrate left in the soil after harvest can be lost by leaching, denitrification, or volatilization
  - Fertilizer P not removed by the crop at harvest remains in the soil
- Low efficiency is an artifact of the method used to calculate it



Recovery efficiency by balance method for P

- Global review by Syers, Johnston and Curtin (2008).
- When soils are maintained near the critical level for crop yield, P recovery efficiency by the balance method frequently exceeds 90%.

Nutrient Use efficiency terminology

Example:

P applied (F)	Grain yield (Y)	P Uptake (U)	P removal (U_H)
kg/ha	Kg/ha	kg P/ha	kg P/ha
20	Y = 3,160	U = 20	16
0	Y_0 = 2,624	U_0 = 17	

NUE Term	Calculation	Example
Agronomic efficiency	$(Y-Y_0)/F$	(3,160 kg/ha – 2,624 kg/ha) = 536 kg grain 536 kg grain/20 kg applied P = **27 kg grain/kg P**
Recovery efficiency by difference method	$(U-U_0)/F$	(20 kg P/ha -17 kg P/ha) / 20 kg P applied = **15%**
Recovery efficiency by balance*	U_H/F	16 kg P/ha / 20 kg P applied = **80%**

** Also referred to as "partial nutrient balance" or "removal to use ratio".*

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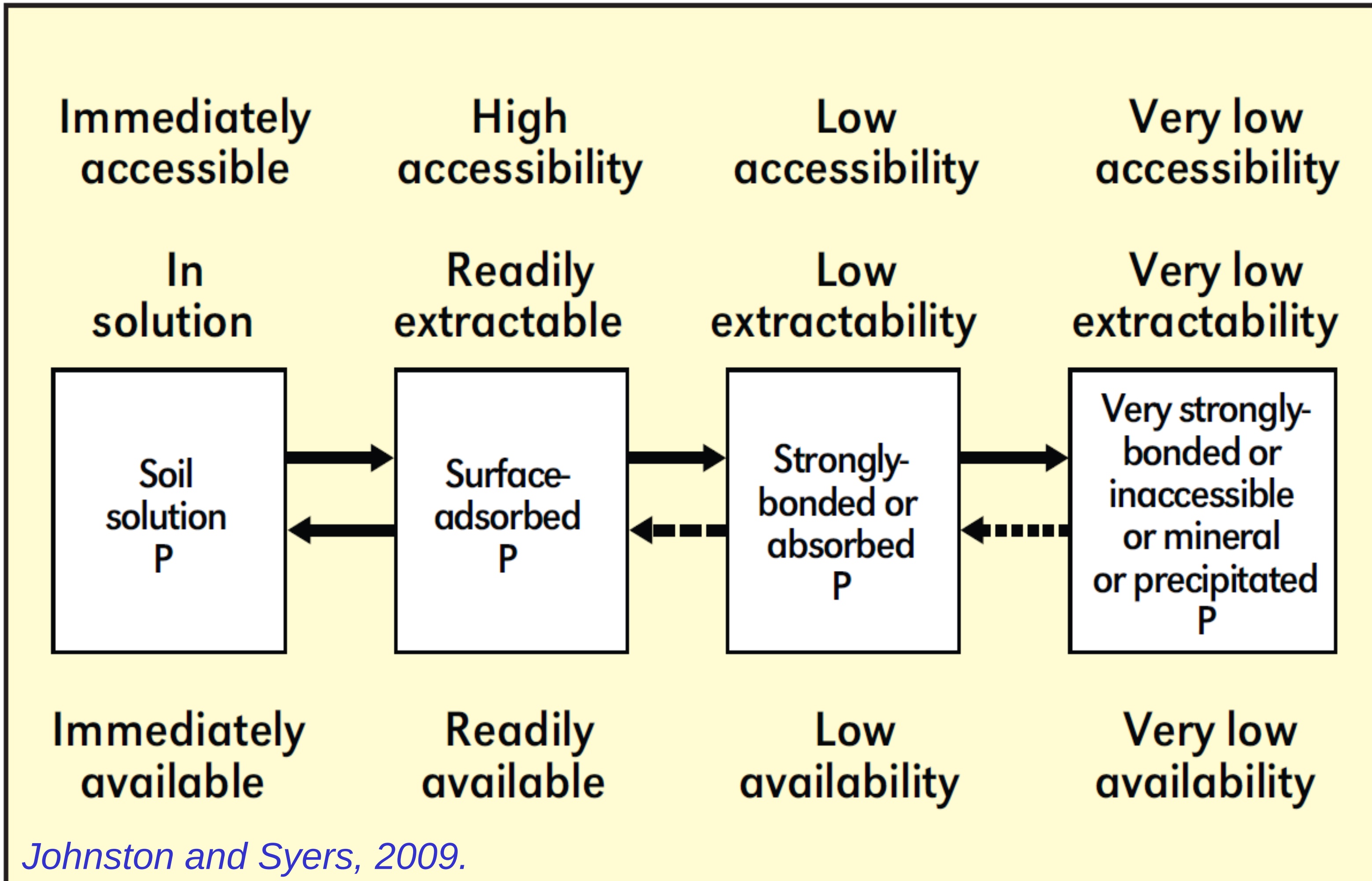
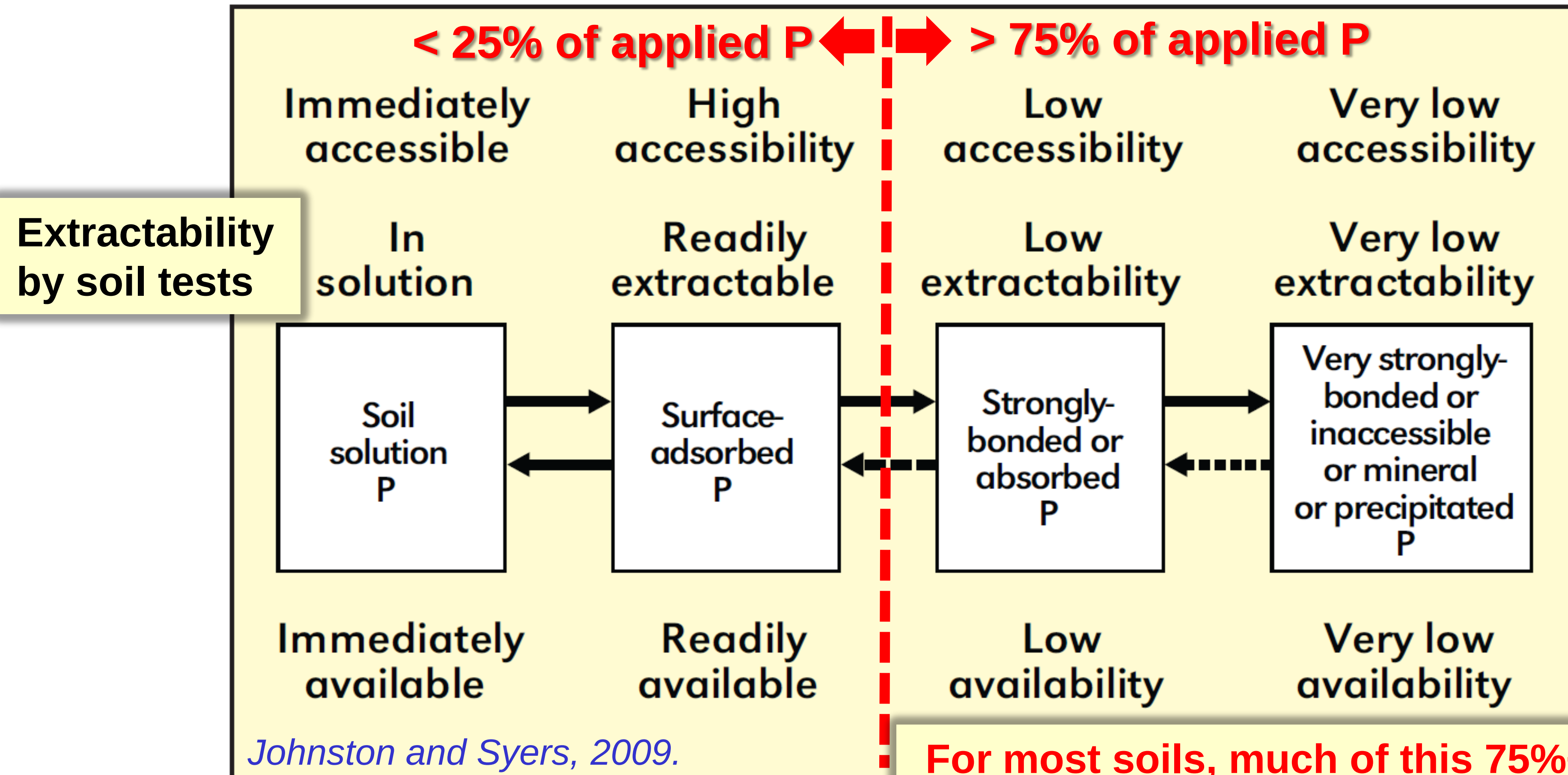
If the percent recovery of P fertilizer in the crop rarely exceeds 20 or 25% … the remaining P in crop comes from the soil reserves



Johnston and Syers, 2009.

Availability and extractability of soil P pools



For most soils, much of this 75%+ enters the low availability pool … becomes plant available over time

Recovery by balance method accounts for fertilizer P that enters the less available pools

P nutrient balance (kg/ha/yr) in corn-based agricultural systems – low input corn in Western Kenya, high input wheat/corn double cropping systems in North China, and corn/soybean rotation in Midwest U.S.

	Western Kenya	North China	Midwest U.S.
P applied as fertilizer	8	92	14
P removed in harvested crop	7	39	23
Balance	+1	+53	-9
Recovery by balance method (removal to use ratio)	0.88	0.42	1.64

Potential yield in these systems were similar, but realized yields were 2 t/ha/yr in Kenya; 8.5 in China, and 8.2 in the U.S. Wheat yielded another 5.8 t/ha/yr in China and soybeans 2.7 t/ha/yr every other year in Illinois.

Illinois Median Bray P in 2005 = 36 ppm, in 2010 = 24 ppm

Vitousek et al., Science, 2009

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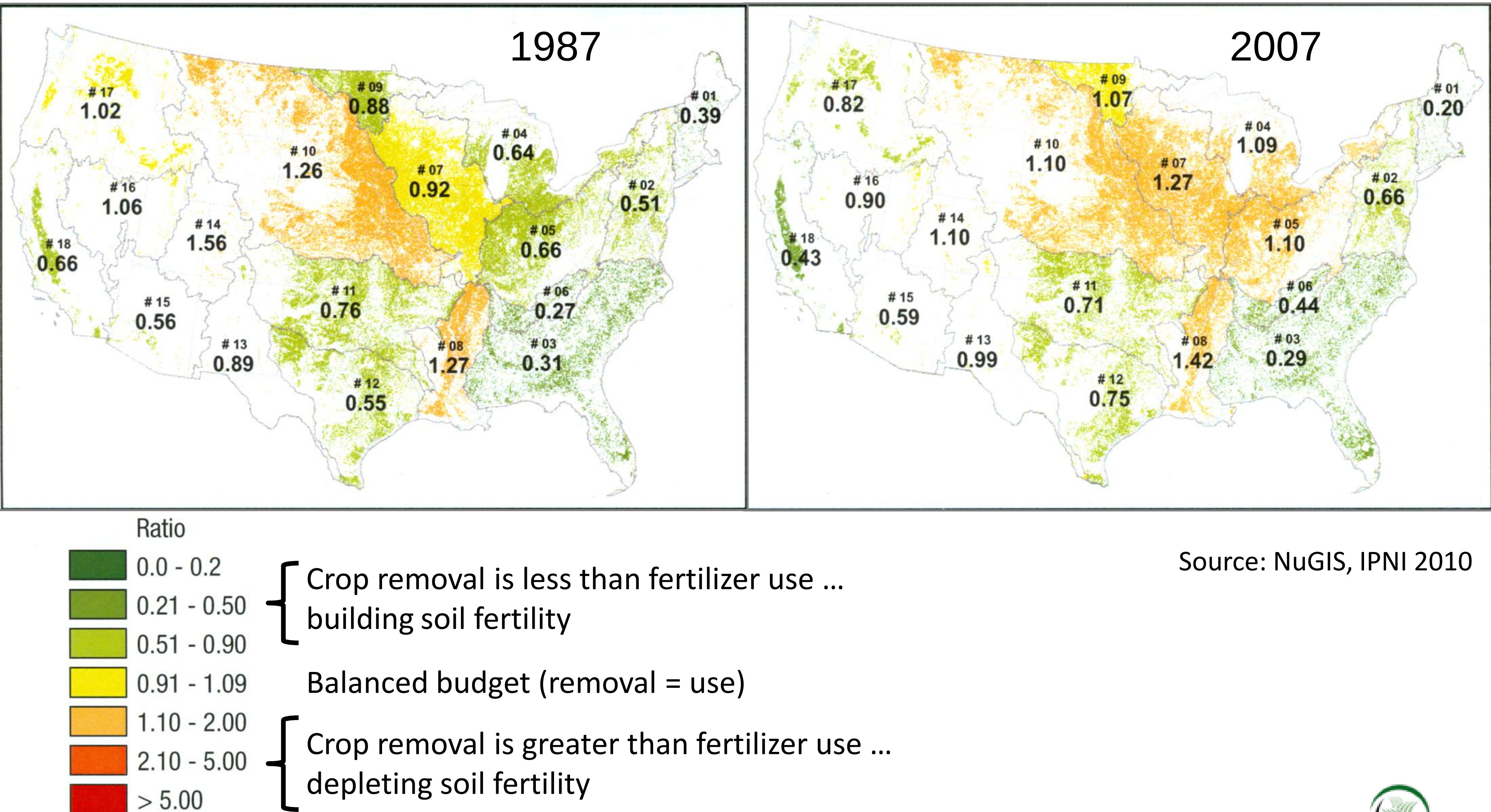
Estimated P recovery by balance (removal to use ratio), by hydrologic region, 1987 – 2007

(fertilizer + recoverable manure nutrients + legume N fixation – nutrient removal by crops)



Crop removal is less than fertilizer use … building soil fertility

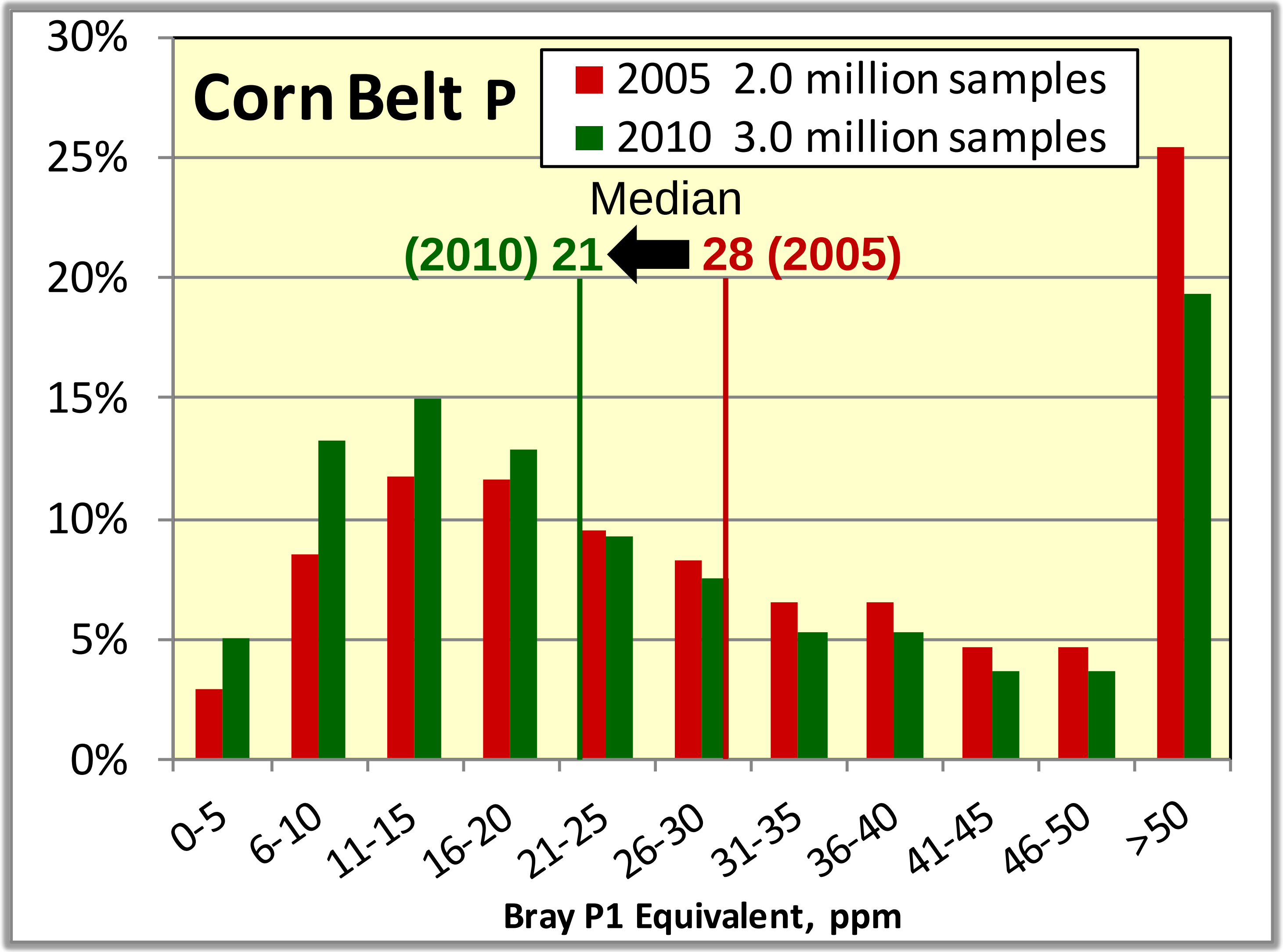
Balanced budget (removal = use)

Crop removal is greater than fertilizer use … depleting soil fertility

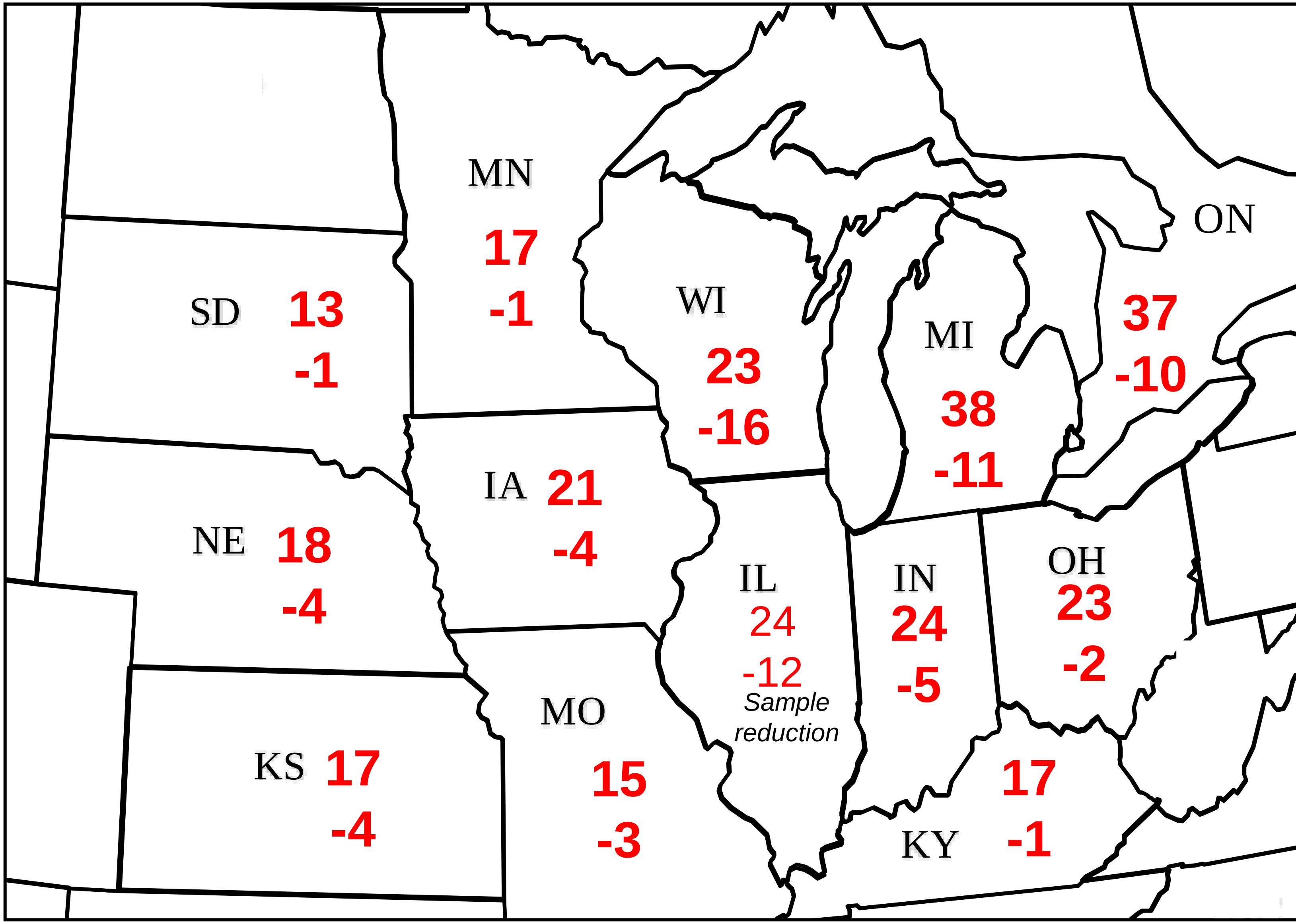
Source: NuGIS, IPNI 2010

Preliminary soil test P distribution in 2010 compared to 2005 for the Corn Belt

9/2/2010 (12 states plus Ontario)



2010 median soil P levels* and change from 2005
(Soil samples, millions: 2005=2.0; 2010=3.0)



*Median Bray P1 equivalent, ppm

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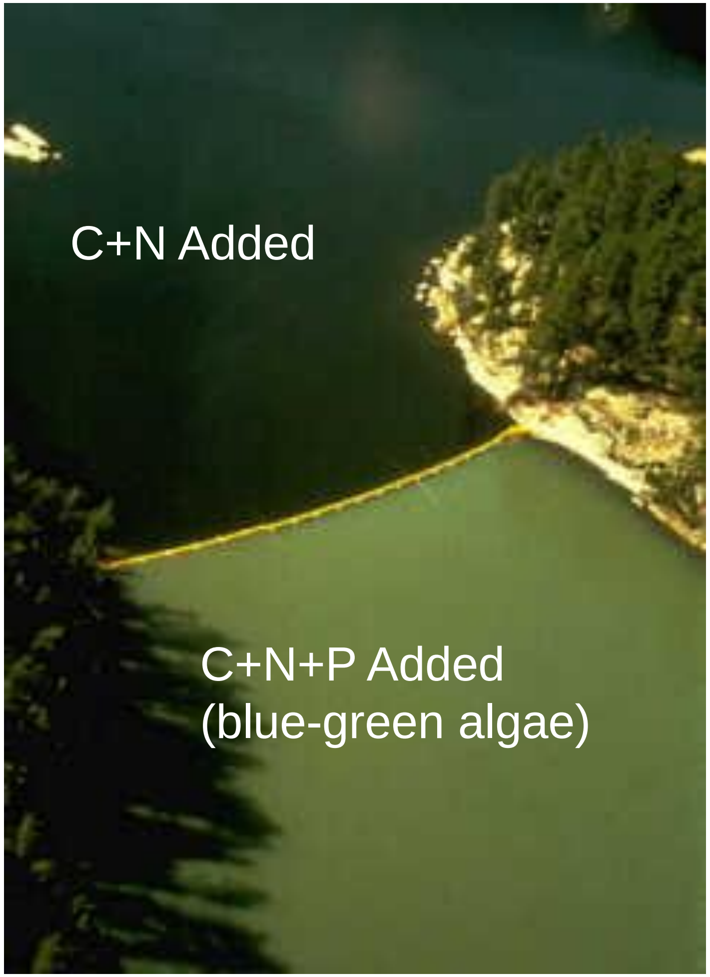
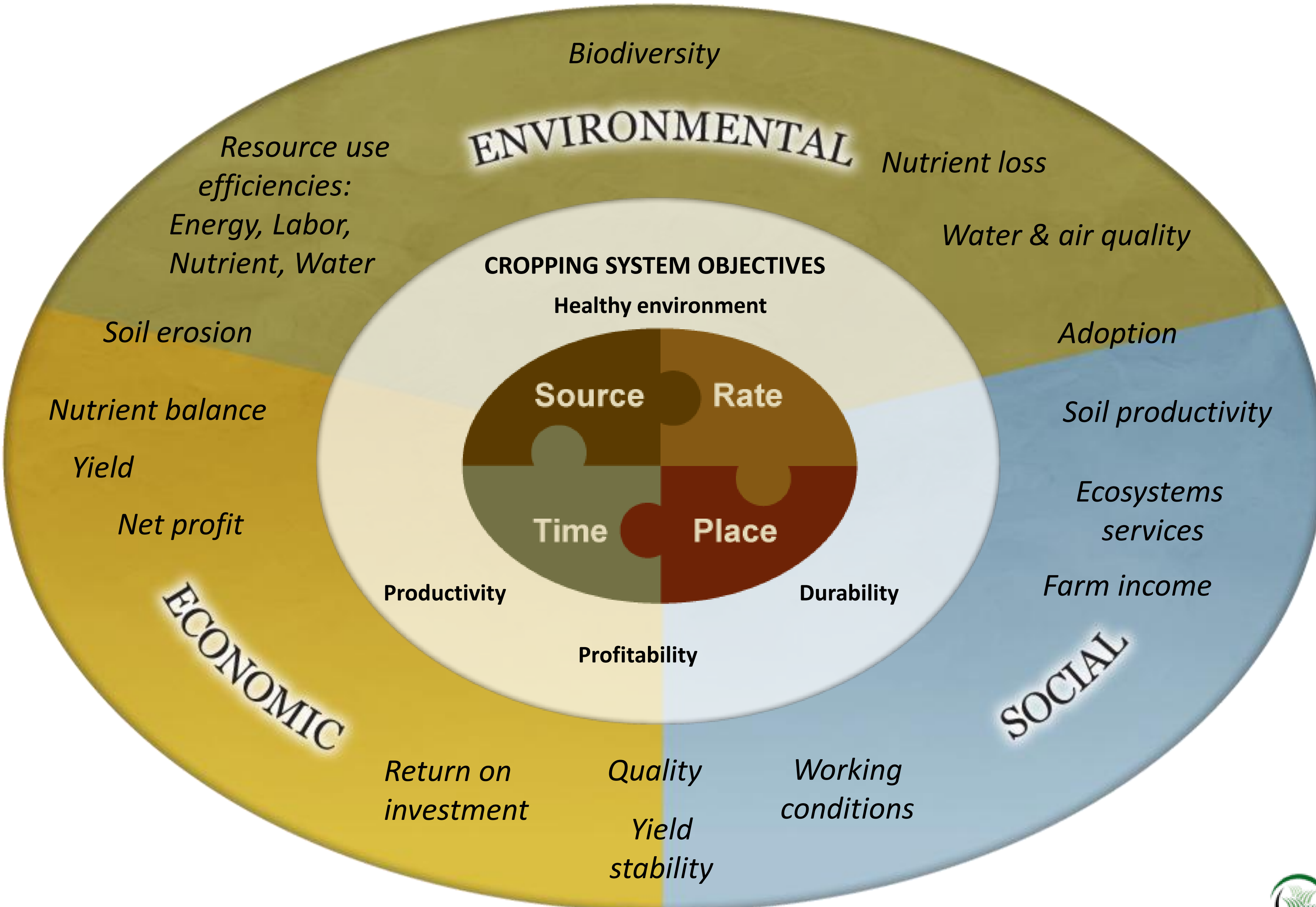
Phosphorus and the environment

- Eutrophication- the natural aging of lakes or streams by nutrient enrichment
- Nutrient additions can accelerate the process
- P is often the limiting element
- Dissolved oxygen is depleted by excessive plant growth
- BMPs can help minimize P runoff from fields



4R Nutrient Stewardship



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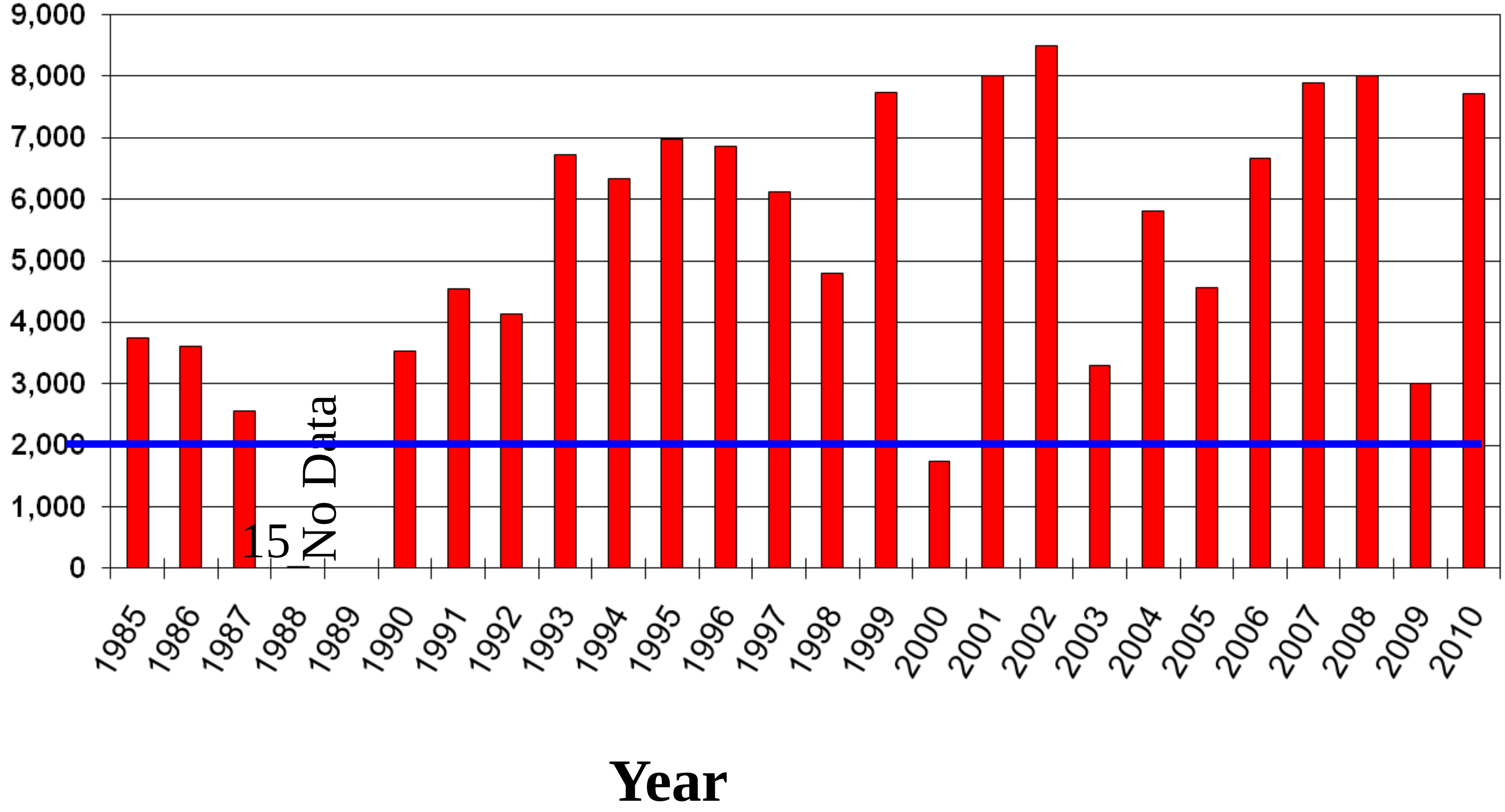
Gulf of Mexico Hypoxia Area (new estimates Aug. 2, 2010)

Square miles of hypoxia



2015 Hypoxia Goal
(1,930 mi² or 5,000 km²)

Hypoxia data from N. Rabalais, LUMCON

Sub-basin Contributions of N & P

Table 3. Average annual nutrient yields for the five large sub-basins in the Mississippi-Atchafalaya River Basin for water years 2001-2005. Source: EPA SAB, 2008.

Sub-basin	NO_3-N	NH_4-N and organic N (Total Kjeldahl N)	Total P
	---------- kg/ha/yr	----------	----------
Upper Mississippi	7.1	2.7	0.8
Ohio-Tennessee	6.4	3.3	1.1
Missouri	0.6	0.6	0.2
Arkansas-Red	0.5	0.8	0.1
Lower Mississippi	1.2	-0.5	0.9

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Annual P silicate discharge into Mississippi-Atchafalaya River Basin (MARB) from EPA's SAB on Hypoxia in the northern Gulf of Mexico (2008).

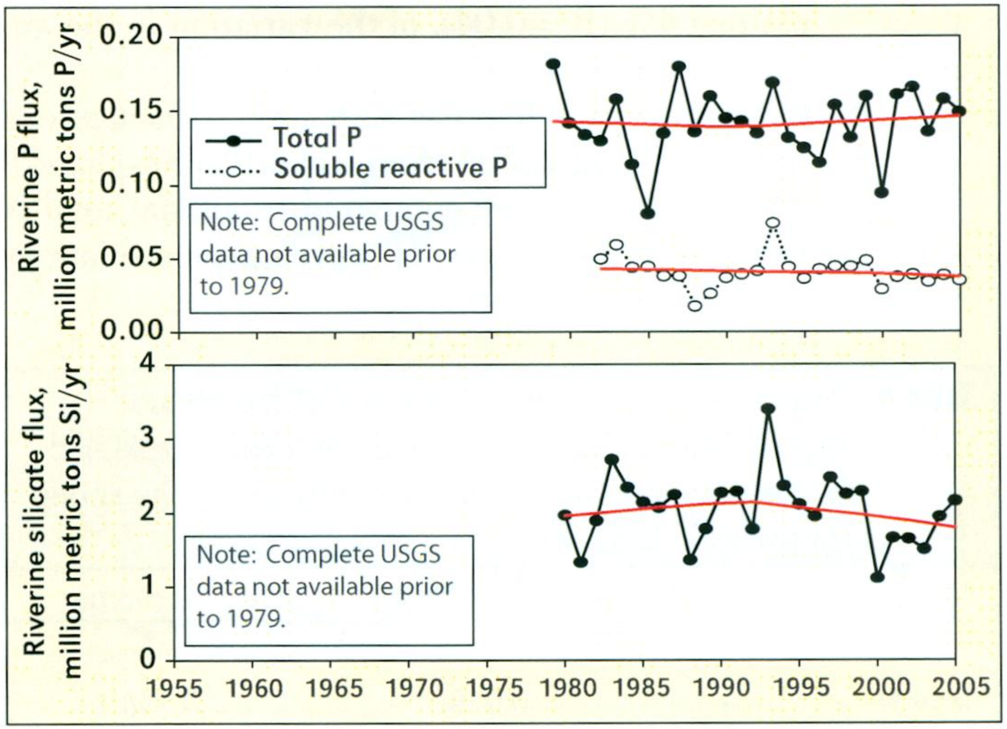

Figure 4. Annual P and silicate discharge (flux) for the Mississippi-Atchafalaya River Basin for 1979-2005. Red curves represent statistically-based, smoothed trends.

- Total P discharge has remained constant or increased slightly since 1980s
- Orthophosphate P (soluble) has declined slightly

Snyder. 2008. Better Crops 92(2):16-22

Nutrient mass balances estimated for MARB

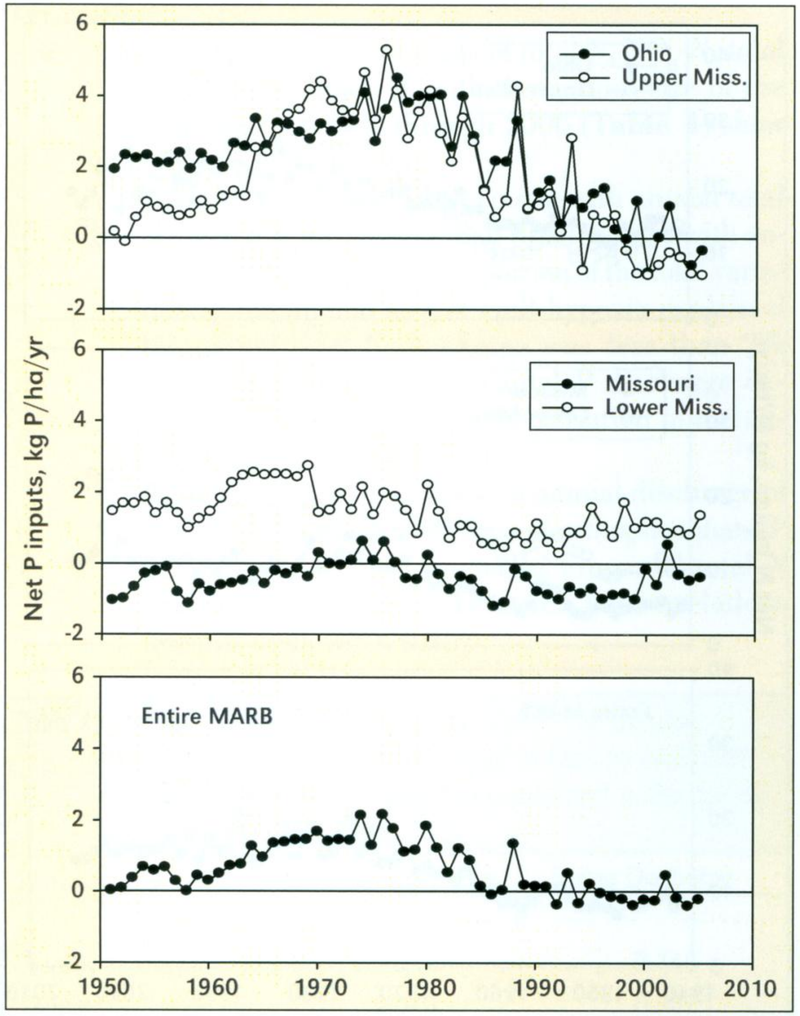

Figure 9. Phosphorus mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

- Voluntary actions are also reducing the "net" phosphorus (P) balance in the Mississippi River Basin; especially in two key upper sub-basins.
- This is a concern, however, because soil P may be "mined", and may lead to yield reductions and lower N use efficiency

Snyder. 2008. Better Crops 92(2):16-22

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