Phosphorus in Agriculture

What we know, what we need to know

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Phosphorus Management

- Based on 4 basic factors
  - Science
    - Soil P chemistry --- Soil P availability
    - Crop response
  - Philosophy
    - How do you view the world/ cropping operation
  - Economics
    - Business decisions to minimize risk
  - Environmental Implications
    - Will what we do impact our neighbors?

The Science

Phosphorus in the Plant

- P is essential nutrient in plant
  - One of 16 known essential nutrients
  - One of 6 Macro nutrients
- P conc in plant --- 0.1 to 0.4%
  - Significant component of:
    - DNA and RNA
    - Cell membrane structure
  - Energy Transfer within cell

Phosphorus in the Plant

- 2nd or 3rd most limiting in crop production
  - After N and sometimes K
- Plant absorbs P from the SOIL SOLUTION
  - $H_2PO_4^-$ or HPO_4^{2-}
- P is mobile in the plant
  - When deficient
    - Translocates P from older tissues to young tissue
    - Visual symptoms often difficult to discern
      - Purpling color, dark green color, retarded growth, lack of tillering

Phosphorus in the Soil

- Surface soils: 0.02 to .10% P
  - Very limited mobility in soil
    - Very little P in soil solution
    - Most P in soil solids
      - Active P: readily supplies soil solution
      - Fixed P: organic or inorganic P
- Solution, Active, and Fixed P in equilibrium
- Soil solution quickly depleted by crop
  - Must be quickly and readily resupplied
    - Intensity or Buffering capacity

$$\text{Soil Solution P} \rightleftharpoons \text{Active P} \rightleftharpoons \text{Fixed P}$$

Relationship of Soil Solution P to Sorbed P

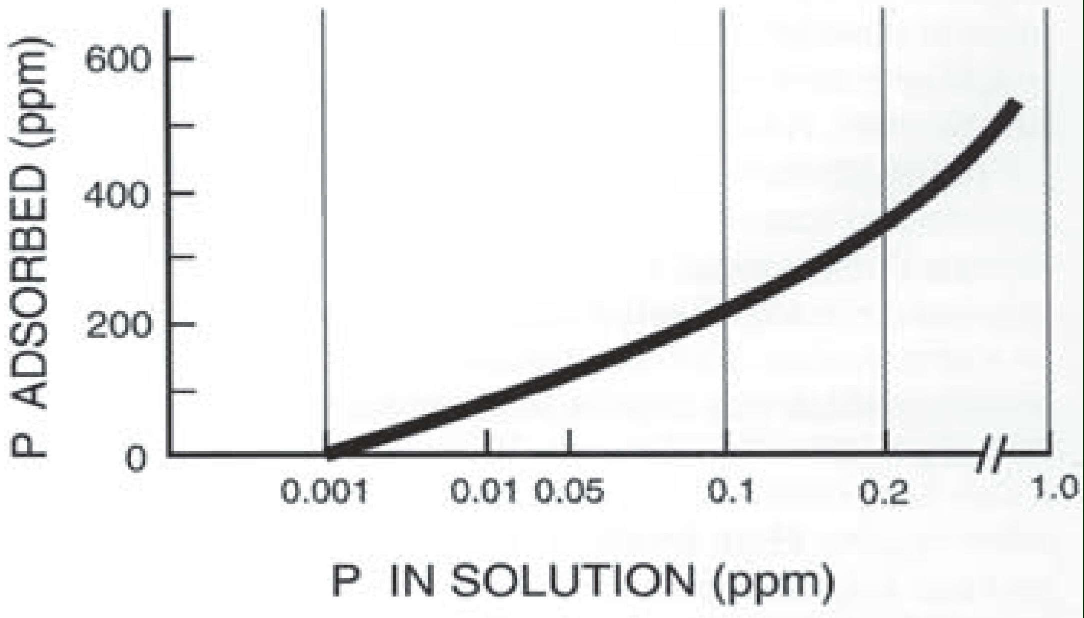


Figure 2. Relationship between P adsorbed by soil and P in solution.

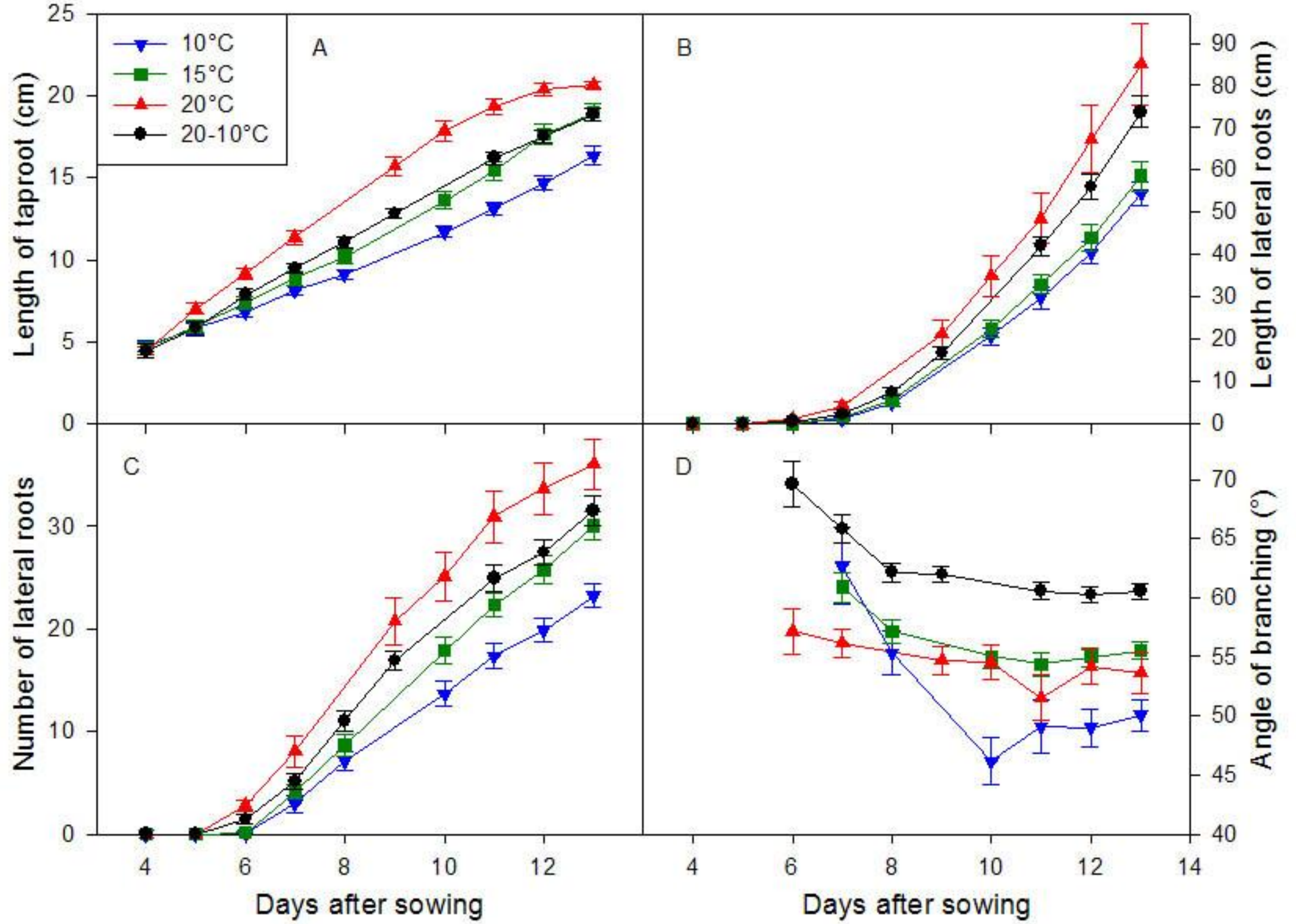
Adapted from Busman et al., Minn. Ext. Service FO-6795-B

Root Acquisition of P

- Root acquisition of P is effected by:
  - Distance between Root and P
  - Time required to traverse that distance
- Distance between Root and P Determined by:
  - Placement of P in the soil relative to root
    - Managed by P application amount and placement
  - Root growth through the soil profile

Root Acquisition of P

Root growth inhibited by cold temperatures



Length of taproot (A), total length of lateral roots (B), number of lateral roots (C) and branching angle between taproot and lateral roots (D). Plants were exposed to a uniform root temperature (10°C, 15°C or 20°C, respectively) or a vertical gradient in root temperature 20-10°C (mean value +/- SE, n=11-23).

Kerstin A. Nagel, Bernd Kastenholz, Matthias Mühlich, Hanno Scharr, Ulrich Schurr and Achim Walter, Forschungszentrum Jülich 2008

Nagel K.A. et al. (2009) Temperature responses of roots: impact on growth, root system architecture and implications for phenotyping. Functional Plant Biology, 36, 947-959

Root Acquisition of P

- Time to traverse the Distance Effected by Diffusion Rate
  - P moves to root surface by diffusion
    - Diffusion over very short distances
    - Diffusion rate controlled by:
      - Concentration gradient
        - » Difference between high conc. zone (soil solution) and low conc. zone (root surface)
      - Temperature
        - » Lower temp = slower diffusion

Root Acquisition of P

- P uptake as affected by temperature and concentration gradient

	Soil Temperature (º F)		
P rate	59	68	77
lbs P_2O_5/acre	----- mg P/pot -----		
35	3.5	10.4	18.0
70	6.7	13.5	19.6

Adapted from G. Rehm, June 29, 2009, Agbuzz, Univ. of Minn.

Soil P Chemistry

- Fertilizer increases solution P concentration
  - P rapidly leaves soil solution
    - Binds to surfaces of minerals
    - Precipitates (absorption into Ca-P, Al-P, Fe-P)
- Initially, bound and precipitated P readily resolubilizes
  - Active P or Labile P
- In time, precipitated P can form new, less soluble compounds.
  - Fixed P or Non-labile P
  - Depends on soil chemical characteristics
  - May take weeks, may take years.

Phosphorus Availability and Soil pH

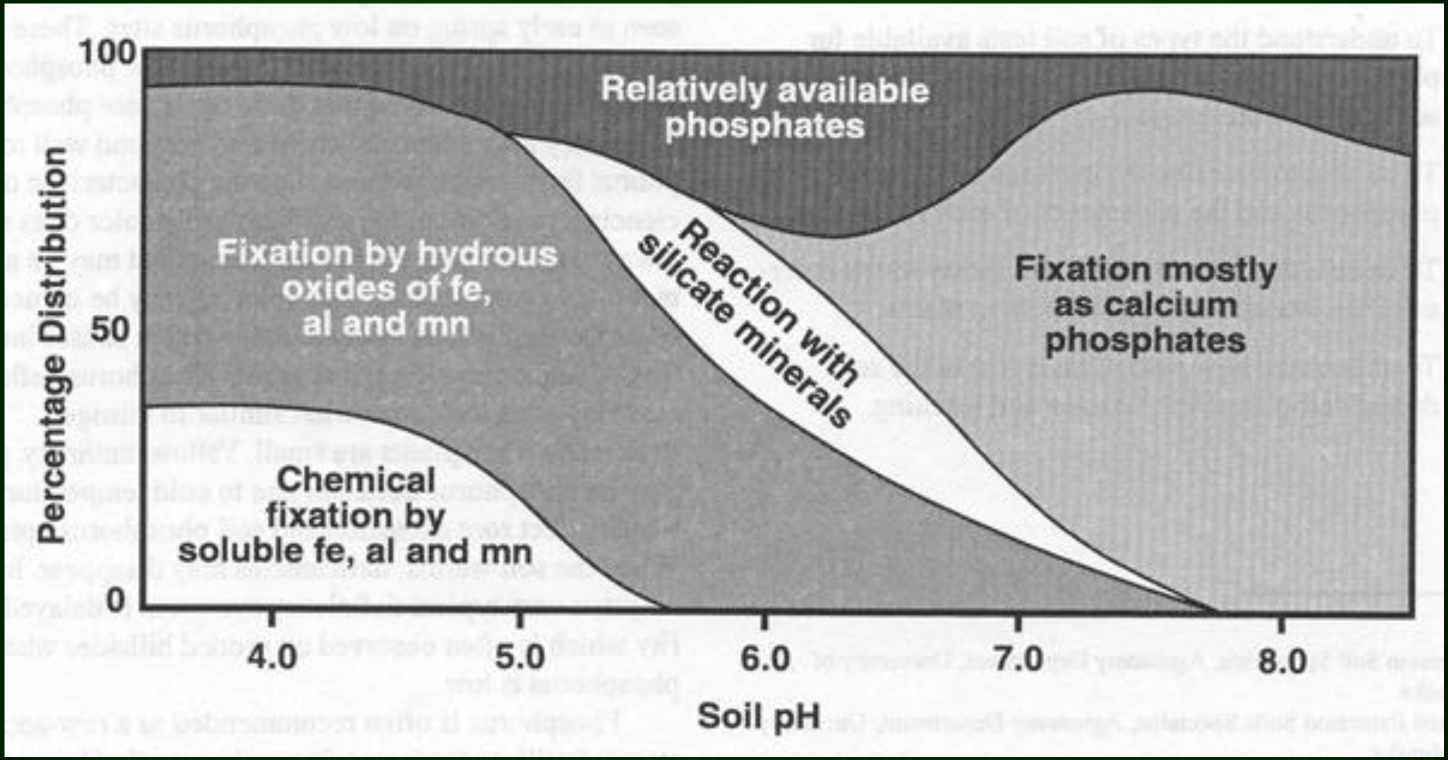
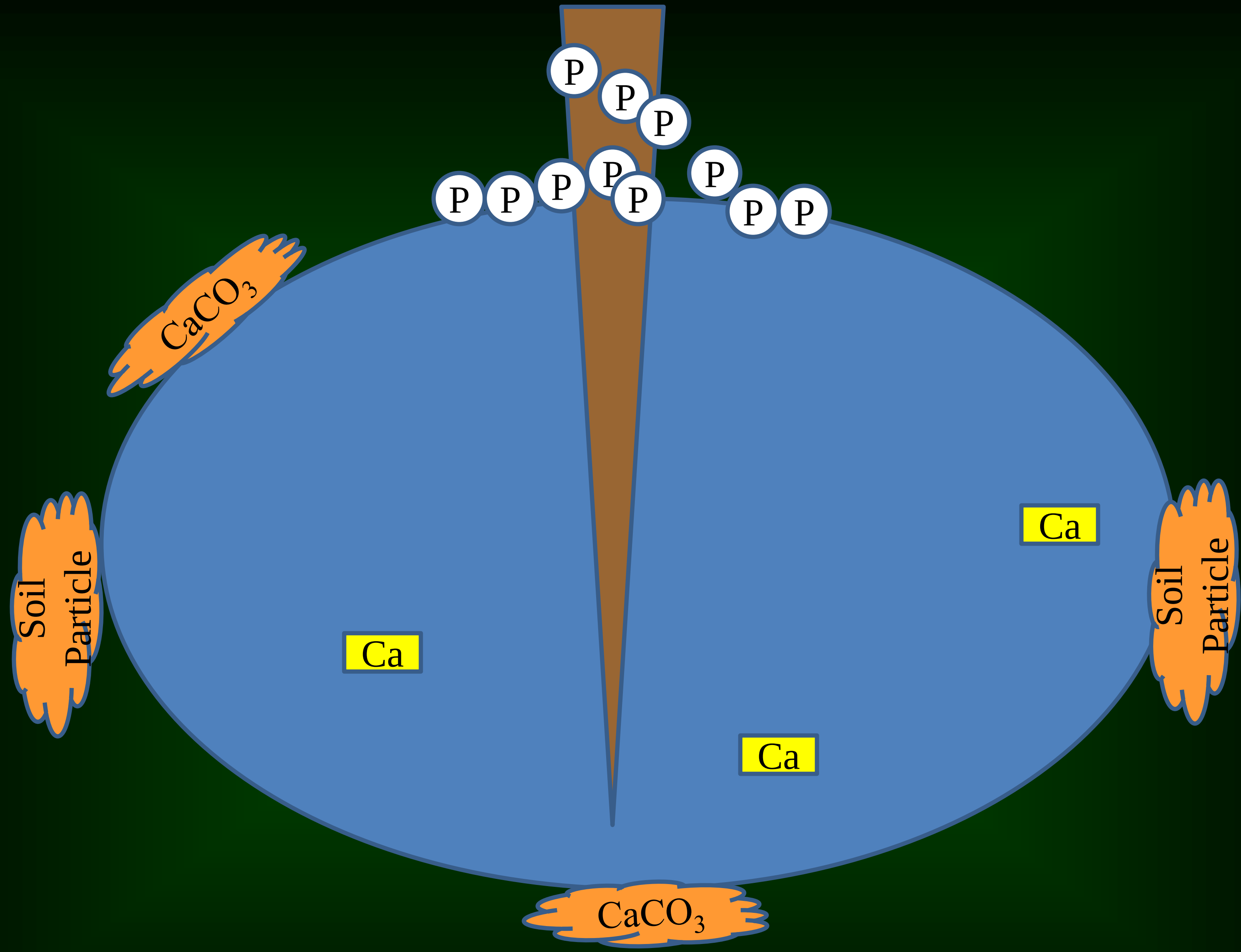


Image from plantandsoil.unl.edu/croptechnology/2005


P
P
P
P
P
P
P
P
P
P
P
P
CaCO3
Soil Particle
Ca
Ca
Ca
Soil Particle
CaCO3

Soil P Chemistry

- The crop might recover only 20-30% of the P applied
- What happens to the rest?
  - Some remains in Active P pool
  - Some chemically migrates to Fixed P pool
    - "P fixation capacity"
    - Amt and rate of this migration depends on soil characteristics/properties.

Dicalcium-P → Octacalcium-P → Tricalcium-P → Hydroxyapatite → Fluorapatite

→ Increasing Time

→ Decreasing Solubility

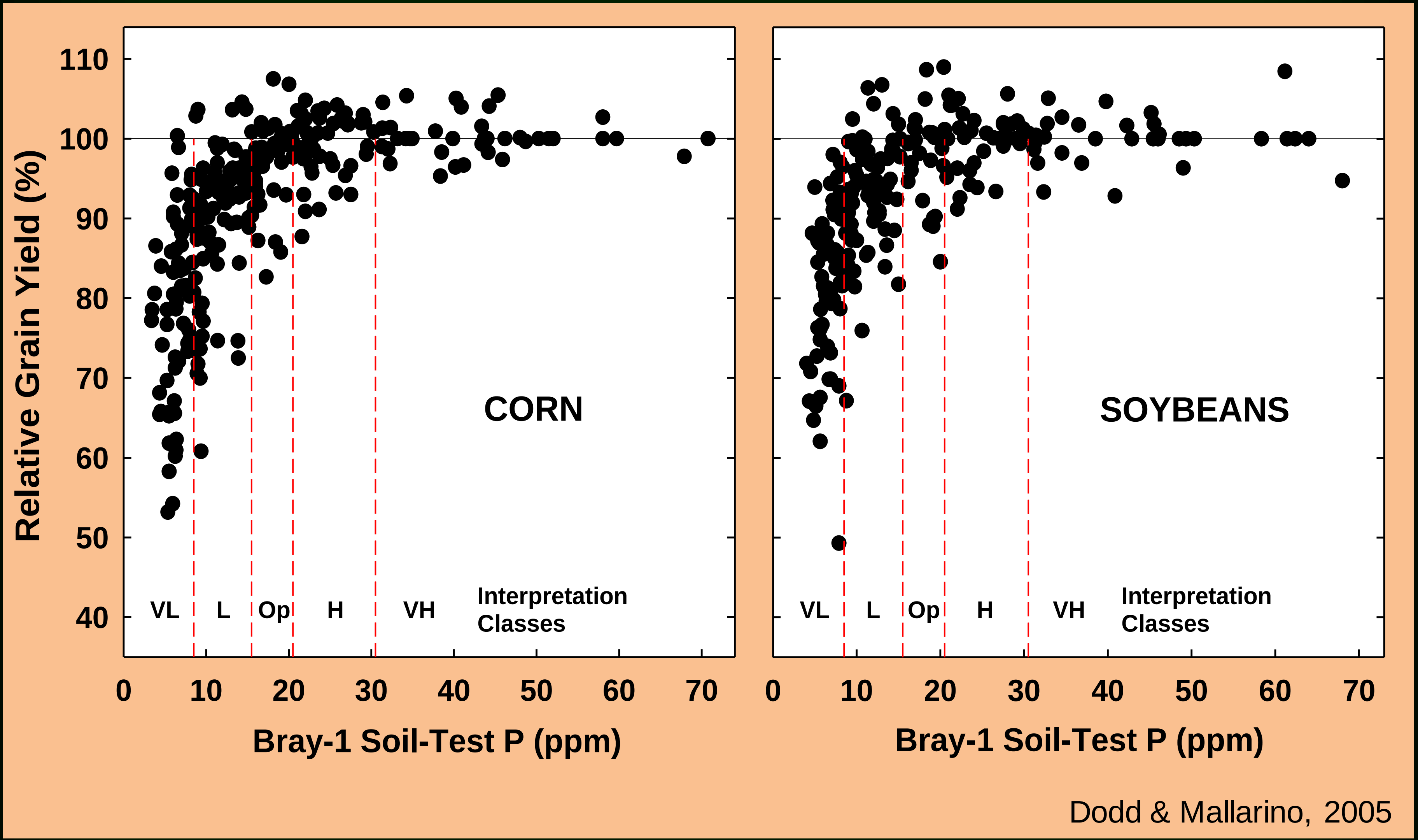
How do we know if we need to add fertilizer?

- Soil Testing for P
  - Soil Samples
    - Send to laboratory for Analysis
  - Chemical extractant and extracting procedure
    - Extracts P from the soil sample (ppm P)
  - Many extractants and procedures available
    - Only a few are useful
      - Tested through extensive research: Correlation and Calibration
        - » Extracted P must correlate with crop growth
        - » Extracted P indicates likely response to fertilizer
  - In Minnesota:
    - Bray P1 used on soils with pH less than 7.4
    - Olsen $NaHCO_3$ used on soils with pH 7.4 or greater

Soil Testing for P

- P Soil Test:
  - Not a direct measure of labile or total P
  - It’s an index value
- P Soil Test does not predict yield!
  - Predicts probability of response to applied fertilizer
- Field Calibration gives meaning to P Soil Test Value
  - Critical value
  - Interpretation class
  - Fertilizer rates when STP in responsive range

Example of STP Calibration



Slide courtesy of Antonio Mallarino, ISU

Minnesota STP Categories

	STP Category				
Extractant	Very Low	Low	Medium	High	Very High
	---------- ppm P extracted ----------				
Bray-P	0-5	6-11	12-15	16-20	21+
Olsen-P	0-3	4-7	8-11	12-15	16+

Probability Crop will Respond to Fertilizer

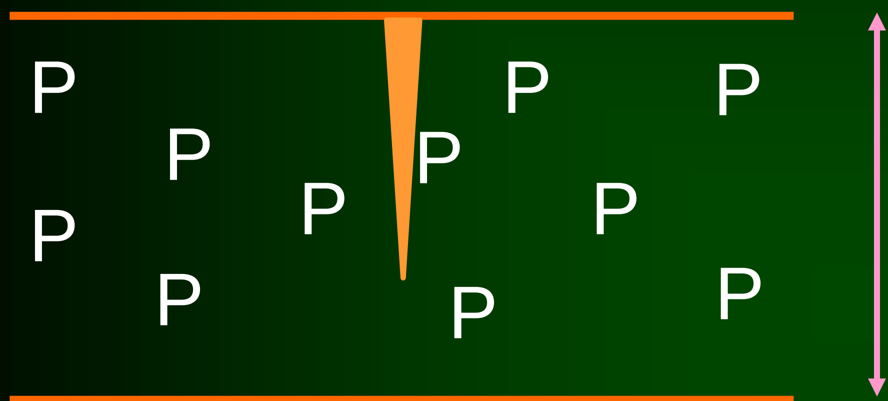
STP Category	**Iowa**	**Wisconsin**	**North Dakota**
	----------- % probability ---------		
Very Low	> 80	> 90	> 80
Low	65	60-90	50-80
Optimum/Medium	25	30-60	20-50
High	5	5-30	10-20
Very High	< 1	< 5	< 10

How Much Fertilizer based on Soil Test P

		------- STP (ppm P) --------									
		V. Low		Low		Medium		High		V. High	
Bray P		0-5		6-10		11-15		16-20		21+	
Olsen P		0-3		4-7		8-11		12-15		16+	
Yield goal		Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band
-- bu./A --		---------- P_2O_5 per acre to apply (lbs. per acre) --------									
< 100		60	30	40	20	25	20	15	10-15	0	10-15
100-124		75	40	50	25	30	20	15	10-15	0	10-15
125-149		85	45	60	30	35	25	15	10-15	0	10-15
150-174		100	50	70	35	40	30	15	10-15	0	10-15
175-199		110	55	75	40	45	30	15	10-15	0	10-15
200+		120	60	85	45	50	35	15	10-15	0	10-15

Band vs Broadcast

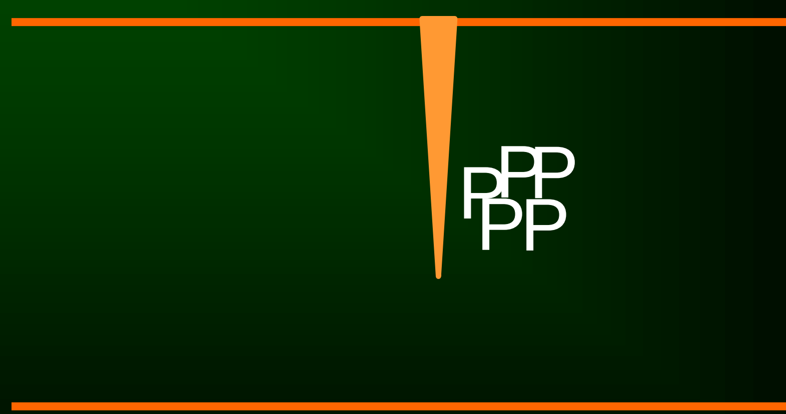
Broadcast



Soil Surface

Depth of Incorporation

Band



Banding used less P

Increased P Concentration Gradient

Placed P closer to plant root

Perhaps reduces P exposure to soil P fixing capabilities

Band vs Broadcast P Fertilizer

P^{32} Trial

	Sampling times		
lbs. P_2O_5/acre	1	2	3
	------ % P from fertilizer ------		
20 band	23.8	13.4	11.9
40 bdcst	2.8	5.1	8.6
80 bdcst	4.4	7.5	11.8

Caldwell and MacGregor: adapted from G. Rehm, Feb 24, 2009, Agbuzz, Univ. of Minn.

The Philosophy

Two Main Philosophy of P Management

- Sufficiency Philosophy
  - Fertilizer the Crop
  - Apply what the crop will need this year
- Build and Maintain Philosophy
  - Fertilizer the Soil
  - Build STP level to or above critical level
    - Maintain STP at that level
- Both use Soil Test P
  - Use it for different objectives

Sufficiency Philosophy

- Soil Test P (STP) used to:
  - Determine if fertilizer is needed
  - Determine fertilizer rate to optimize production
- Generally requires vigilance in P management
  - Annual soil testing
  - Must make sure soil test represents the field
    - Soil sampling procedures
      - Whole field sample, zone sampling, grid sampling, etc.
- Fertilizing the crop
  - Allows for banding instead of broadcasting fertilizer
    - Can significantly reduce fertilizer input

Sufficiency Philosophy

- Lower STP
  - P recommendations tend to be liberal
    - Supply P for inherent soil needs
    - Supply P for the crop
- Higher STP
  - P recommendations tend to be conservative
- Over time, tends to build to and maintain medium STP level
  - Not necessarily the case in soils with HIGH P fixing capacity
- Relies on soil P reserves to contribute to crop

Build and Maintain Philosophy

- Presumes high level of P fertility will maximize crop production potential

- Soil Test P used to:
  - Monitor soil fertility level
  - P rates applied:
    - Amt required to build STP
    - Amt required to maintain STP
      - Frequently based on crop removal

- Less intensive management required
  - More tolerant of soil sampling errors
  - Mainly monitor the soil's fertility status

Build and Maintain Philosophy

- Fertilizing the Soil
  - Build STP to or above Critical value
  - Primarilty interested in STP response to fertilizer
    - Less interested in crop response to fertilizer
- Presumes to build and/or preserve soil P reserves
- Will not necessarily work on high P fixing soils

Economics

- Lets assume if P is limiting it is good economics to apply P fertilizer.
- The question is what is the most economical management philosophy by which that P fertilizer should be applied?

Long term trials in Nebraska and Minnesota

- Established plots
  - Soil samples sent to various soil testing labs anonymously
    - Commercial Labs
      - Primarily used Build and Maintain
    - University Labs
      - Primarily used Sufficiency
- Plots fertilized in strict accordance to recommendations.
  - Complete fertilizer program
    - Not just P fertilizer

Long term trials in Nebraska
(total fertilizer program)

	Mead		North Platte		Clay Center		Concord	
	--- Annual Average (1973-1980) ---							
	Bu/A	$/A	Bu/A	$/A	Bu/A	$/A	Bu/A	$/A
Lab A	160	65	169	52	191	65	94	26
Lab B	160	57	169	53	191	55	94	24
Lab C	160	75	169	67	191	61	94	30
Lab D	160	48	169	42	191	42	94	28
Univ.	160	34	169	24	191	30	94	12

Long term trials in Minnesota
(Total fertilizer program)

	Waseca	
	Total value (1980-1987)	
	Crop Value $	Fertilizer Cost $
Lab A	2657	436
Lab B	2676	547
Lab C	2659	344
Univ.	2666	295

Medium Soil Test Trial, WCROC
(Specific to P fertilizer)

Treatment	P_2O_5	Cost	Yield
	- lbs/acre -	- $/acre -	- bu/acre -
0 P	0	0	169
Crop Removal	49	22.05	174
U of M Bdcst	35	15.75	175
U of M band	25	11.25	175

Rehm: adapted from G. Rehm, Feb 24, 2009, Agbuzz, Univ. of Minn.

Economic Implications

- Data indicate Sufficiency is most economical approach
  - Similar crop yields --- lower fertilizer costs
  - Maximum return for $ spent on fertilizer
- Some argue these trials have little relationship to today
  - Yields are consistently higher than in 1970s & 1980's
  - More P is being removed in grain
    - 165 bu corn: approx. 72 lbs P_2O_5
    - 240 bu corn: approx. 105 lbs P_2O_5
  - Are current yield levels sustainable if we do not replace P removed in the crop?

Economic Implications

- Sufficiency recommendations
  - STP is medium
    - 165 bu: Prate = 40 lbs P_2O_5
    - 240 bu: P rate = 60 lbs P_2O_5
    - Monitor STP
      - If STP lowers, increase P rate
      - If STP increases, decrease P rate

- Build and Maintain recommendations
  - Assume STP built to critical or target level
    - 165 bu: Prate = 72 lbs P_2O_5 +
    - 240 bu: Prate =103 lbs. P_2O_5 +
      - STP will monitor status

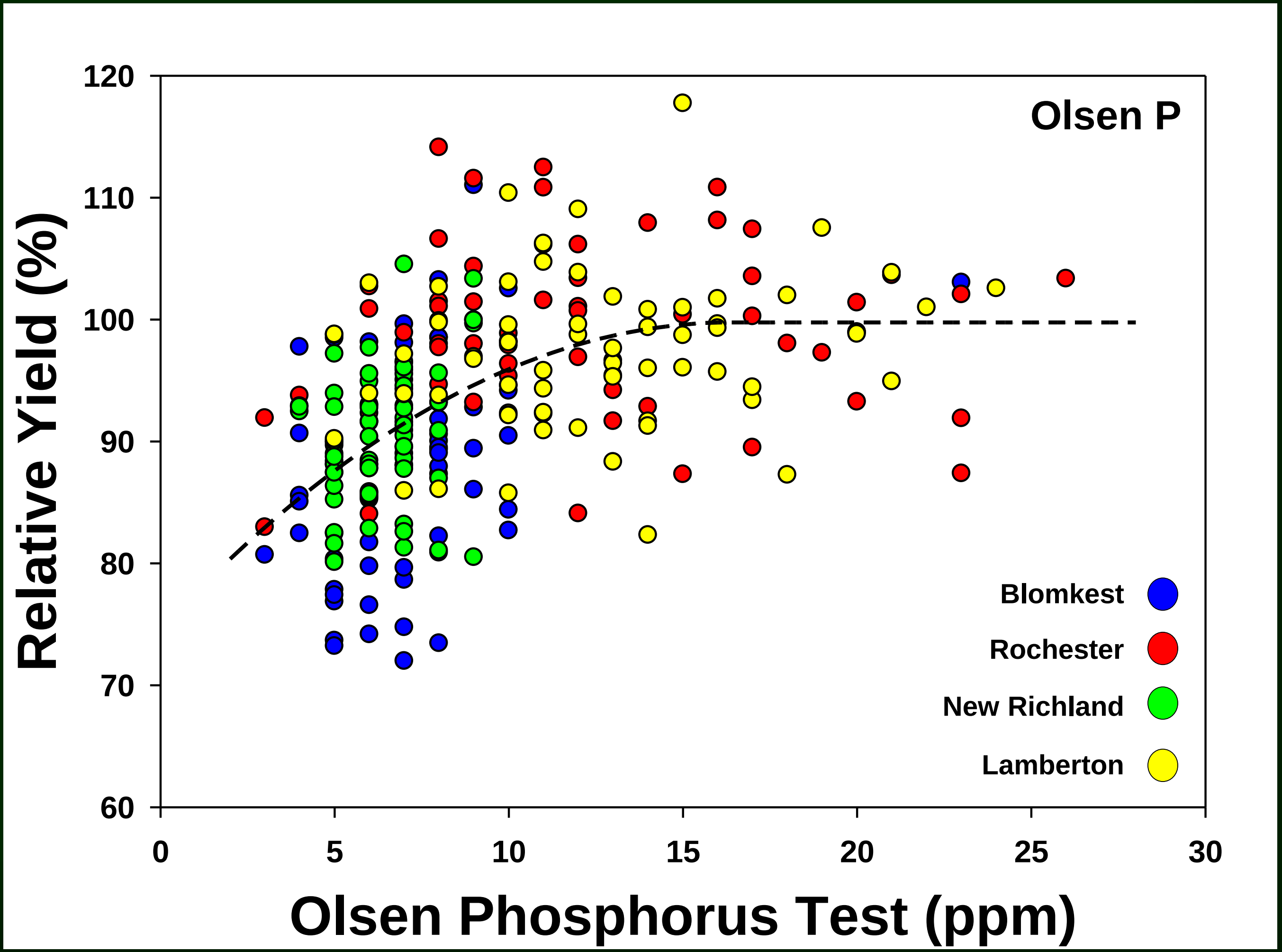
Economic Implications

- Current research shows both will get you production
- Current research suggests Sufficiency is more economical
  - $ return for $ spent on P fertilizer
- Build and Maintain is less management intensive
  - Is it worth the extra $ on fertilizer?
- Which philosophy to use?
  - It appears to be a business decision, not necessarily a scientific decision

Is one philosophy better than the other?

- Several Questions need to be answered
  - To what STP level should we build?
    - What is the critical value
      - Is it higher now than older research indicates?
  - Yield potential difference between the two philosophies?
    - Is there a yield potential difference between the two philosophies?
  - Long-term field trials are necessary to determine sustainability concerns

Current Minnesota Research



Kaiser et. al. 2012

Kaiser et al., 2012

		Relative Yield		
		95%	98%	100%
		---------------ppm---------------		
Bray-P1		9.7	15.0	18.3
Olsen-P		9.3	12.0	16.0
Mehlich-3		15.3	23.5	29.3

Is there a limit to how far we can go?

- Must be aware of the impact of our decision:
  - Economical considerations
  - Sustainability considerations
    - Both production and use of a limited resource
  - Impact on our surroundings
      - Surface water contamination with P

Environmental Implications

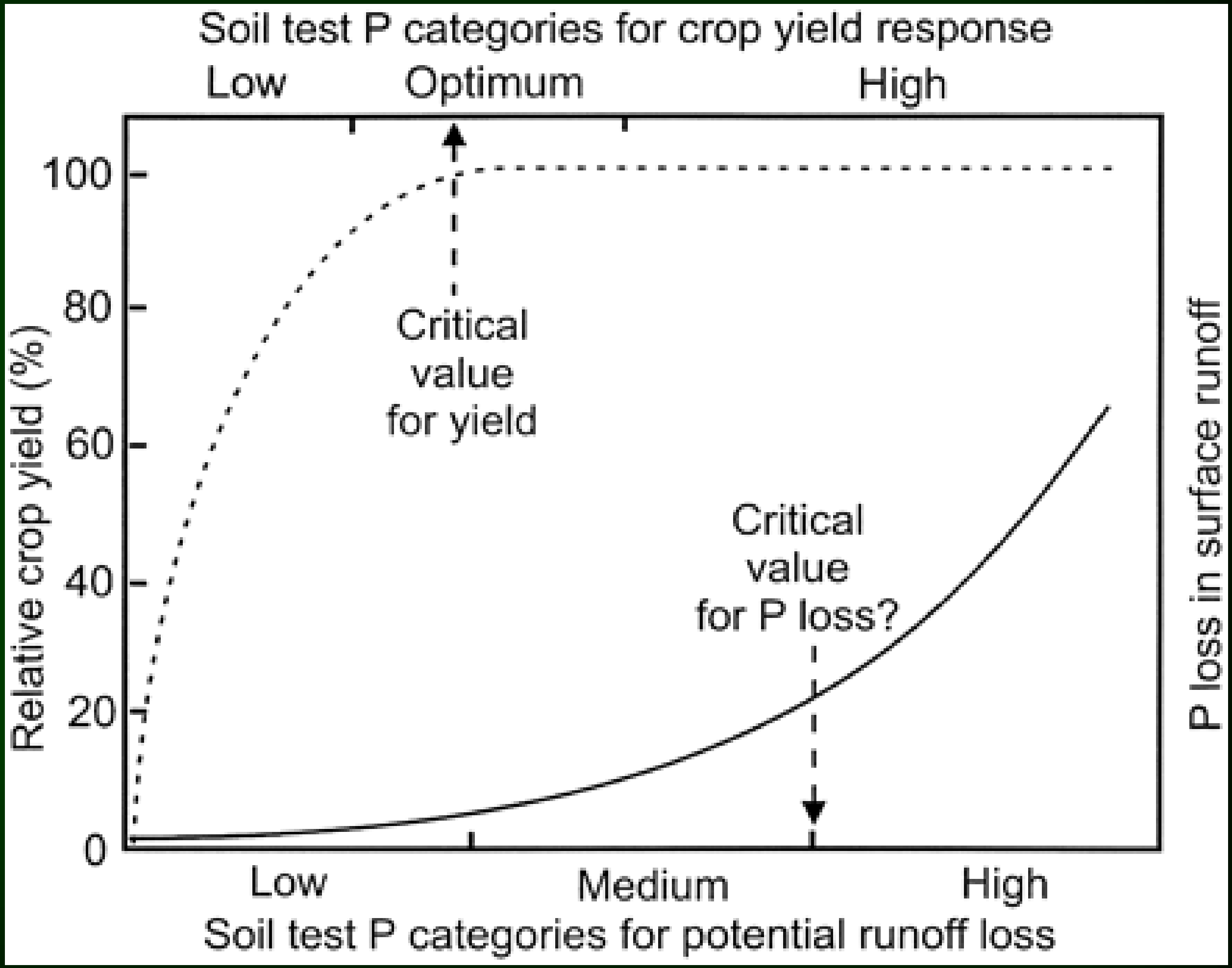
- Mainly concerned about P movement into surface waters.
  - Causes over growth of water algae and plants
    - Upon decomposition O_2 in the water is depleted

P moving off the field

- P movement in two forms
  - Soluble P
    - P diffusing into the flowing water
    - USUALLY FROM SURFACE 1-2 INCH OF SOIL
  - Particulate P
    - P attached to or precipitated in soil
    - Usually lost through erosion

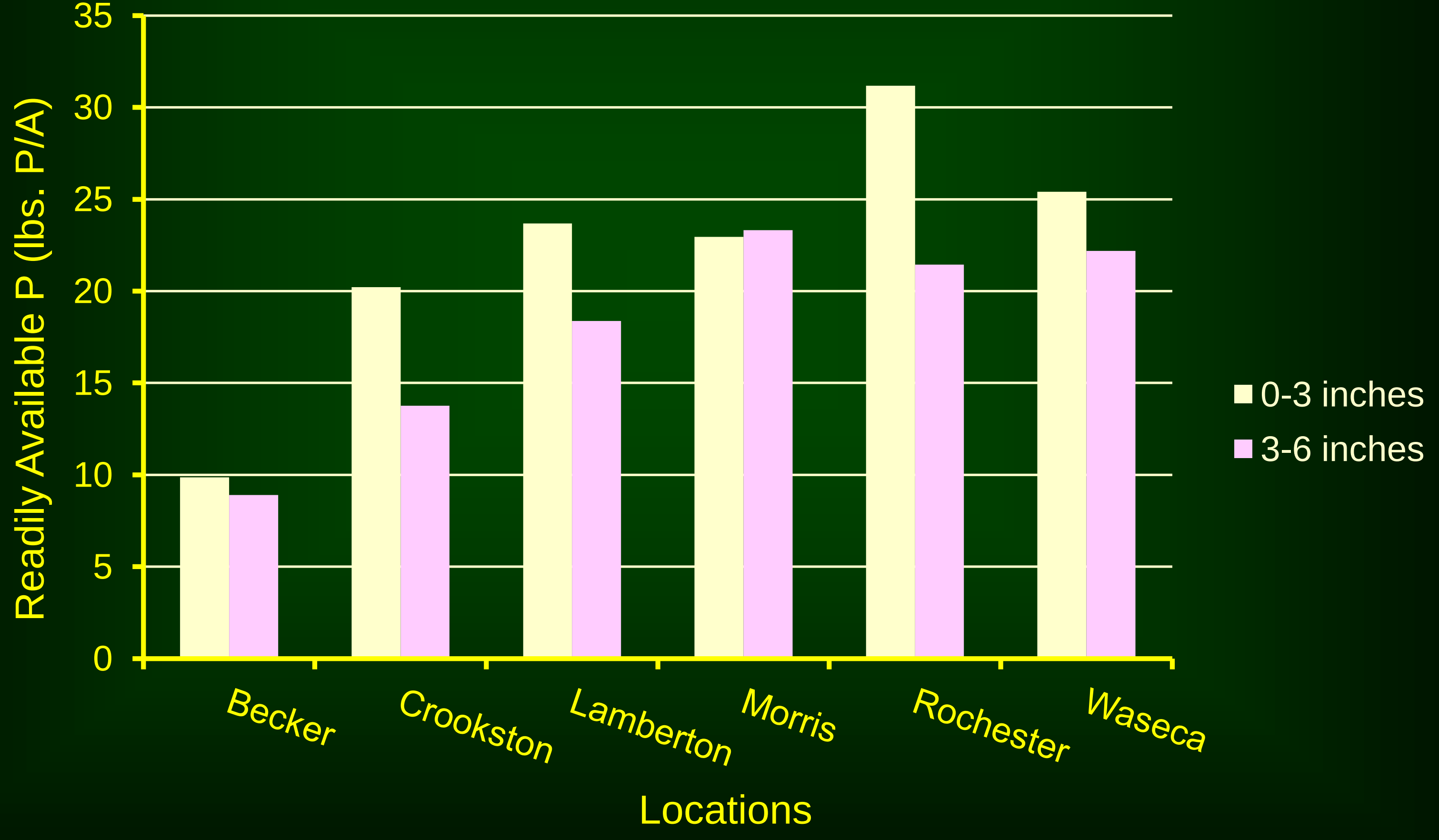
Critical STP (Crop Production vs P Runoff)

- Appears to be a separation of critical STP for crop production and that for P loss
- Use of Best Management Practices are essential
- STP for crop production is usually from surface 6 inches. P loss normally from surface 1-2 inches.



McDowell et. al. 2002.
Acquired from Hart et. al. 2004

Where in soil profile is P located



Sims et. al., 2012

Manage P to Optimize Production and Protect the Environment

- Best management practices
  - Manage STP levels
  - Reduced or limit water runoff and soil erosion
  - Make sure P is below the soil surface
- Be aware of other issues surrounding phosphorus
  - Depletion of rock phosphate resources
  - Environmental issues associated with manufacturing and shipping of P fertilizer
  - Increased P fertilizer costs

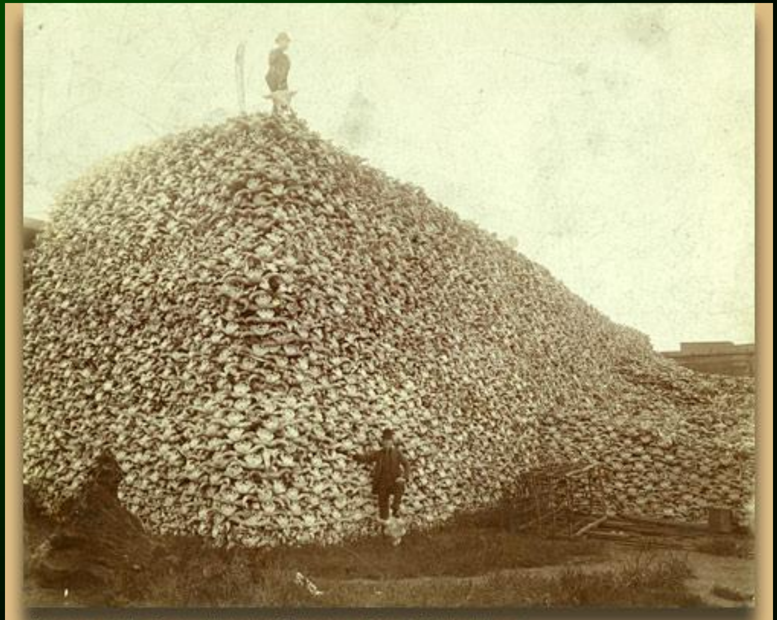
Phosphorus Fertilizers

- TVA was instrumental in developing modern P fertilizer industry.
- Phosphate Rock (mined) treated with strong acid
  - Results in more soluble P material
- Today most P fertilizers are ammonium phosphates
  - Liquids
  - Granule
  - All are highly soluble in the soil
    - Readily available

Phosphorus Fertilizers

- Phosphate Fertilizer Industry has had major impact on our culture

- Original fertilizers were organic
  - Manures
    - Farm animals
    - Guano from coastal island
      - Seabird poop
  - Bones
    - Crushed
    - Treated with Sulfuric Acid
      - P was more soluble


Courtesy of the Burton Historical Collection, Detroit Public Library

Phosphorous Fertilizers

- Manures shipped to England and North America
- Manures were dried and placed in containers before shipping
  - Lighter and better shelf life
  - Sometimes water got into the ship's cargo hold.
    - Water mixed with dry manure
      - Fermentation
      - Methane production
    - Once they realized what was happening, all containers were stamped with:
      - Stow High In Transit

S.H.I.T.