

Proceedings of the 10th Annual Nutrient Management Conference



Do not reproduce or redistribute without the written consent of author(s)



Phosphorus Management

Past, Present, and Beyond

What we know, what we need to know

PAULO PAGLIARI

EXTENSION NUTRIENT MANAGEMENT SPECIALIST

UNIVERSITY OF MINNESOTA

SOUTHWEST RESEARCH AND OUTREACH CENTER

LAMBERTON, MINNESOTA

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
 - H_2PO_4^- or HPO_4^{2-}
 - Deficiency determined by:
 - How much and how fast P gets to plant root
- 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 0.10% P
 - Very limited mobility in soil
 - Very little P in soil solution
 - Most P in soil solids
 - Labile P: readily supplies soil solution
 - Non-labile P: organic or inorganic P
- Solution, Labile, and Non-labile P in equilibrium
- Soil solution quickly depleted by crop
 - Must be quickly and readily resupplied
 - Buffering Capacity



P Movement to Root Surface

- Diffusion: How P moves to surface of plant root
 - P migration from area of high concentration (soil solution) to area of low concentration (root surface)
 - Concentration gradient
 - Diffusion rate increases
 - Increase concentration gradient
 - Soil temperature increases
 - Diffusion rate decreases
 - Decrease concentration gradient
 - Soil temperature is cool or cold



How Quickly P gets to Root Surface

- P diffuses over very small distances
 - P must be close to plant root
 - Plant root must grow towards the P

	Soil Temperature (° F)		
P rate	59	68	77
lbs P ₂ O 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.

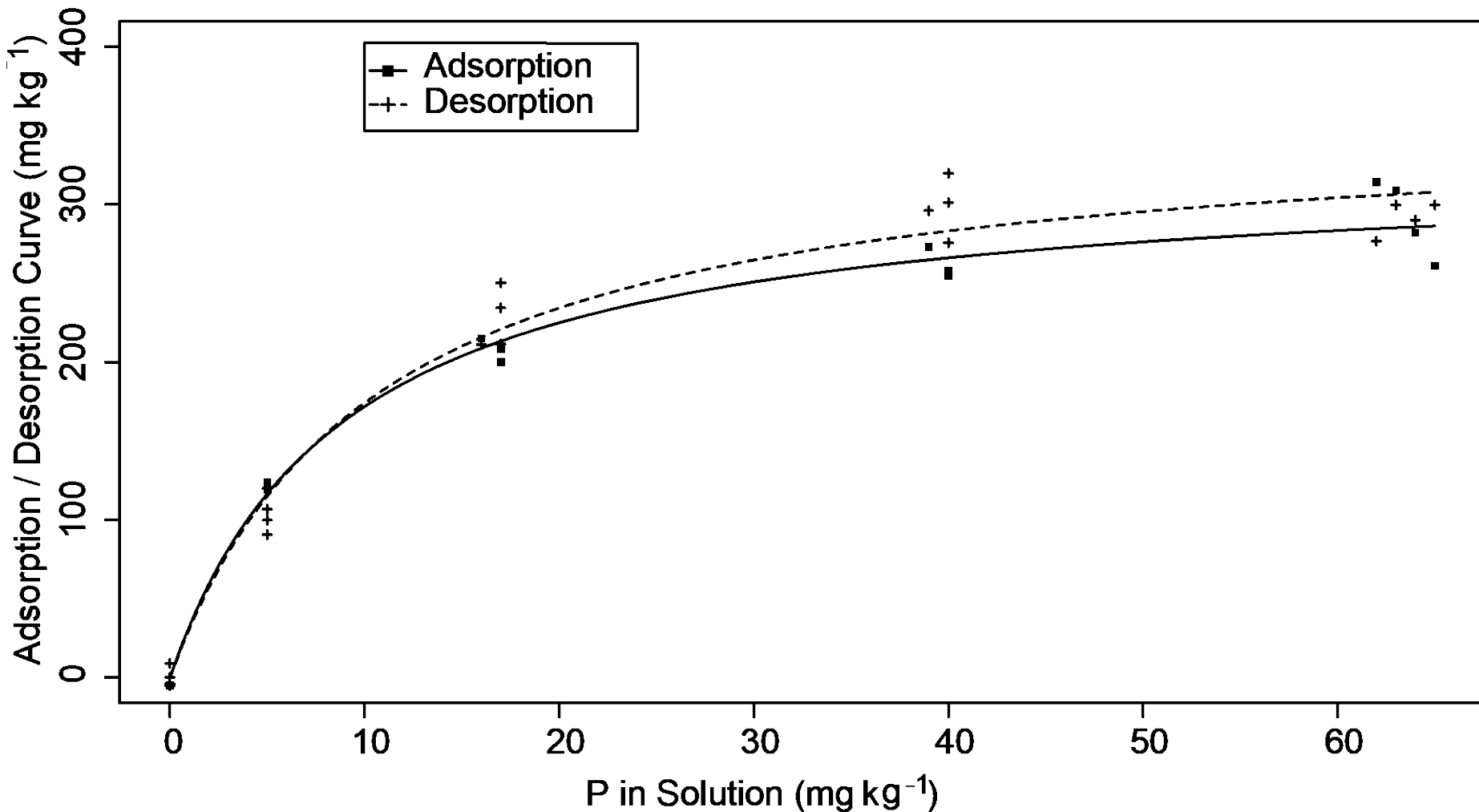


Soil P Chemistry

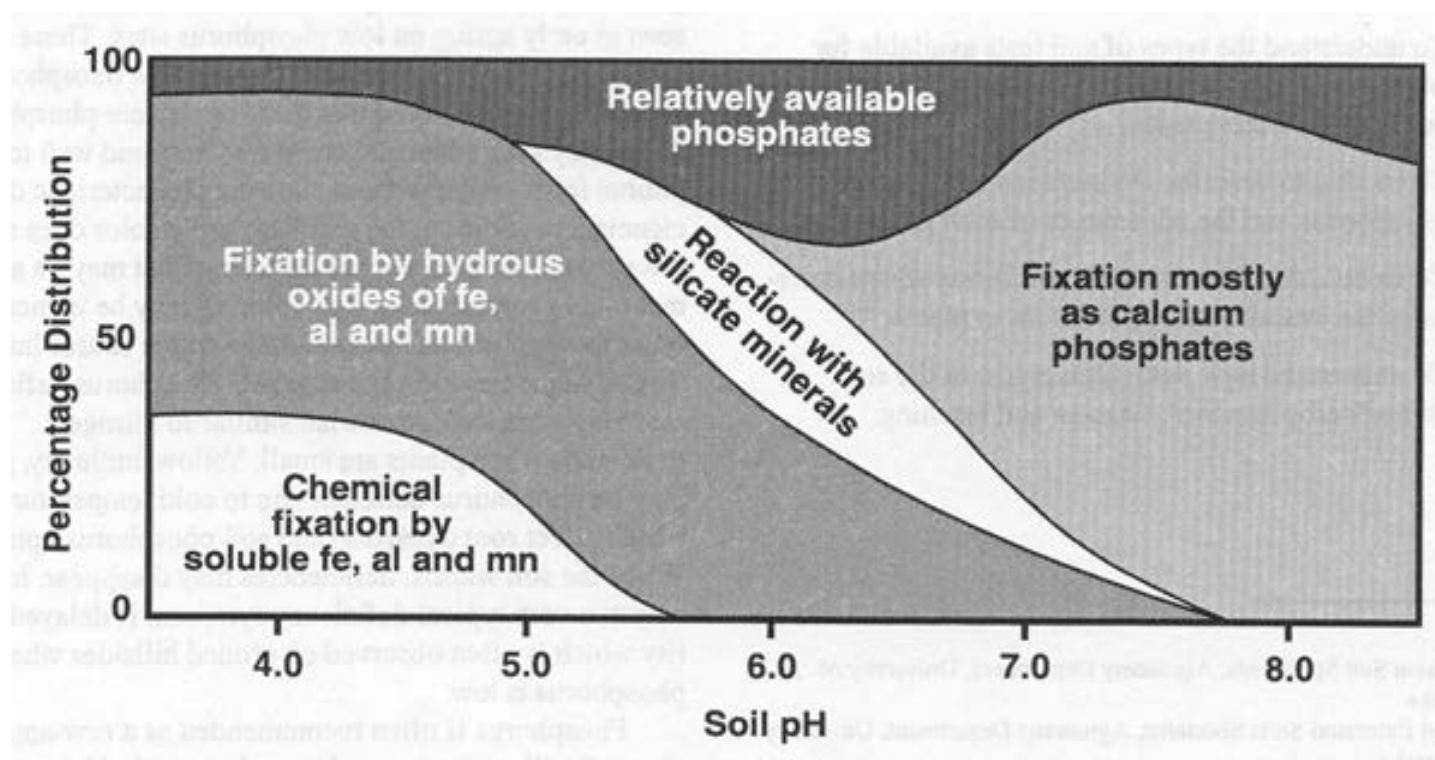
- Fertilizer increases solution P concentration
 - P rapidly leaves soil solution
 - Binds to surfaces of minerals
 - Precipitates (absorption into Ca-P, Al-P, Fe-P)
- Initially, bound and precipitated P readily re-solubilizes
 - Labile P
- In time, precipitated P can form new, less soluble compounds.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



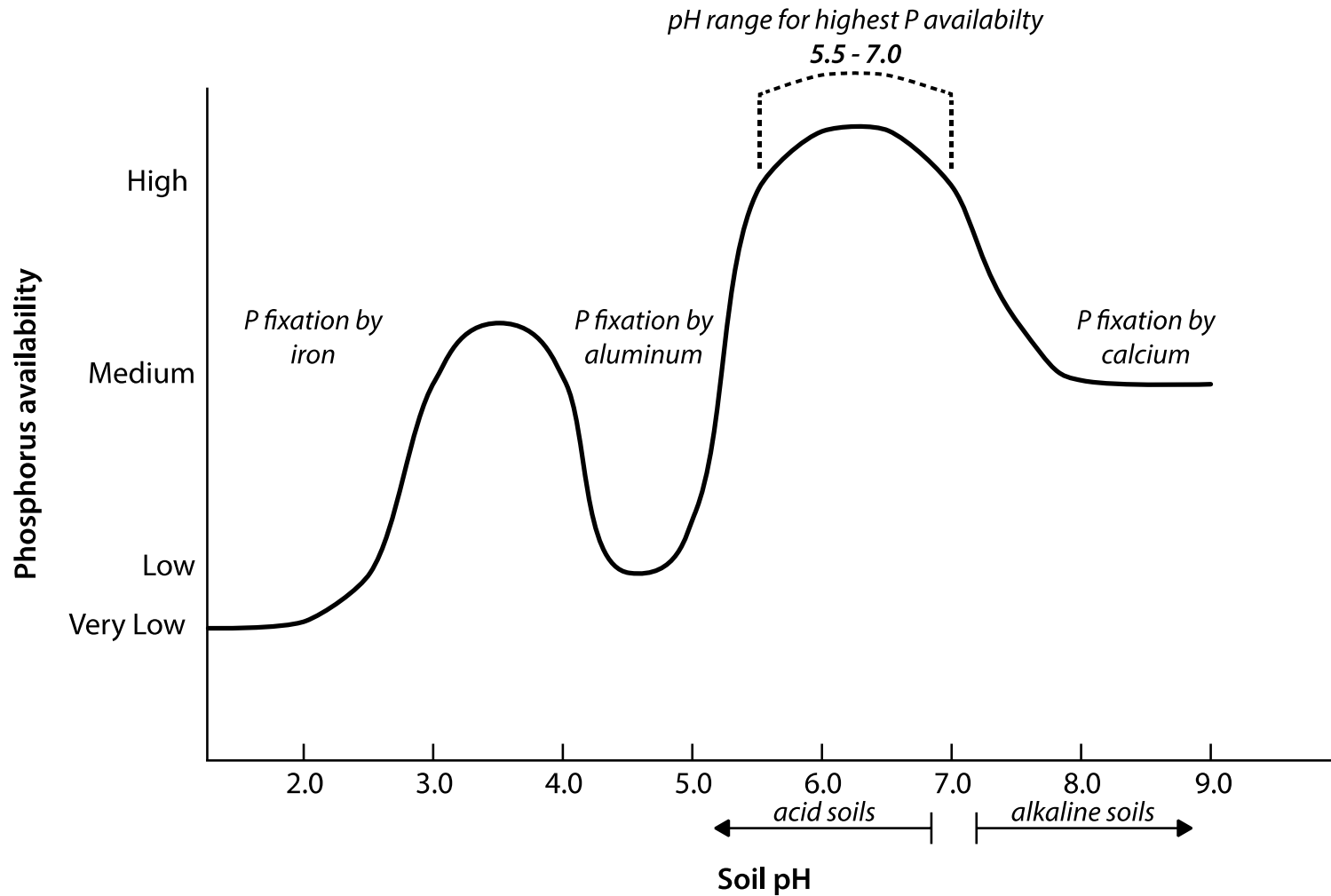
Relationship of Soil Solution P to P Sorption

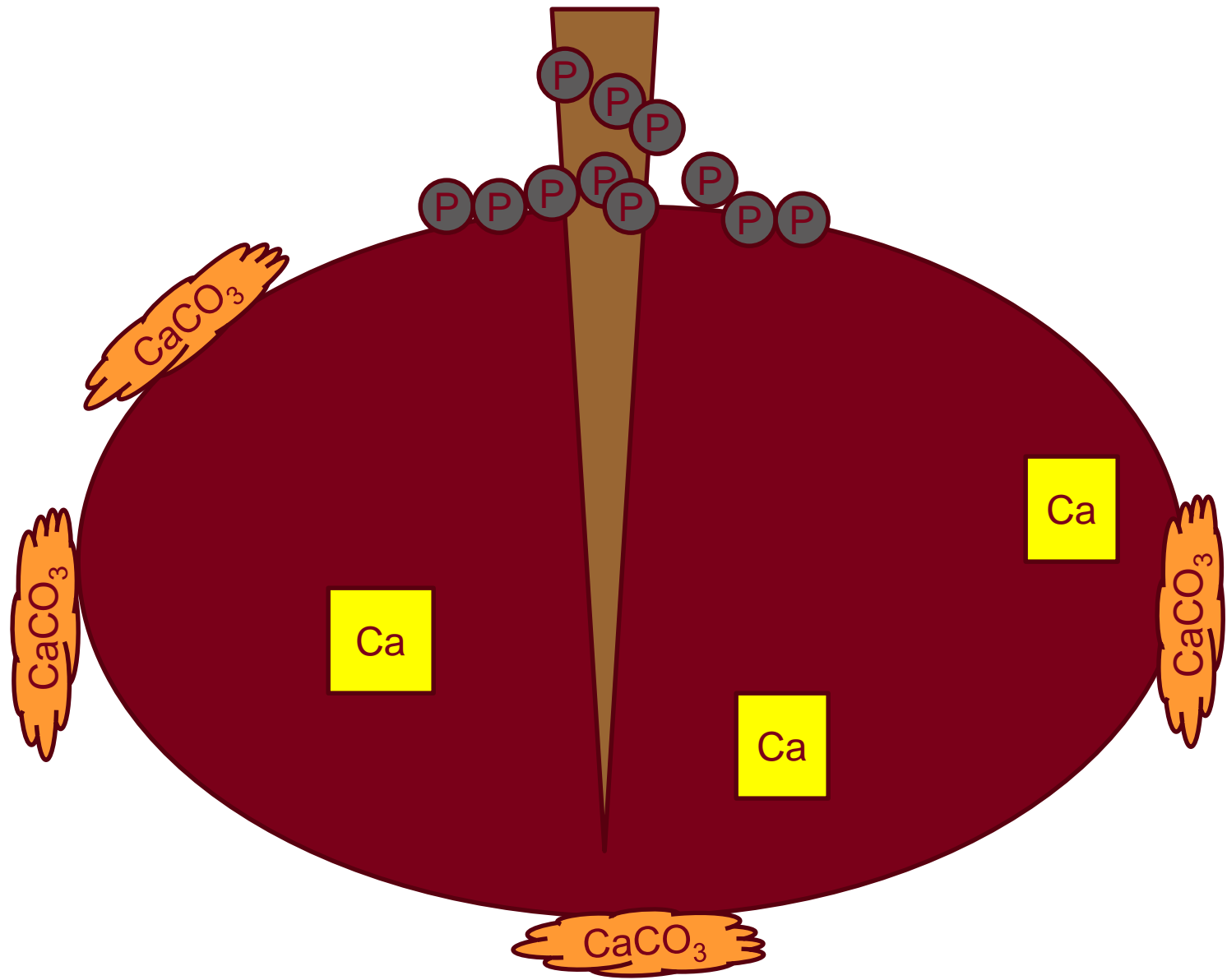


Phosphorus Availability and Soil pH



Phosphorus Availability and Soil pH





Soil P Chemistry

- The crop might recover only 20% of the P applied
- What happens to the rest?
 - Some remains in Labile P pool
 - Some chemically migrates to Non-labile P pool
 - “P fixation capacity”
 - Amount and rate of this migration depends on soil characteristics/properties.

Dicalcium-P Octacalcium-P Tricalcium-P Hydroxyapatite Fluorapatite



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)



How do we know if we need to add fertilizer?

- 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 7.5
 - Olsen NaHCO_3 used on soils with pH 7.5 or greater

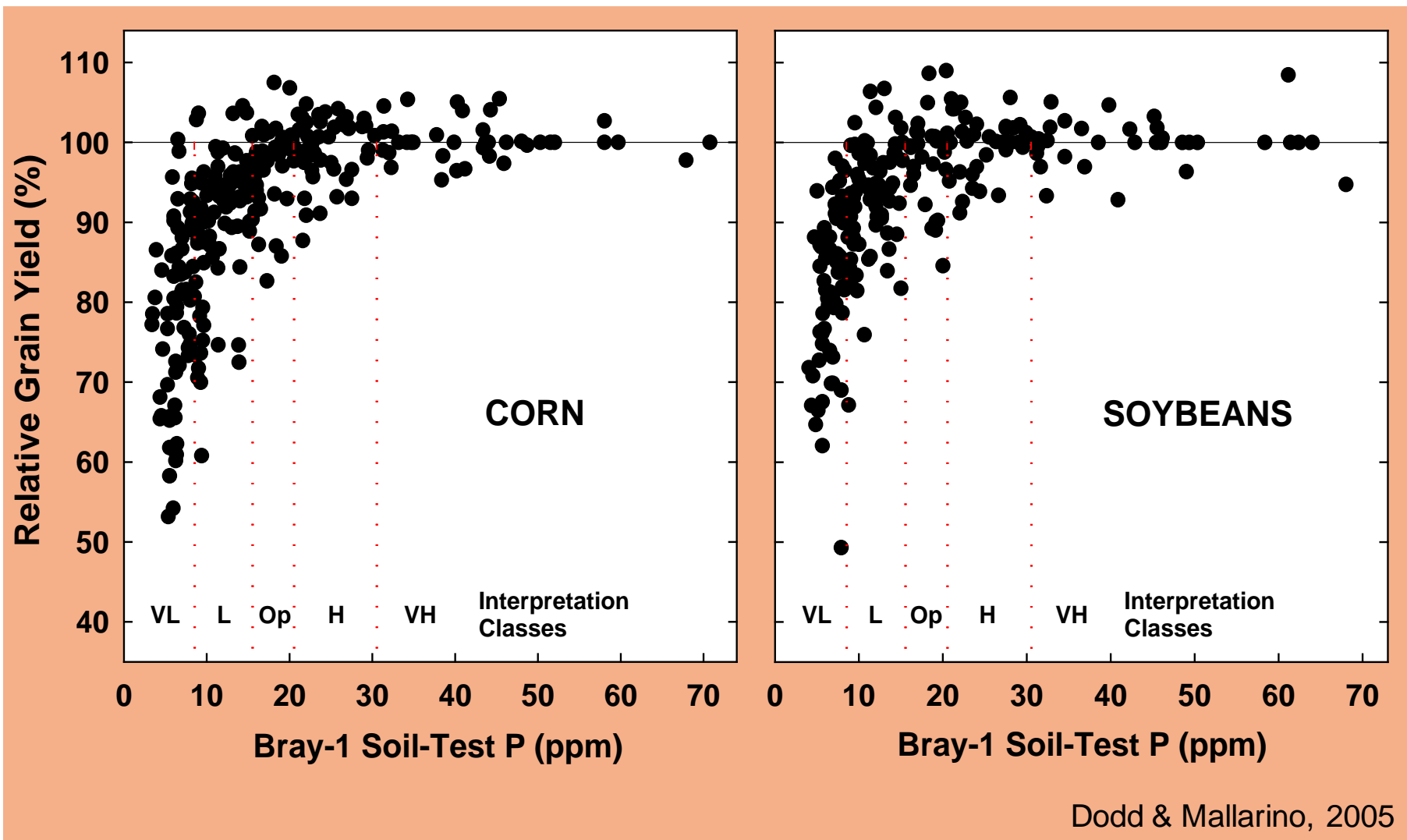


Soil Testing for P

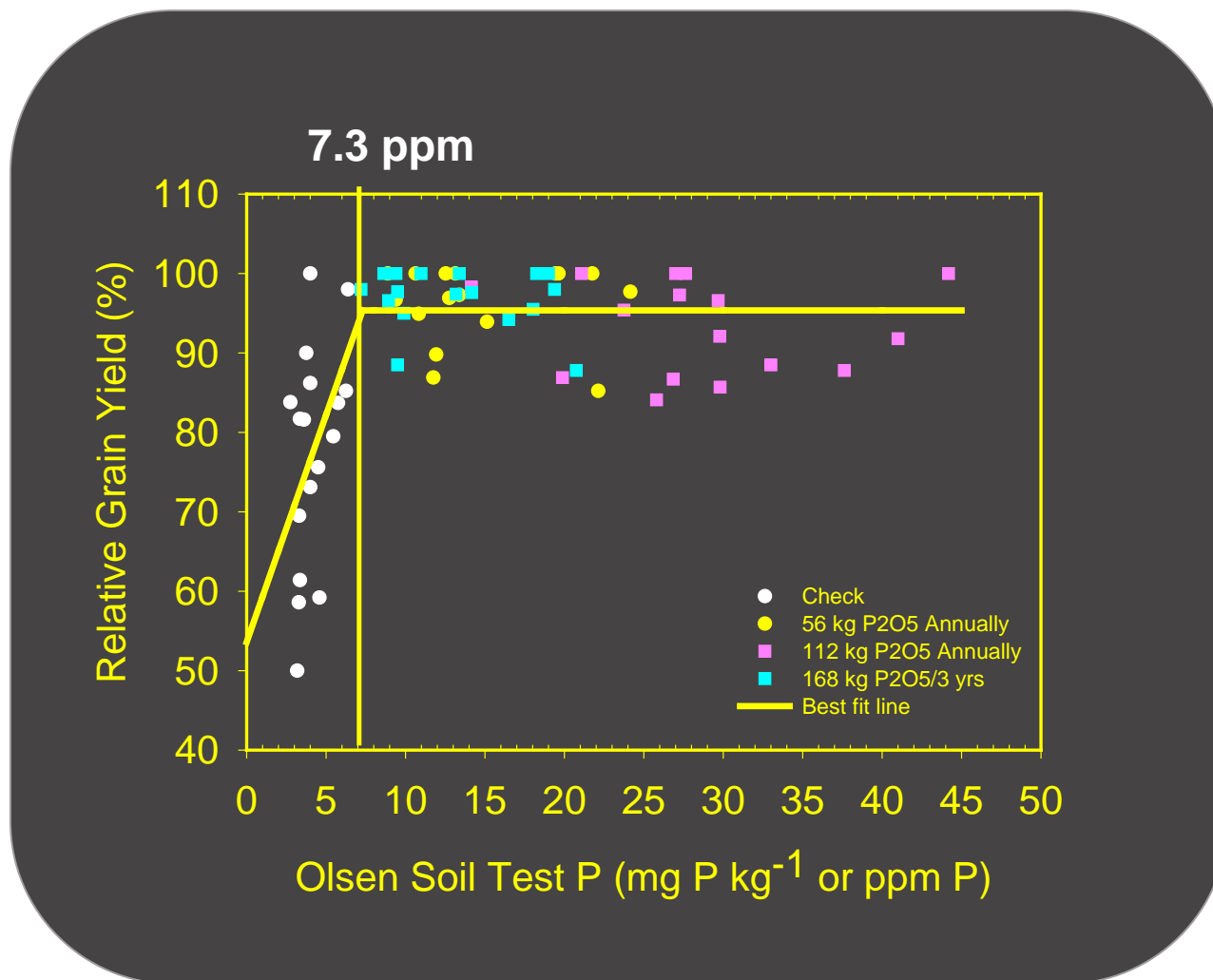
- P Soil Test:
 - Not a direct measure of labile or total P
 - It's an index value
- P Soil Test does not predict yield
 - Predicts probability of response to applied fertilizer
- Field Calibration gives meaning to P Soil Test Value
 - Critical value
 - Interpretation class
 - Fertilizer rates when STP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



Example of STP Calibration



Olsen STP Calibration



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 ₂ O ₅ lbs. 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	



The Philosophy



Two Main Philosophies 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 but they 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 greater vigilance in P management
 - Must soil test annually
 - 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



Band and Broadcast

- Broadcast:
 - Evenly spread P over soil surface and incorporate
 - P distributed over large volume of soil
 - Area (acre) plus soil depth

- Band:
 - P target applied in very small zone
 - P concentrated in small volume of soil
 - Usually concentrated with or near the seed row



Band vs Broadcast P Fertilizer

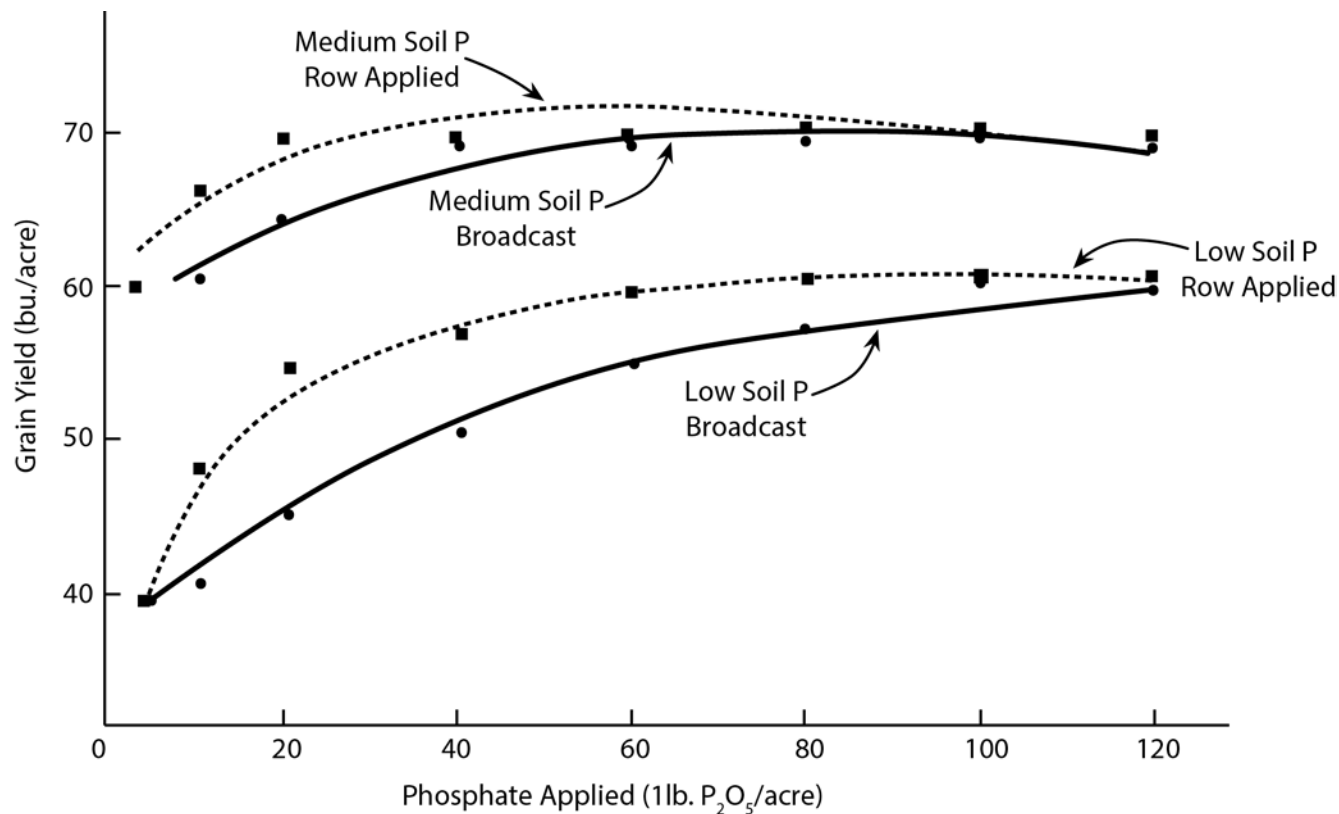
P³² Trial

lbs. P ₂ O ₅ /acre	Sampling times		
	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.



Band vs Broadcast Fertilizer P



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 productivity 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 vigilance required for P management
 - 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
 - STP response to fertilizer vs crop response to fertilizer
- Presumes to build and/or preserve soil P reserves
- Will not necessarily work on high P fixing soils



Build and Maintain Philosophy

- How much P fertilizer is required to Build STP?
 - Must be in excess of what crop removes
- Amount of P_2O_5 A^{-1} to increase STP one unit or ppm
 - Varies with Soil Chemistry (P fixing and buffering capacity), crop removal, and starting point (STP)

Reference	Lbs P_2O_5 / ppm STP
Peck et al. (1971) Illinois	18
Schulte and Kelling (1991) Wisconsin	9
Randall et al. (1997) Southern Minn	41 - 53
Sims and Lamb (Northwest Minn)	35



Economics



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



Long term trials in Nebraska

	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

Waseca			
Total value			
	Crop Value \$	Fertilizer Cost \$	Cost %
Lab A	2657	436	16
Lab B	2676	547	20
Lab C	2659	344	13
Univ.	2666	295	11



Medium Soil Test Trial, WCROC

Treatment	P ₂ O 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 P fertilizer
- Some argue these trials have no relationship to today
 - Yields are consistently higher than in 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



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

- Is the Build and Maintain Wrong?
 - No!
- Designed for overall management returns
 - Maintain high P fertility, can focus on other issues
 - Make sure P is never limiting
 - Low P fixing soils
 - Probably cost more \$ for fertilizer in long run
- Can't allow STP levels to get too high
 - Will become an environmental issue



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 (differs with crops)
 - In today's high yield environment,
 - is there a yield potential difference between High STP (little likelihood of fertilizer response) and lower STP (needed fertilizer applied)?
 - Do we need to redo the long-term fertilizer recommendation trials to fit today's high yielding environment?



Is one philosophy better than the other?

- At this point, it is a business decision!
 - 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?



Environmental Implications



Still a developing science

- P moving off the field
 - 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
- Best management practices
 - Manage STP levels
 - Prevent water runoff and soil erosion
 - Make sure P is below the soil surface



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 of Peru
 - Seabird poop
 - Bones
 - Crushed
 - Treated with Sulfuric Acid
 - P was more soluble



Courtesy of the Burton Historical Collection, Detroit Public Library



Thank you

Questions?

