Addressing Soil Test Phosphorus Recommendations

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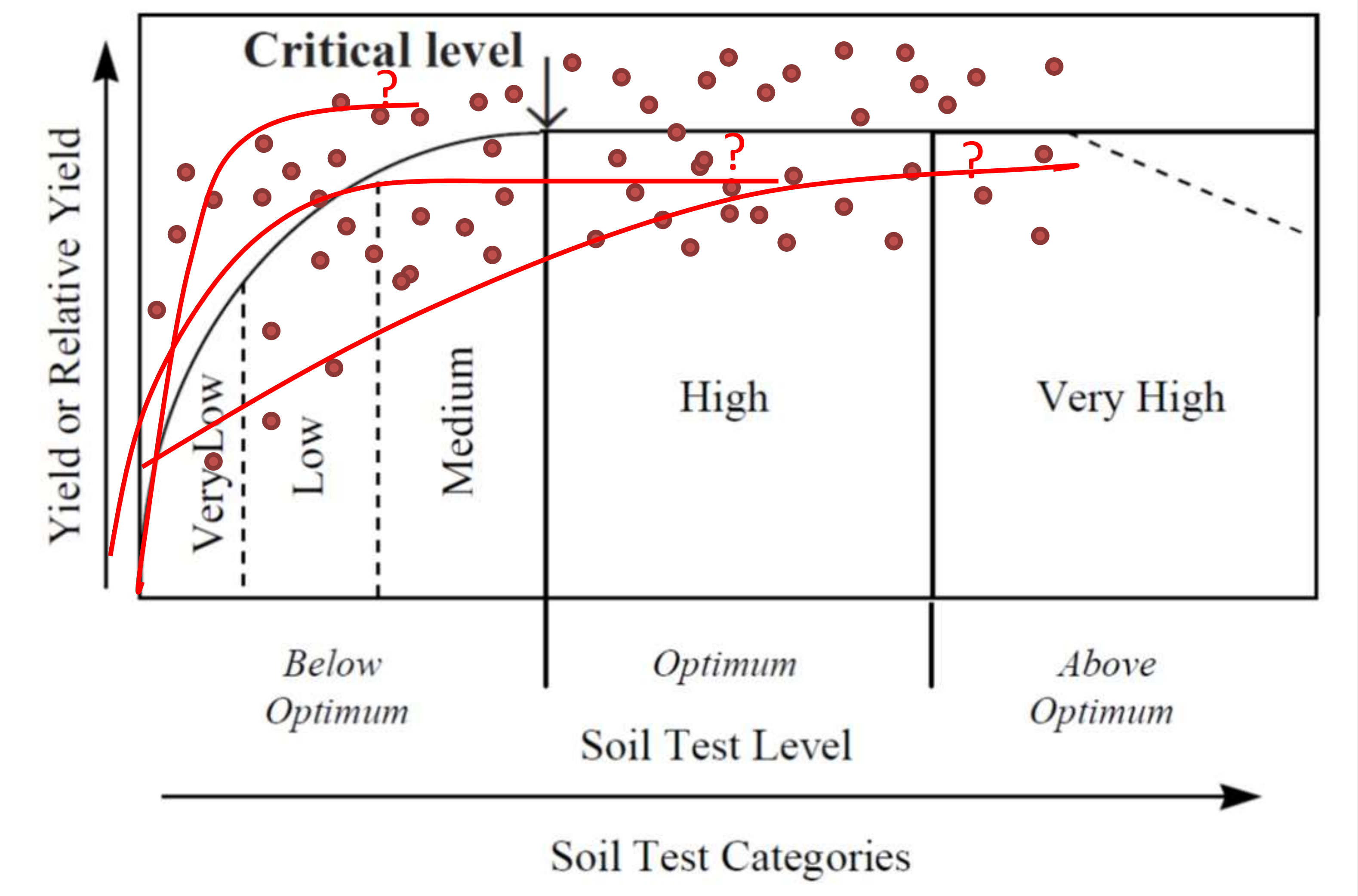
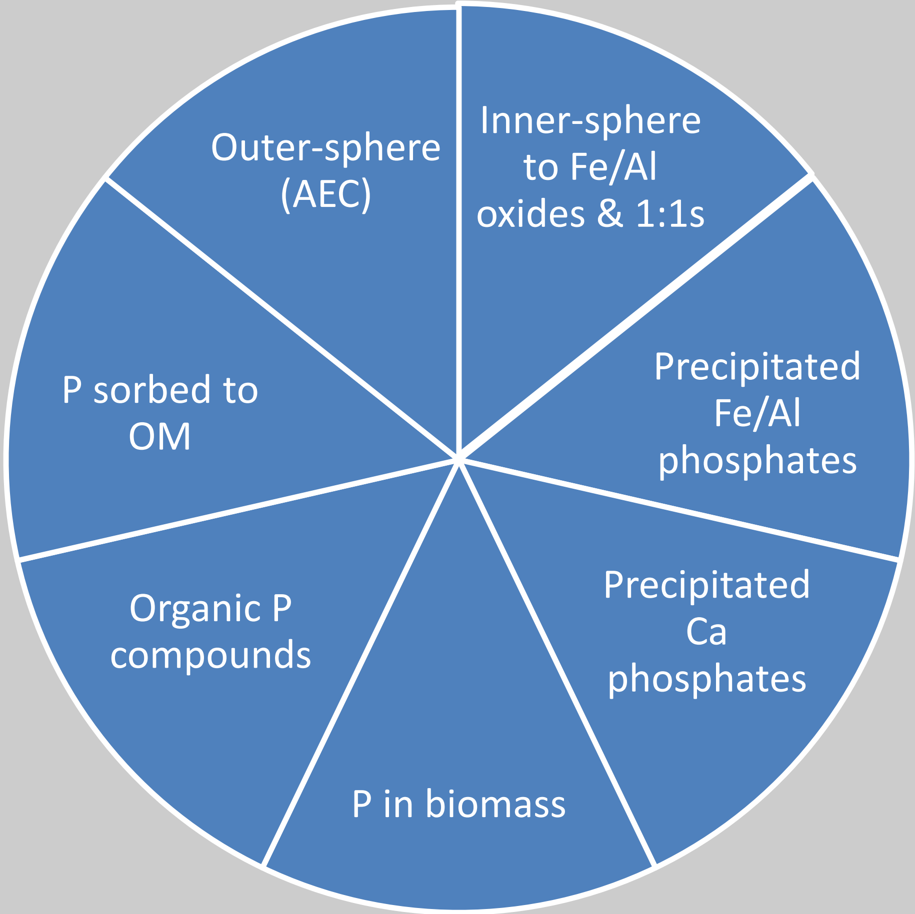
Improving P Soil Testing and Recommendations

- Precise P recommendations
  - Increase agronomic production efficiency
  - Reduce non-point losses of P

Traditional soil P testing



Agronomic soil test extractants



- Dissolve a subsection of various P pools
  - "quantity"
- Aims to dissolve what will become soluble over the growing season
  - Correlated to plant uptake of P and yield

Empirical vs. mechanistic soil testing and fertilizer recs

"The most commonly used tests, extract some portion of the labile soil P pool.

However, when different soils are used, solution P concentration, buffer capacity, and diffusion rate may not be correlated, therefore any one of the values would not be correlated with predicted P uptake and the simpler soil test would not be more reliable"

Stanley Barber: *Soil Nutrient Bioavailability*

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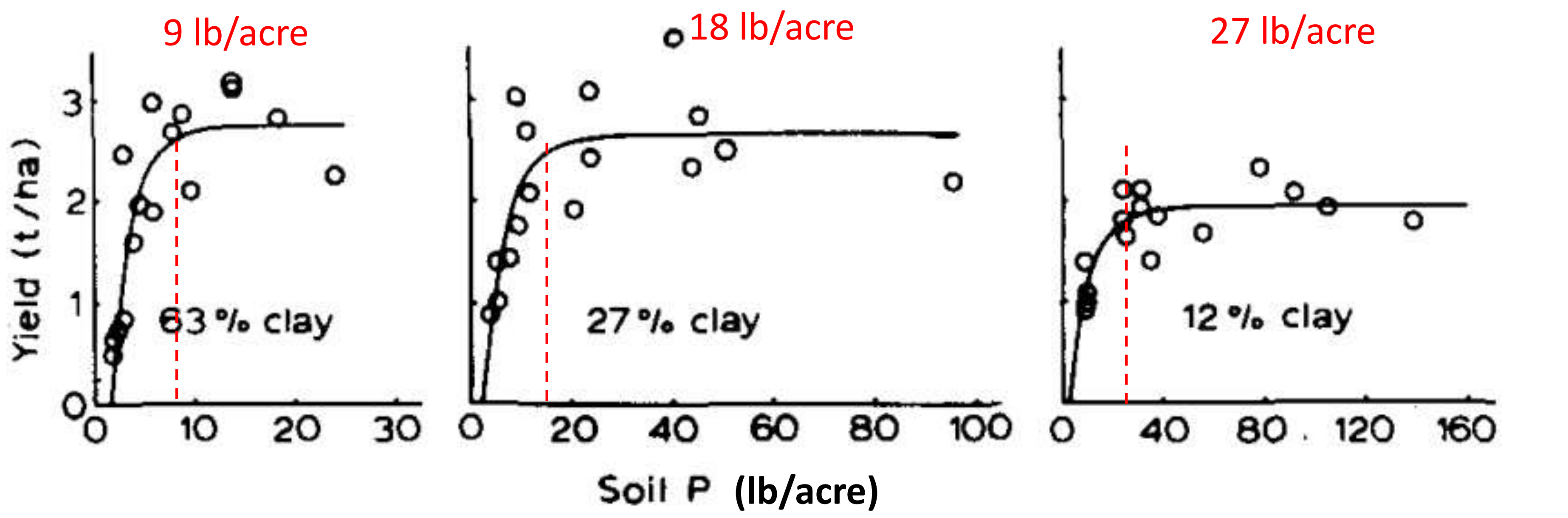
Critical Soil P Levels



Lins, Cox, and Nicholaides, 1985. "Optimizing P fertilization rates for soybeans grown on oxisols and associated entisols". SSSAJ

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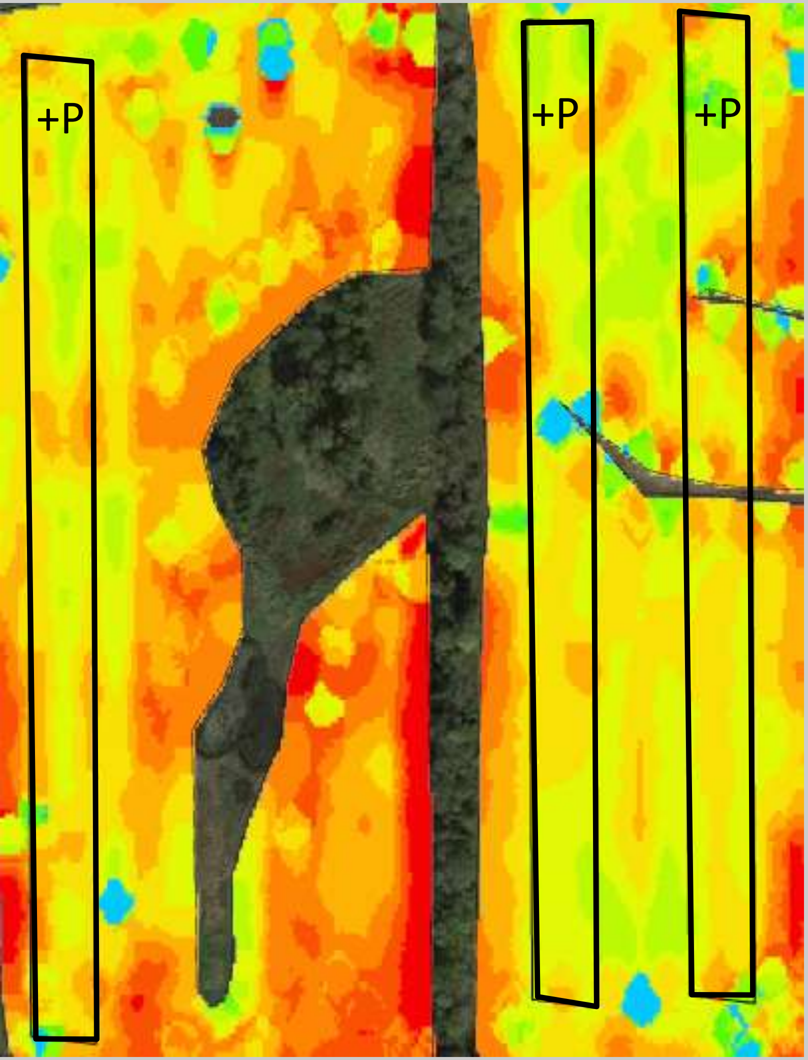
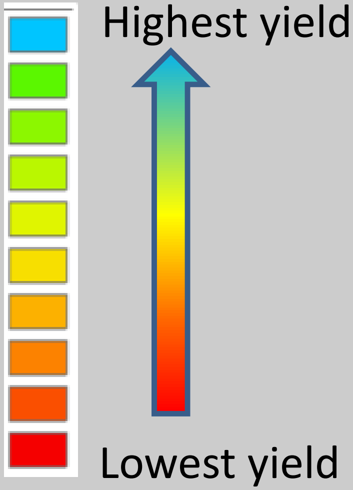
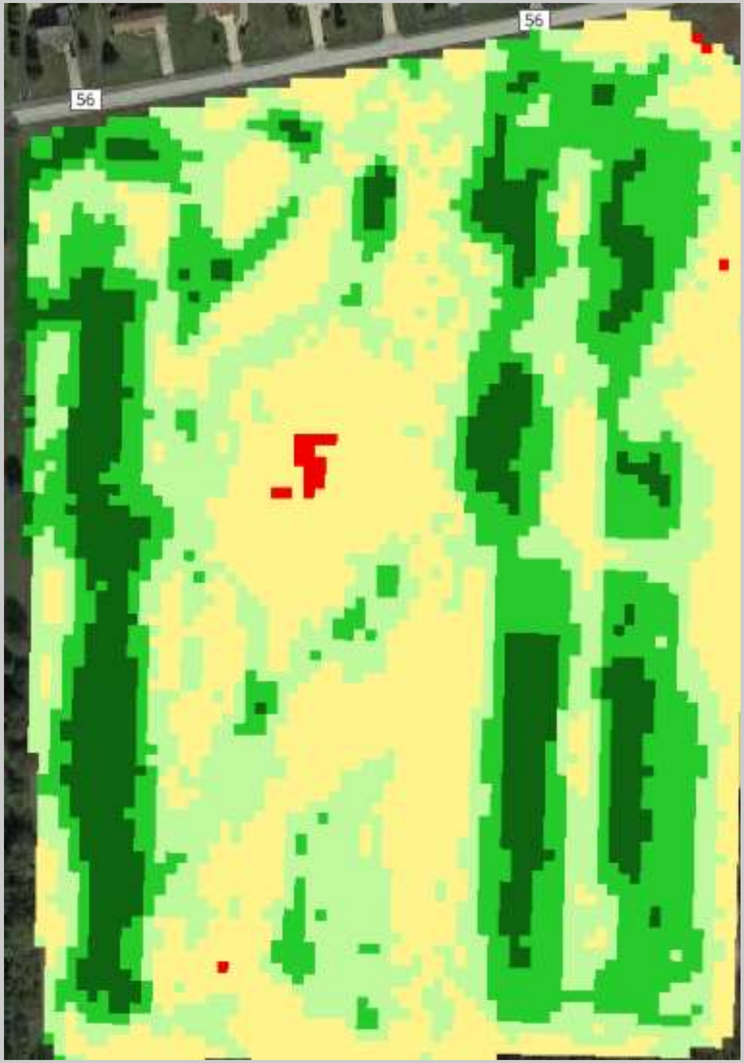
P Strips on Low P Soil:







Soybean: Fall 2017

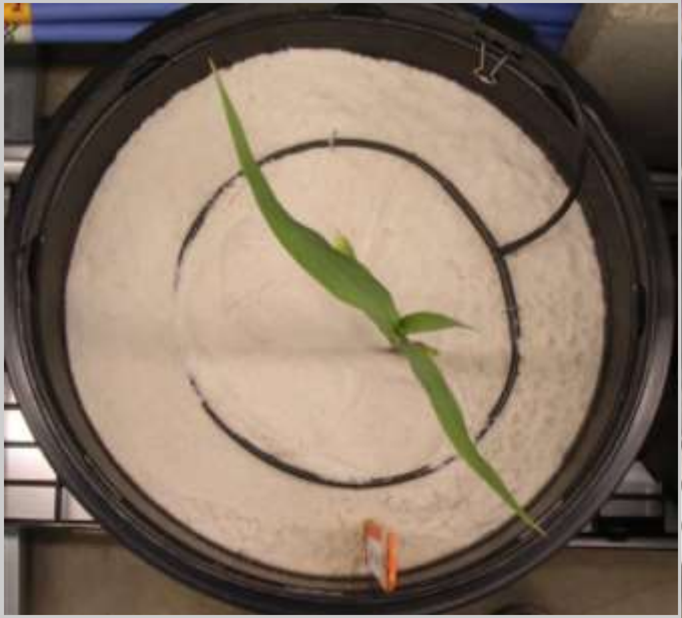
Rye: Spring 2018

What about under-application?

- Don’t assume recommendations are always on the side of over-application
- Higher yields means greater P uptake which may require greater P applications
  - Or more frequent
- Long term tillage study by Karlen et al., 2013
  - “Soil test P and K measurements as well as calculated P and K removal suggest that nutrient mining occurred”

What about under-application?

- P deficiency is usually not visible (i.e. purpling)



05/30/2018

06/04/2018

06/13/2018

This plant appeared perfectly healthy, even though it was P deficient

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Definition of "effective bio-availability"

- Nutrient must be in the:
  - In solution
  - Proper chemical form for uptake
    - Plants do not uptake dissolved organic P
  - In the vicinity of the plant root at the time of uptake
    - Location, location, location!
- Plants take nutrients up from the solution, NOT directly from the soil

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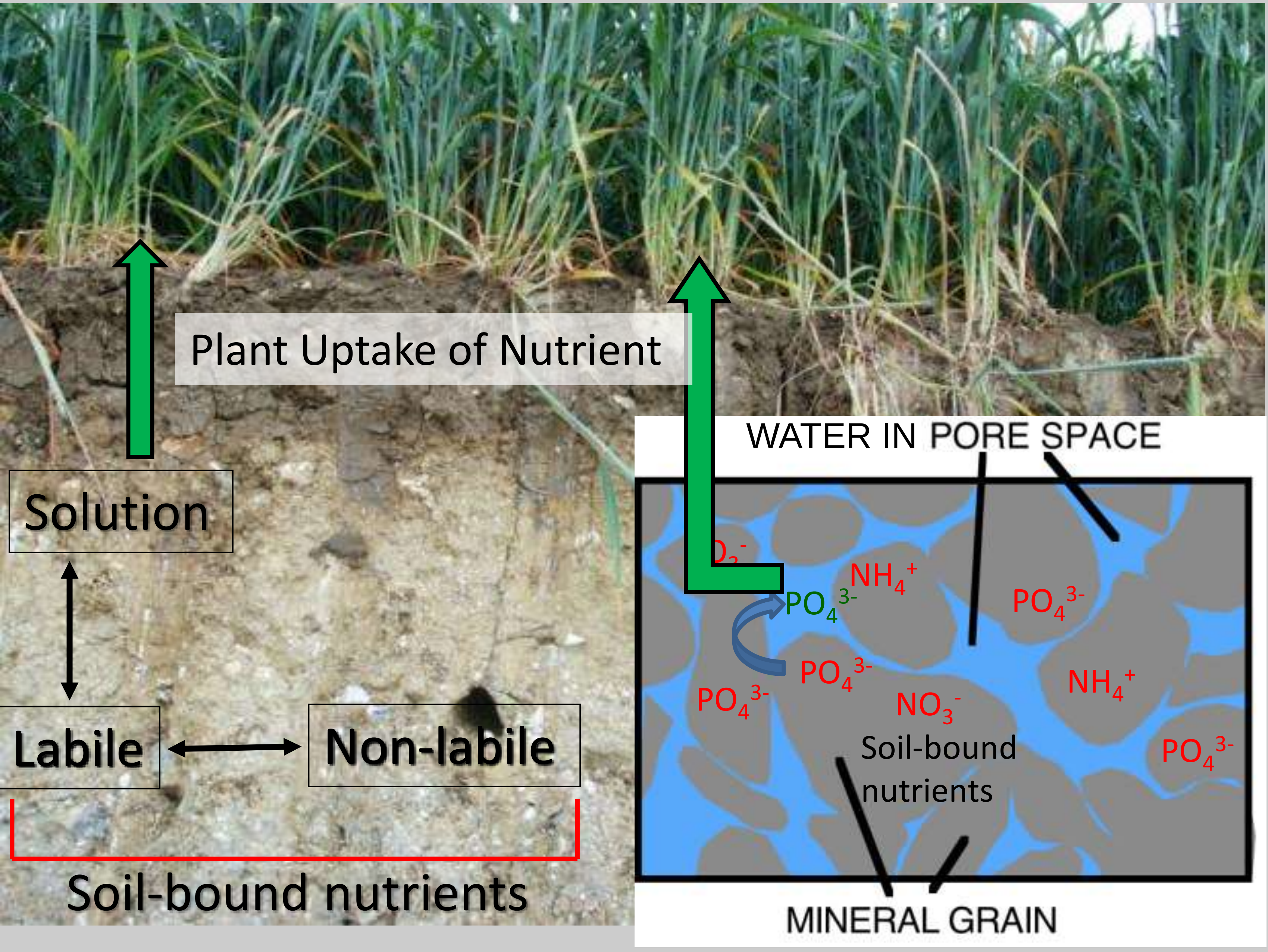
Soil-Plant Nutrient Dynamics

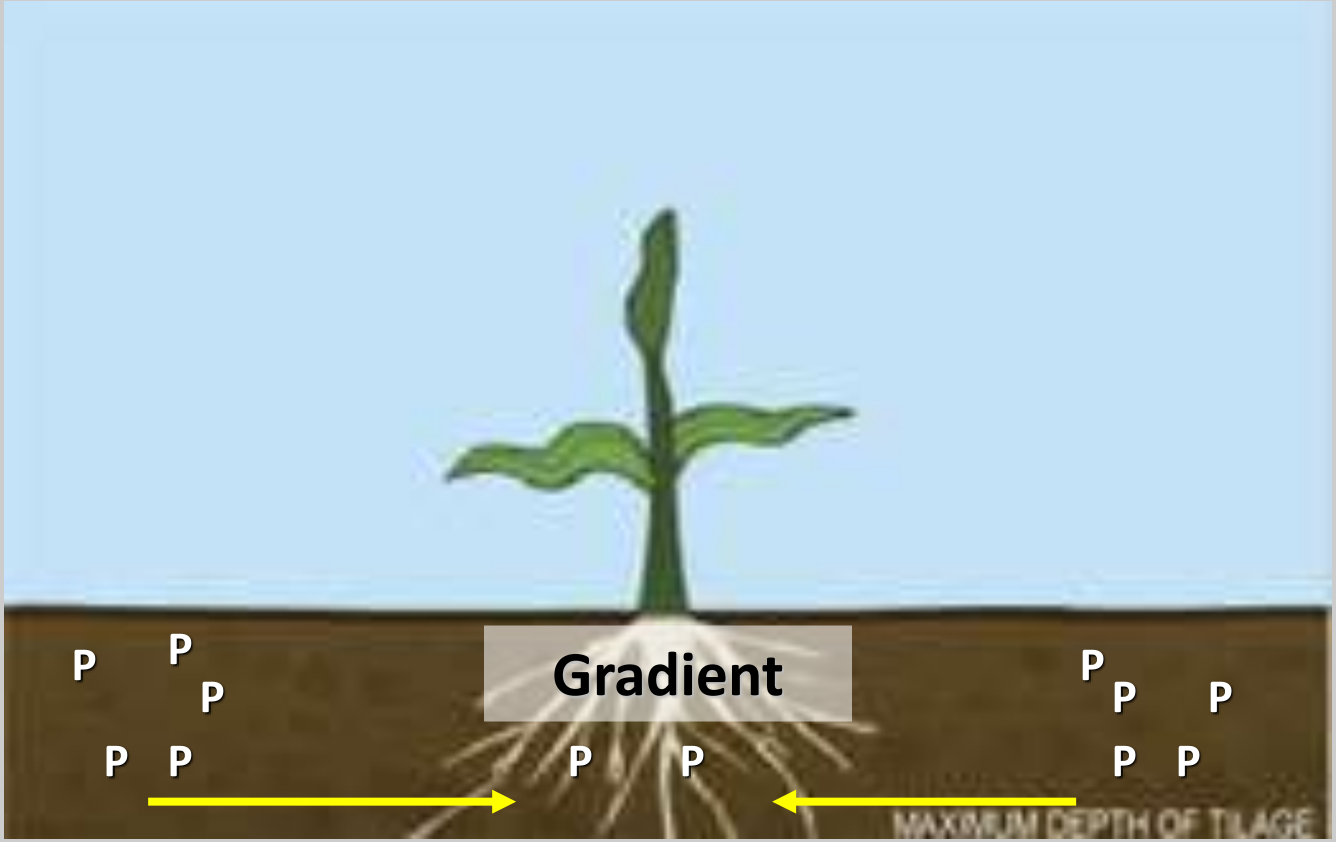


Uptake of solution P by plants

- Function of solution P concentration
- Replenishment by soil solids (quantity)
- Three ways of obtaining solution P
  - All three depend on root architecture, solubility, and location of P near roots
    - Root interception
    - Bulk flow $J_r = v_o C_l$
    - Diffusion: highly dependent on location of P!

P movement to roots: Diffusion

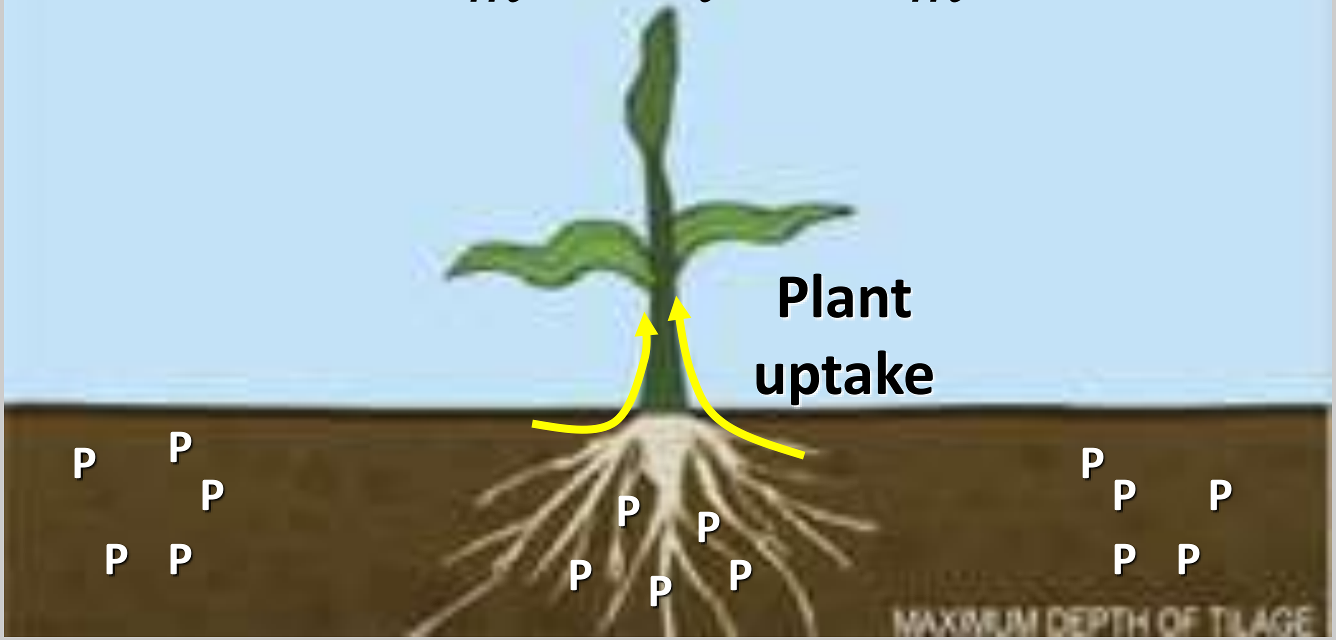
Dominant mechanism, but SLOW and short range



$$J_r = D_e b \frac{\partial C_l}{\partial r}$$

Diffusion followed by root uptake:

$$I_N = \frac{I_{max}\,(C_l - C_m)}{K_m + C_l - C_m}$$



Overall equation describing P uptake with P movement:

$$\underbrace{D_e b \frac{\partial C_l}{\partial r}}_{\text{Ion movement via diffusion}} + \underbrace{v_o C_l}_{\text{Ion movement via mass flow}} = \underbrace{\frac{I_{max}\,(C_l - C_m)}{K_m + C_l - C_m}}_{\text{Root uptake kinetics}}$$

Ion movement via diffusion

Ion movement via mass flow

Root uptake kinetics

Solved transient-state equation using the Crank-Nicholson method by Dr. John Cushman in 1980

Different plants require different concentrations in solution in order to meet the required P mass…..

“External P Requirement”

Crop	*Approximate P in Soil Solution for Yield Indicated (ppm)*	
	75% of Max.	*95% of Max.*
Cassava	0.003	0.005
Peanuts	0.003	0.01
Corn	0.008	0.025
Wheat*	0.009	0.028
Cabbage	0.012	0.04
Potatoes	0.02	0.18
Soybeans	0.025	0.20
Tomatoes	0.05	0.20
Head lettuce	0.10	0.30

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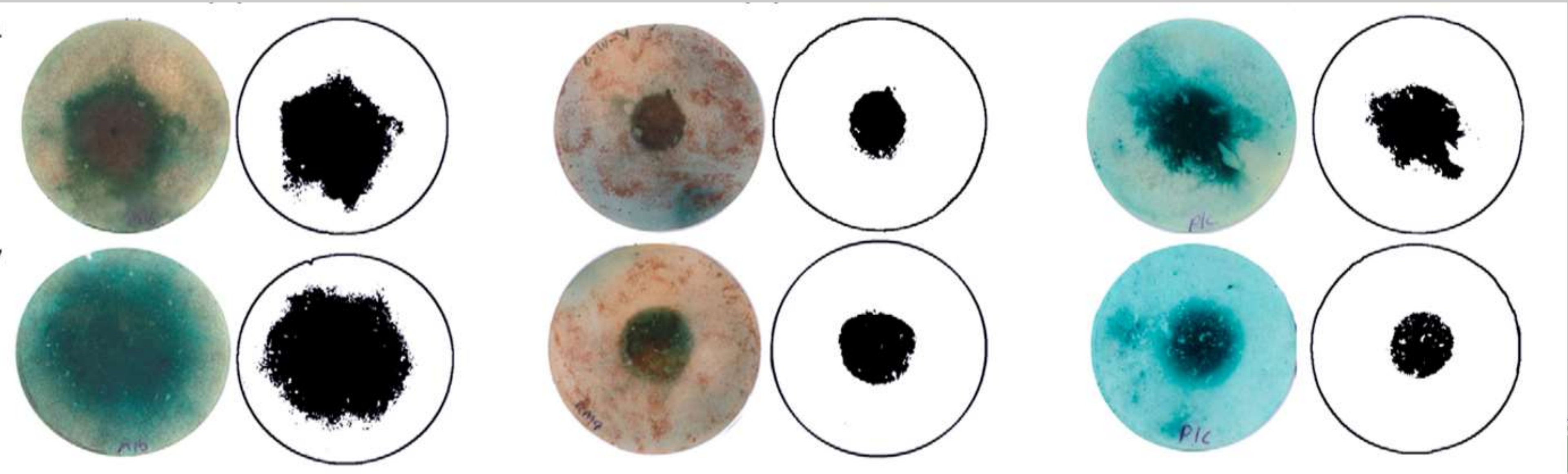
BUT, that requirement varies with soil P buffer capacity and texture:

tortuosity

$$Diffusion\ coefficient:\ D_e = \frac{D_l \O f_l \, dC_l}{dC_s}$$

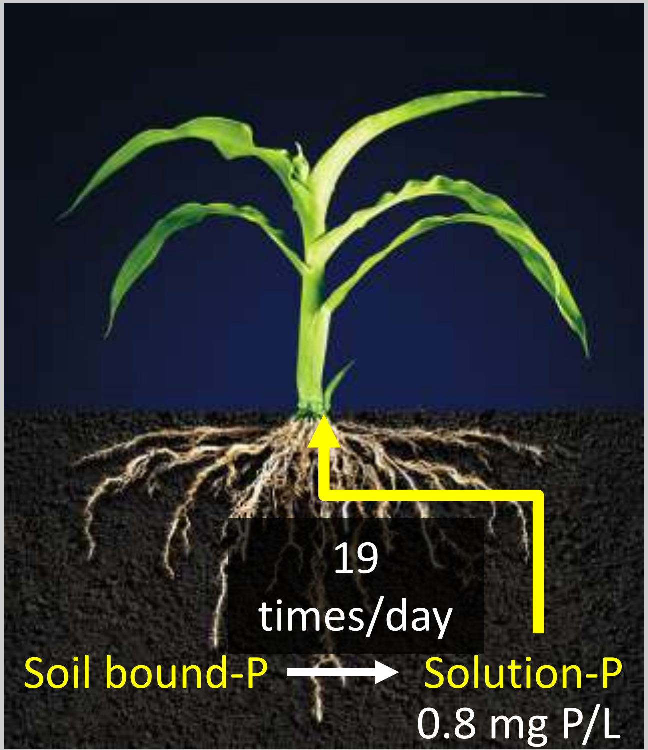
Buffer capacity (b)

Visualization of P diffusion in soils of varying properties *Degryse and McLaughlin, SSSAJ, 2014*

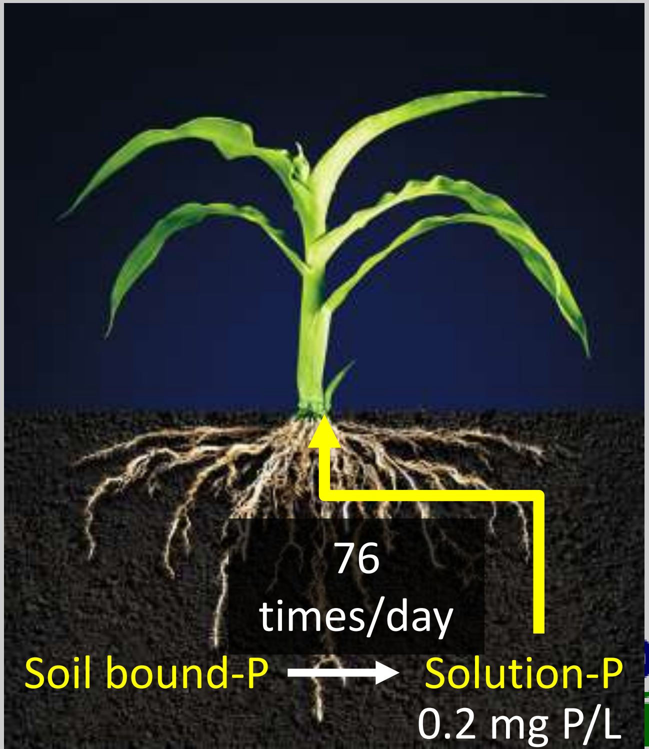


Soil P Requirement

- Mass of solution P uptake is universal across soil properties
  - But that required mass of P can be provided dynamically at different solution concentrations
  - Example: 550 mg P/corn plant over 120 days



*depends on root surface area



Soil P Requirement

- But we don't measure solution P! (Intensity)
  - We measure soil-bound P (Quantity)
- So how much soil-bound P do we need?
  - It depends on the ability of the soil to supply the solution P
    - Quantity-Intensity relationship
      - Soil properties: mineralogy, texture, OM, pH, etc.
      - Total P content and P forms
  - Also depends on physical location of P and ability to move (diffusion)

Quantity/ Intensity

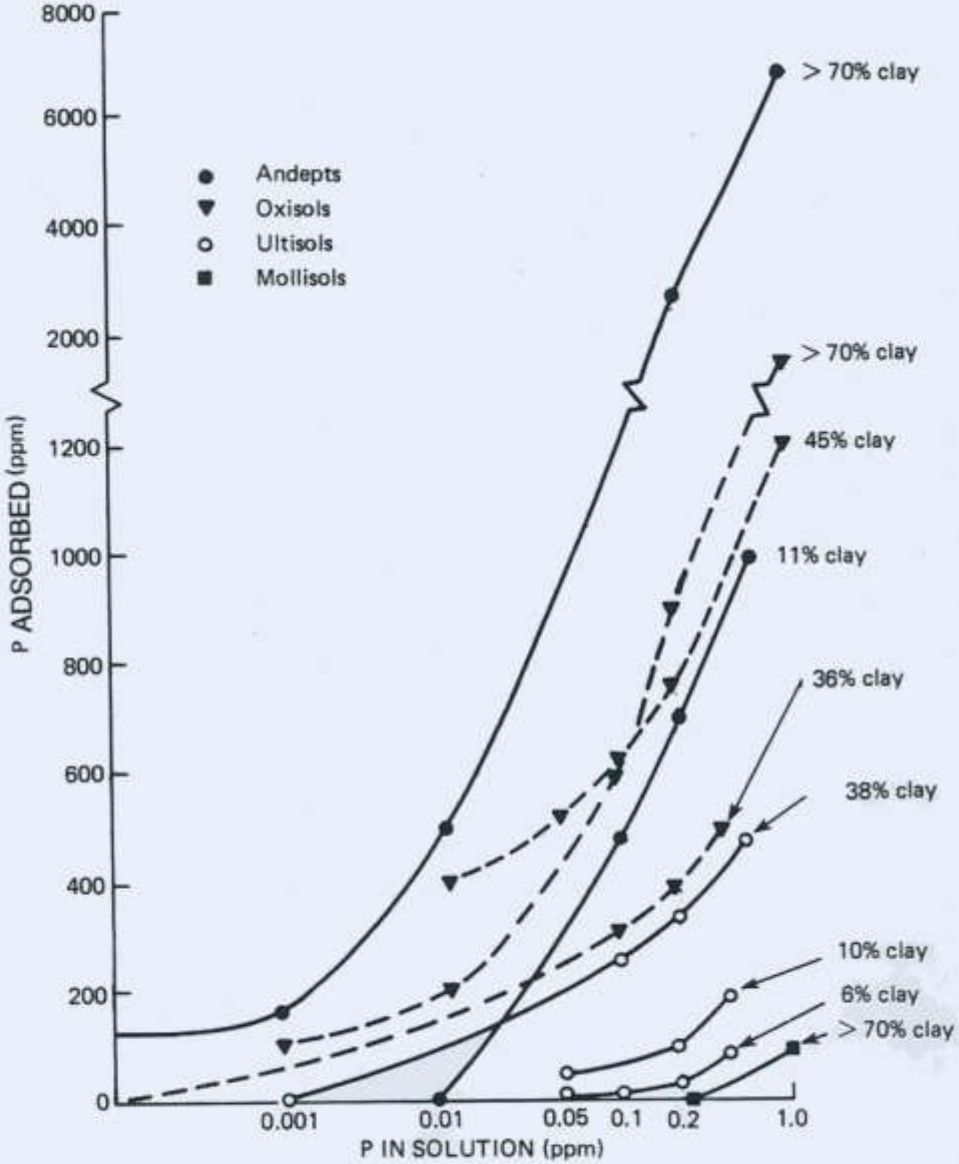
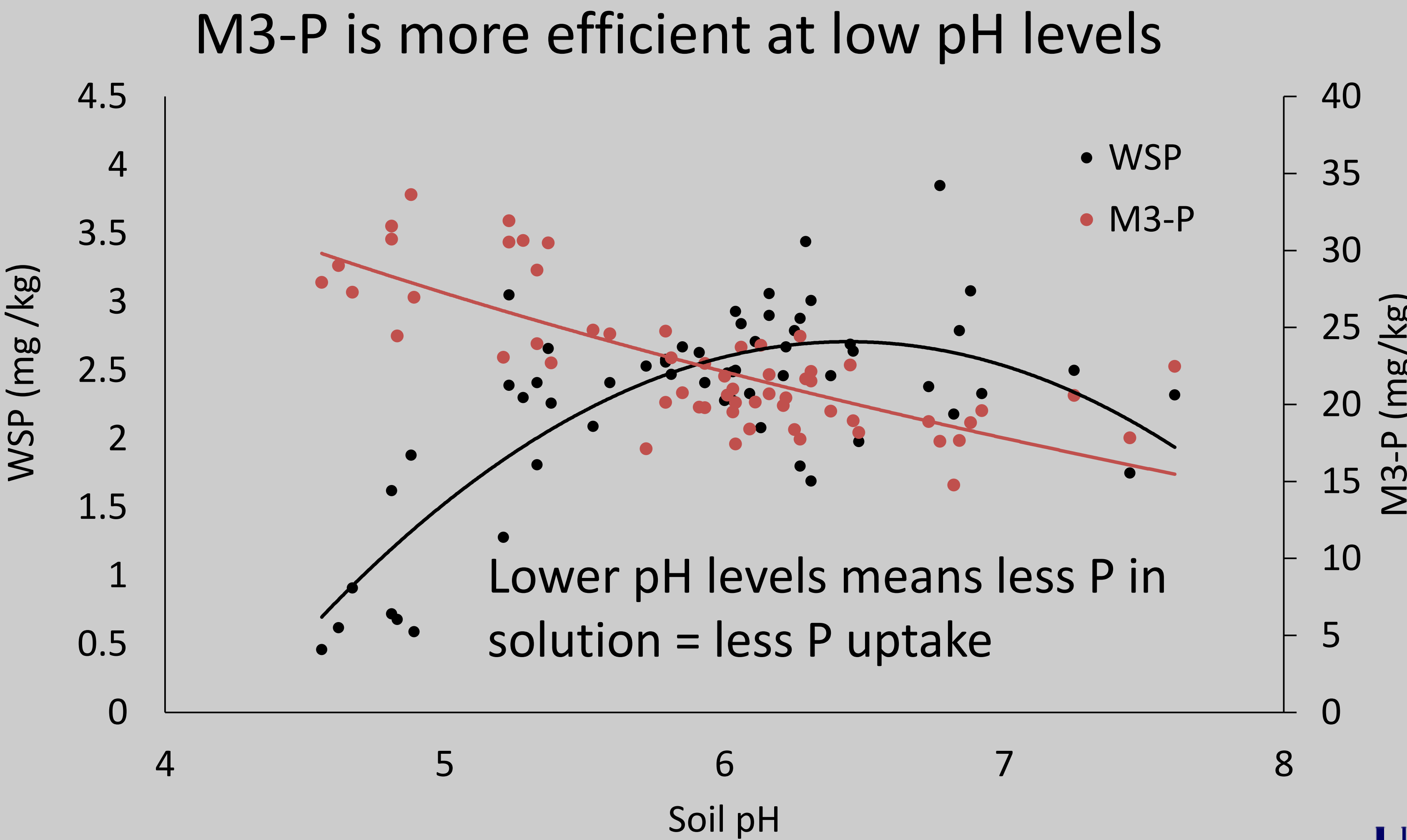


FIGURE 6.16 Examples of P adsorption isotherms determined by the method of Fox and Kamprath. *Sanchez and Uehara, in F. E. Khasawneh, E. C. Sample, and E. J. Kamprath, Eds.,* The Role of Phosphorus in Agriculture, *p. 480. Madison, Wisc.: American Society of Agronomy, 1980.*

Impact of soil pH

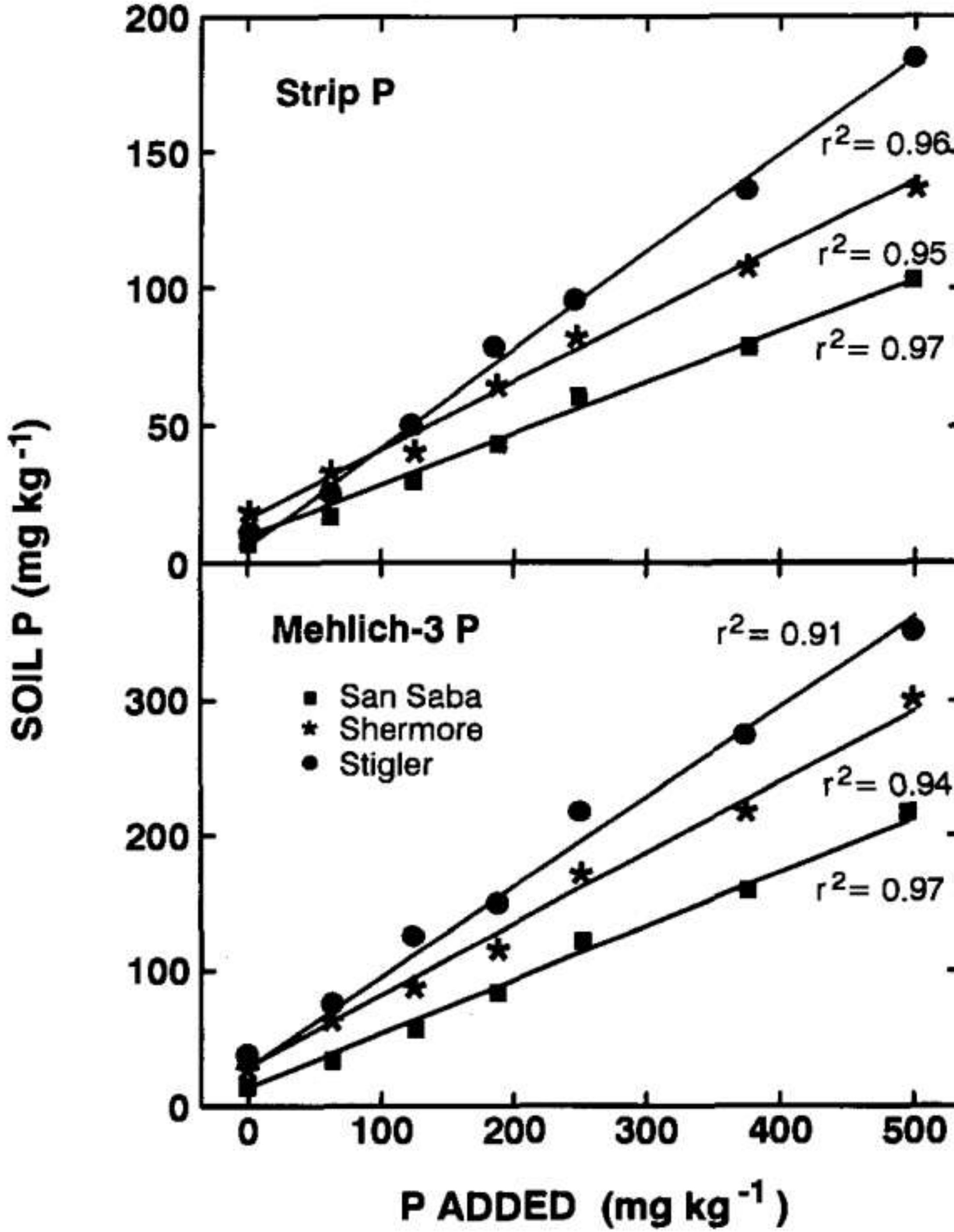


Penn et al., 2018; Agriculture

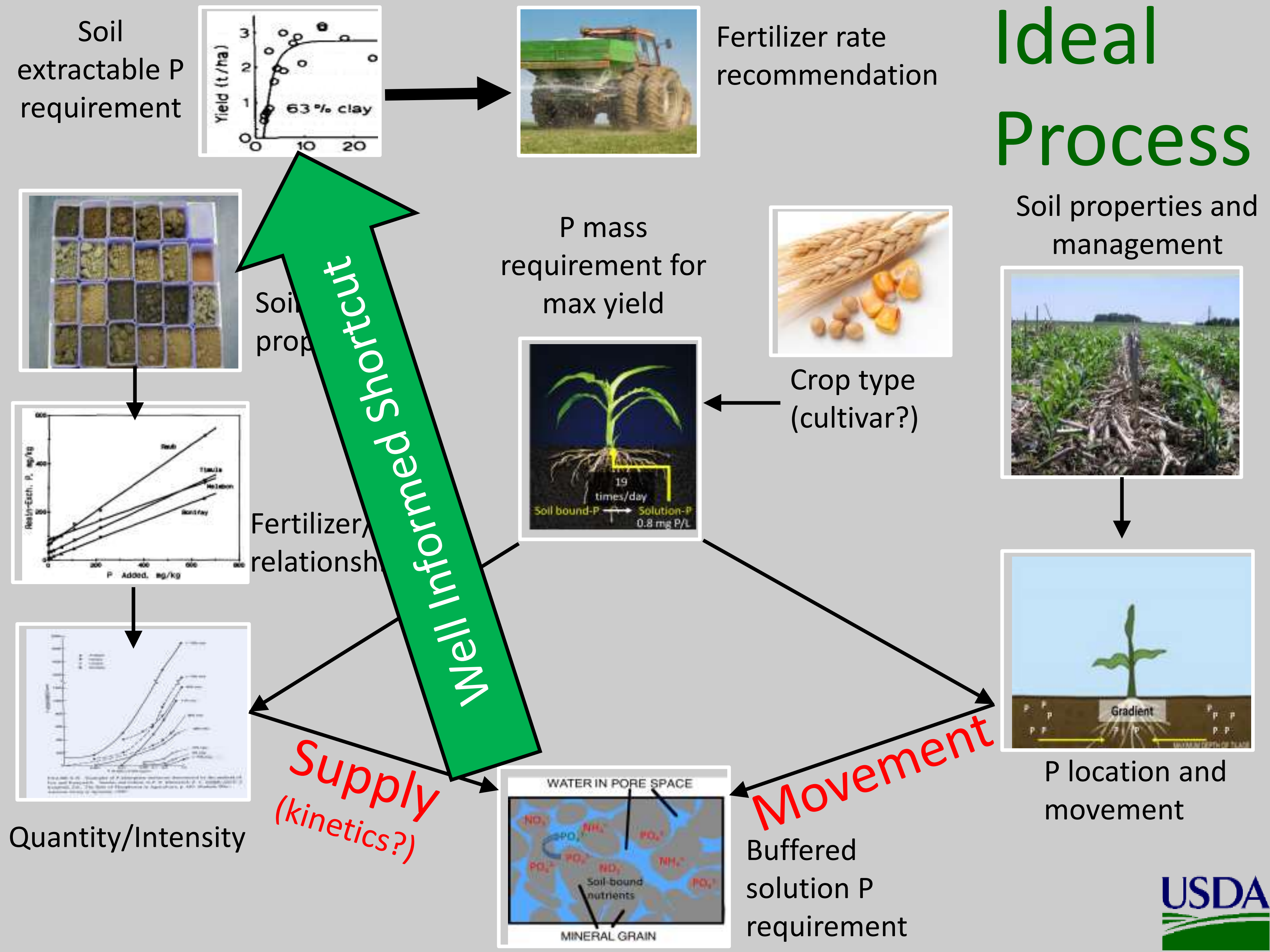
Fertilizer P Requirements

- Function of:
  - P mass required
  - Targeted soil P quantity necessary under the specific conditions
  - Fertilizer P-Soil P relationship
    - Depends on current soil P quantity and soil properties

Fertilizer-Soil P Relationship



A.N. Sharpley. 1995. Dependence of runoff phosphorus on extractable soil phosphorus. JEQ


Ideal Process
Soil extractable P requirement
Yield (t/ha)
63 % clay
Fertilizer rate recommendation
Soil properties and management
Soi
prop
P mass requirement for max yield
Crop type (cultivar?)
19 times/day
Soil bound-P
Solution-P 0.8 mg P/L
Resin-Exch. P, mg/kg
P Added, mg/kg
Fertilizer/
relationsh
Well Informed Shortcut
Quantity/Intensity
Supply (kinetics?)
WATER IN PORE SPACE
Soil-bound nutrients
MINERAL GRAIN
Movement
Gradient
P location and movement
Buffered solution P requirement
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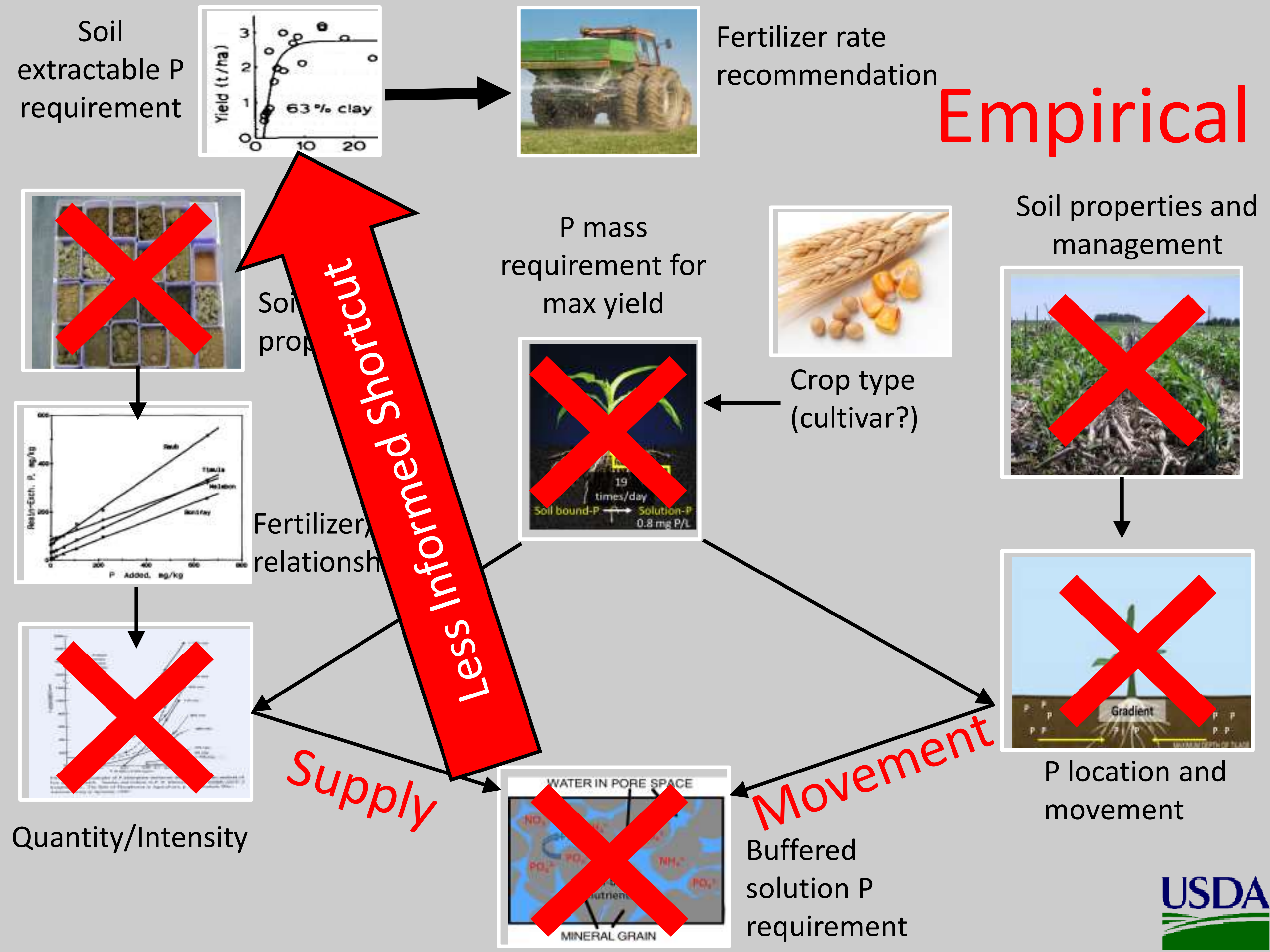
Outdated fertilizer recommendations

- Based on results from soil test
  - 0 to 6 inches
    - Not representative of No-till conditions
      - i.e. P location
- Based on calibrations conducted 30 to 50 years ago
  - No consideration for soil type or conditions
  - We have very different crop varieties now



Soil extractable P requirement
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63 % clay
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Empirical
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P Added, mg/kg
Less Informed Shortcut
Quantity/Intensity
Supply
Movement
Gradient
P location and movement
WATER IN PORE SPACE
MINERAL GRAIN
Buffered solution P requirement
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Potential for Soil Quality

- Soil health can only improve P accessibility, but that does not defeat the mass requirement i.e. thermodynamics
  - – Deeper roots or more roots
  - – Free-living rhizosphere microorganisms
  - – VA mycorrhizae
  - – Changes to Q/I relationship
- "I don't need to fertilize with P anymore"
  - – This is temporary due to the buffered nature of P
  - – Only changes in genetics can change the P mass required by a plant

Current P Recommendations

- Not bad
- Get us in the ballpark
  - Not precise
  - Lots of room for improvement
    - Save $
      - Example: increase M3-P by 10 ppm vs 20 ppm
        - » 40 vs 70 dollars/acre for MAP
    - Improve production efficiency
    - Reduce P losses

Long Term Goal

- Utilize and improve the Barber-Cushman model for developing more precise and condition-specific fertility recommendations
  - Required P mass for various cultivars
  - Plant uptake kinetics curves
  - Incorporate root modelling
  - Predict root solution P concentrations and kinetics using easily obtained parameters
    - At different depths
- Continue to use STP extractants, but vary the optimum level depending on soils, crop, and conditions

Required P uptake mass and P utilization efficiency: sand culture hydroponics

Questions?

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