# 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

$$\text{Soil Solution P} \rightleftharpoons \text{Labile P} \rightleftharpoons \text{Non-Labile P}$$

# 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

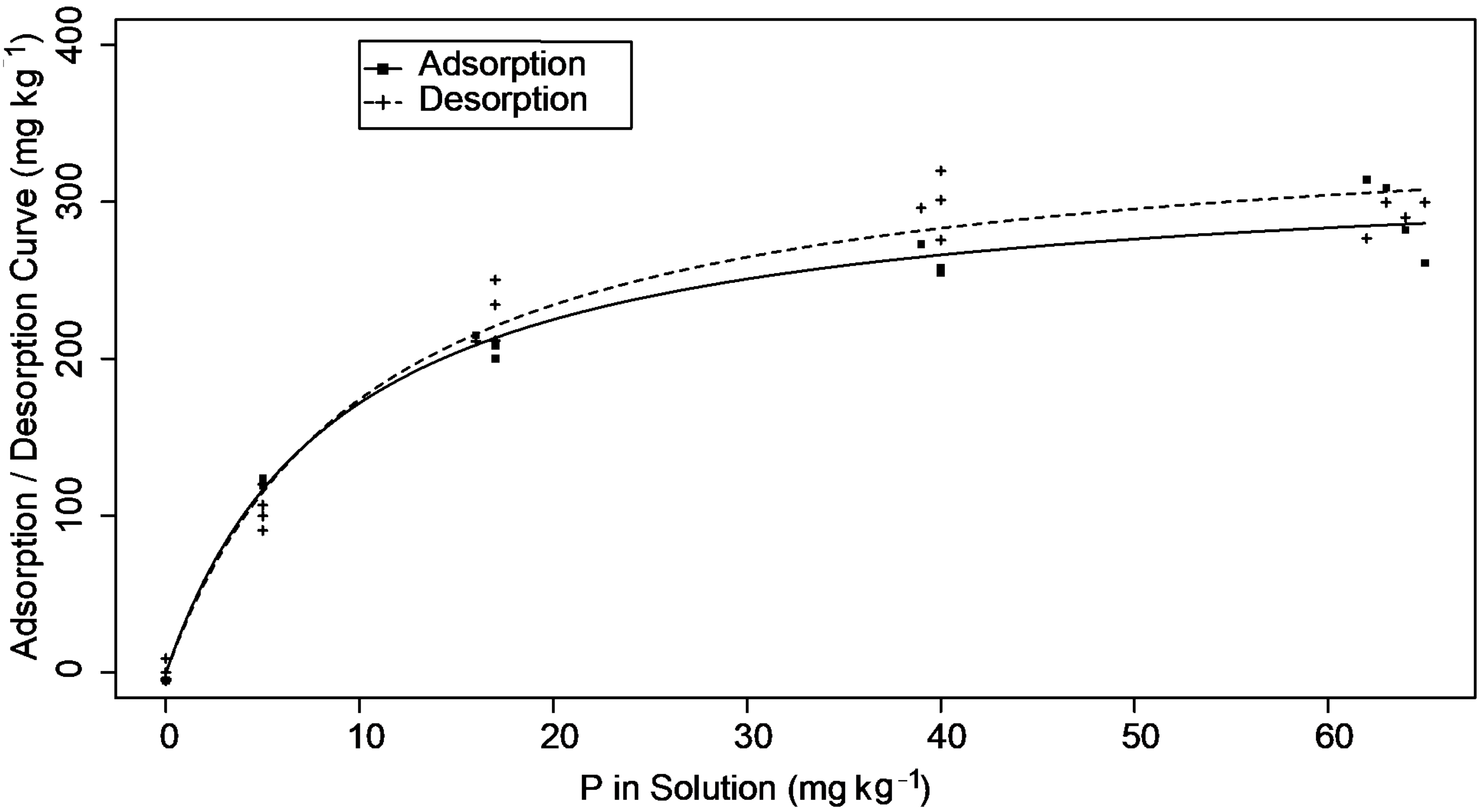
| | Soil Temperature (º F) | | |
|---|---|---|---|
| P rate | 59 | 68 | 77 |
| lbs $P_2O_5$/acre | ----- mg P/pot ----- | | |
| 35 | 3.5 | 10.4 | 18.0 |
| 70 | 6.7 | 13.5 | 19.6 |

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 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

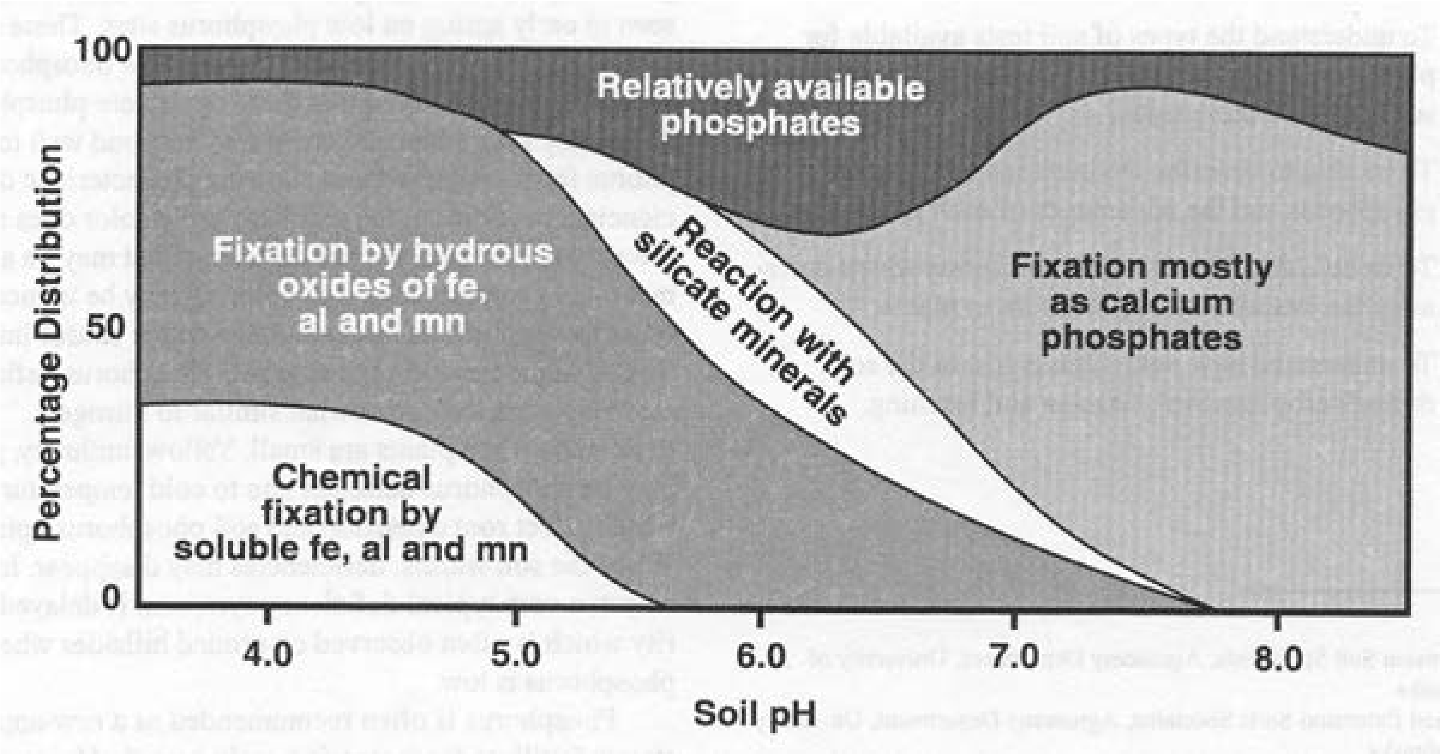
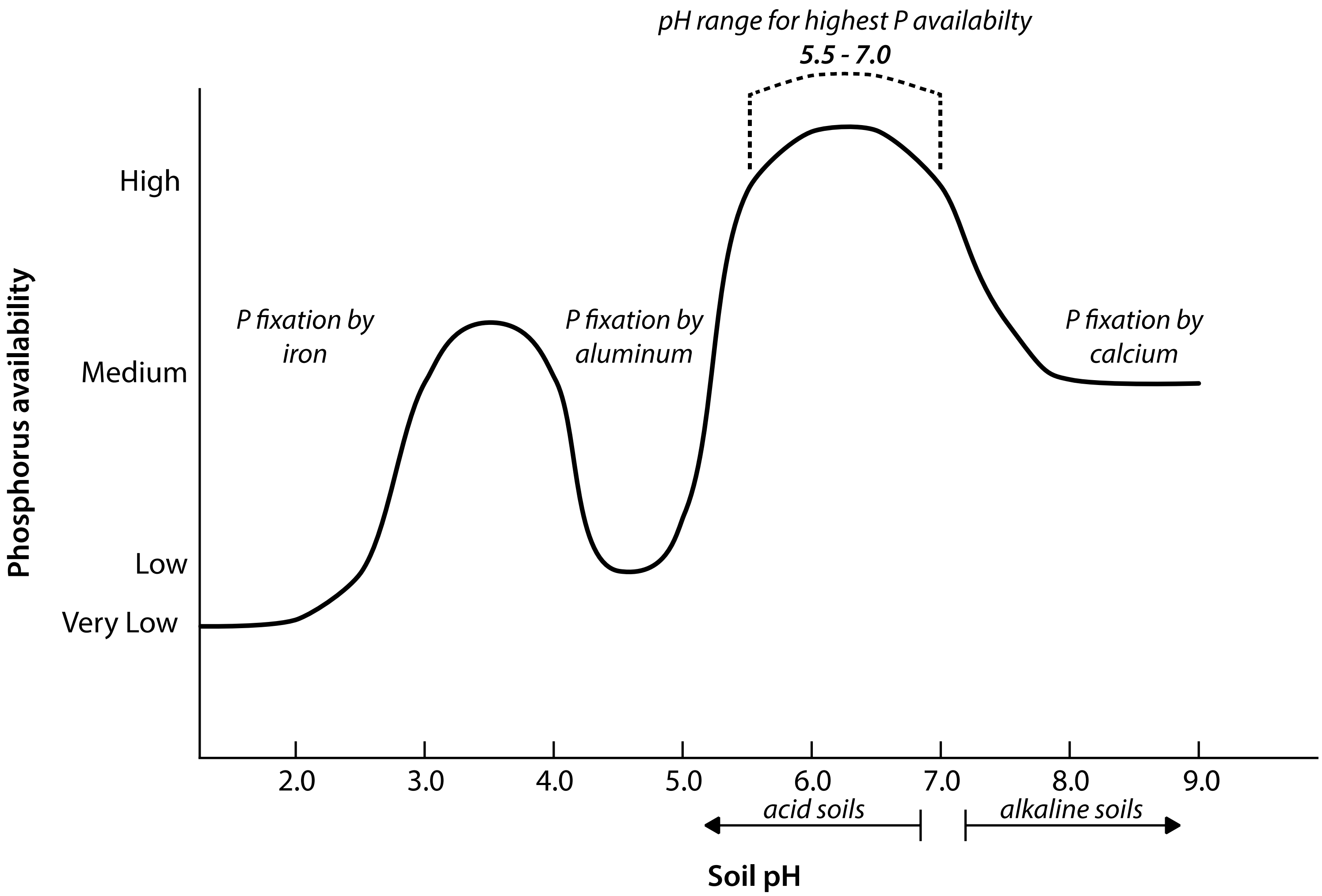
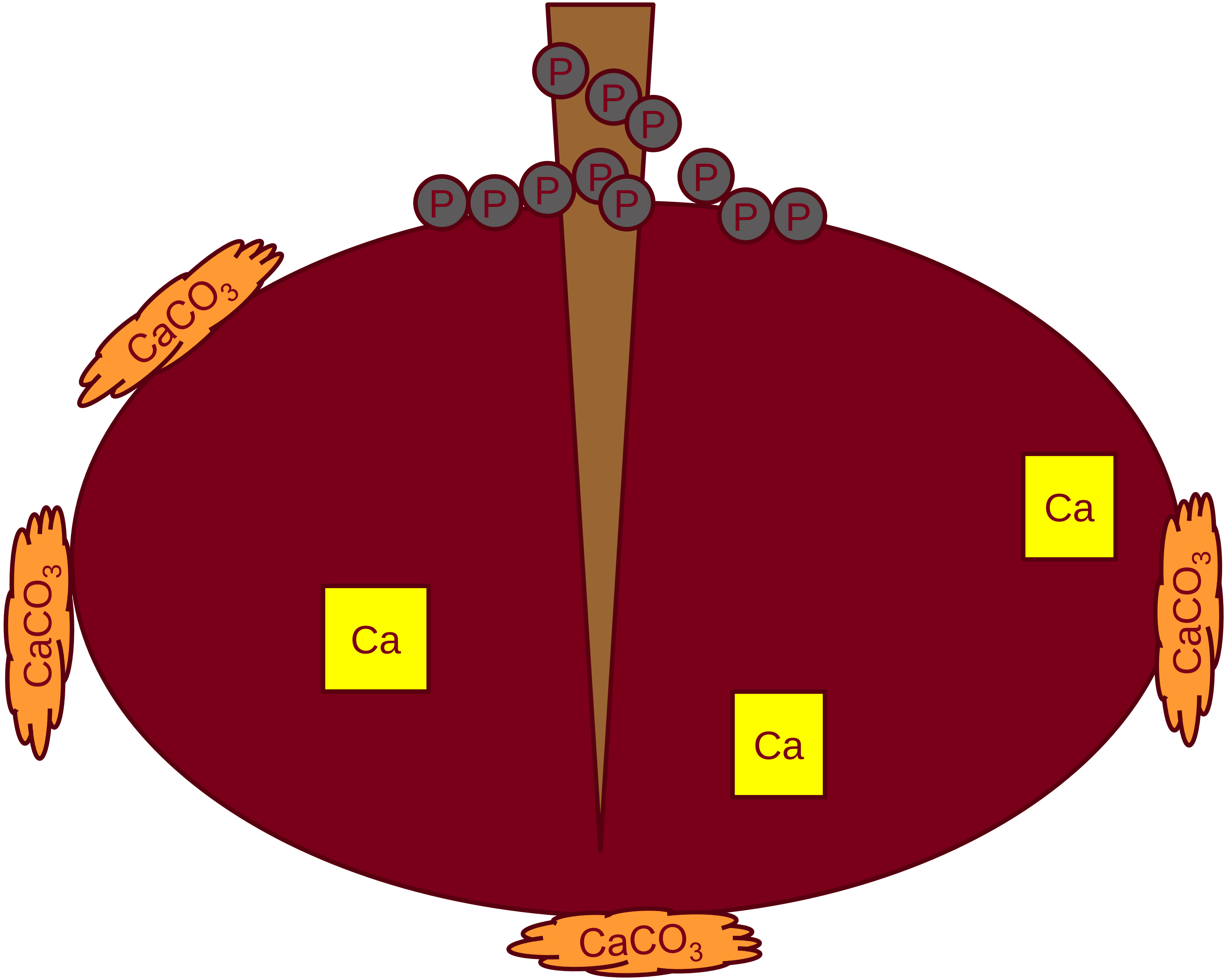



Image from plantandsoil.unl.edu/croptechnology/2005

# Phosphorus Availability and Soil pH




P
P
P
P
P
P
P
P
P
P
P
P
$CaCO_3$
$CaCO_3$
Ca
Ca
Ca
$CaCO_3$
$CaCO_3$

# 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

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)

# 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

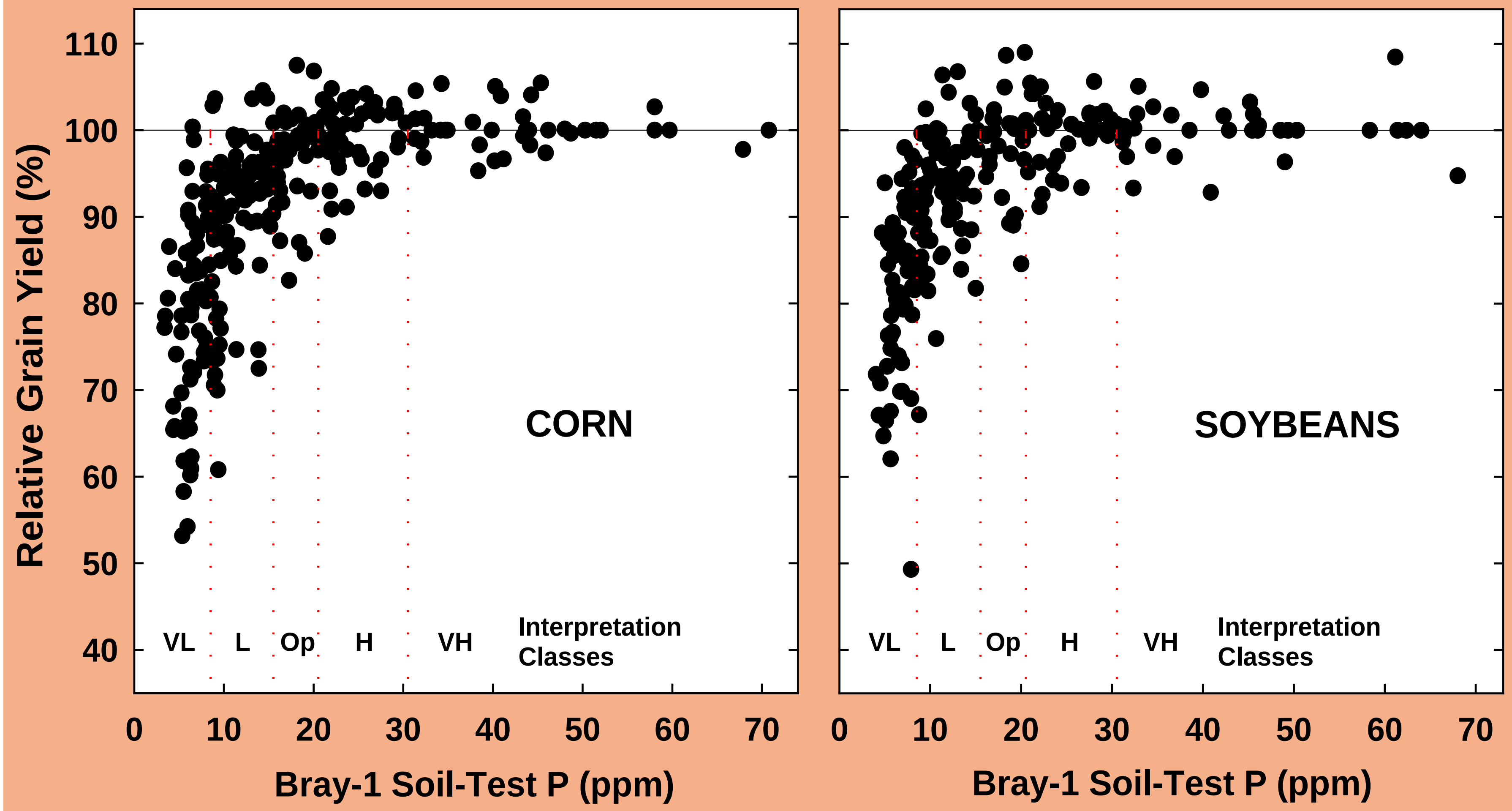
# Soil Testing for P

- 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

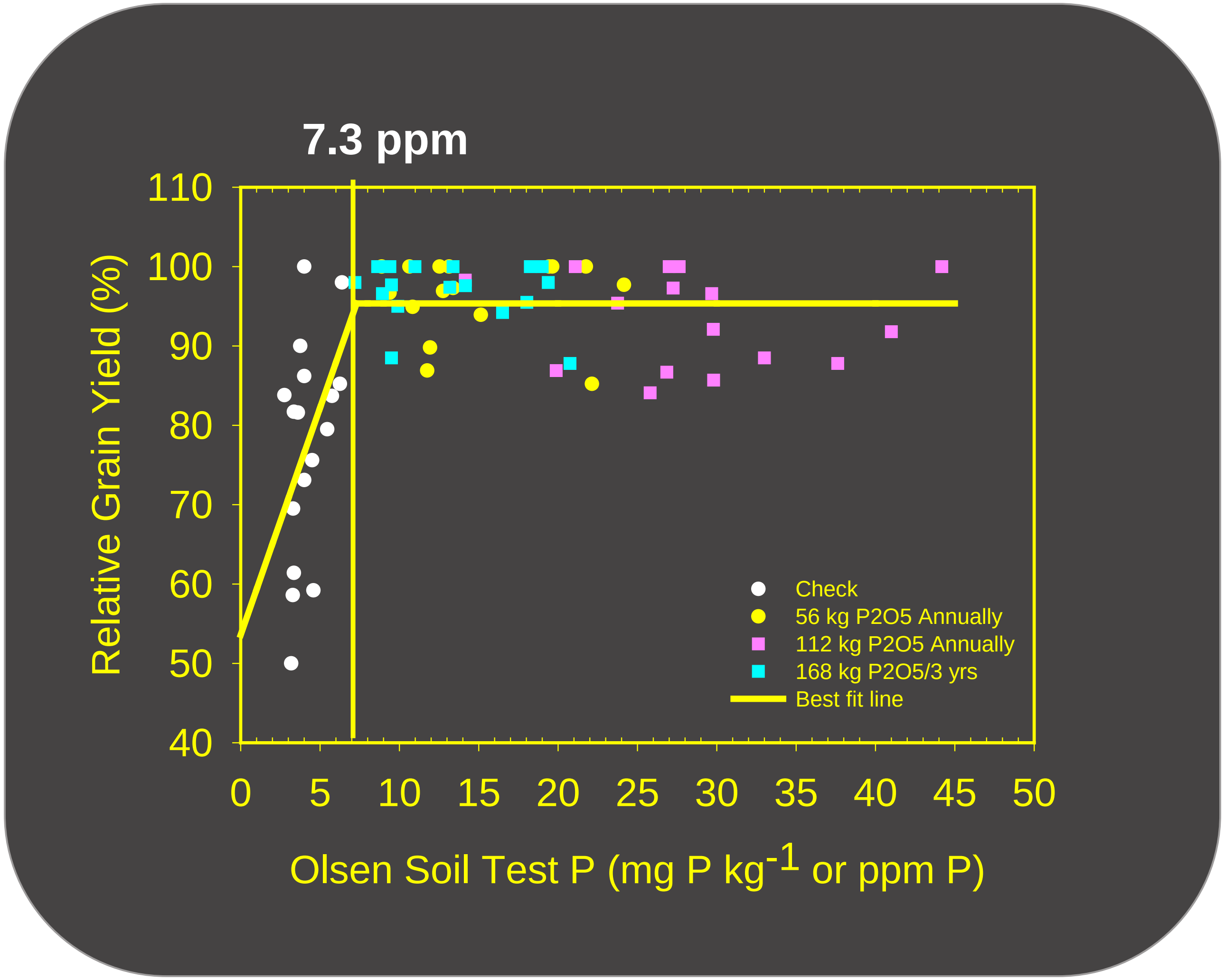
- Field Calibration gives meaning to P Soil Test Value
  - Critical value
  - Interpretation class
  - Fertilizer rates when STP in responsive range

# Example of STP Calibration




Dodd & Mallarino, 2005

# 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 -- | ---------- $P_2O_5$ 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 |

# 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

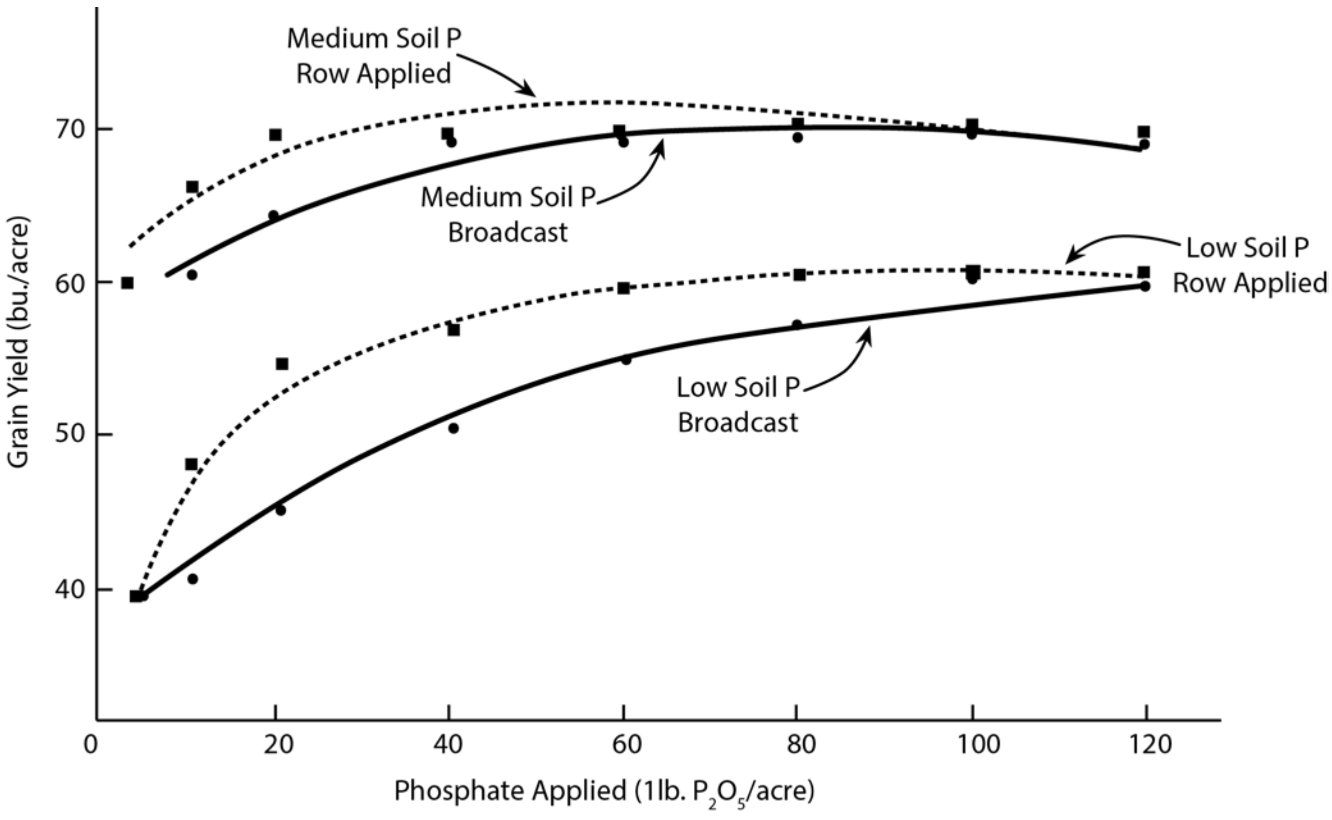
# Band vs Broadcast P Fertilizer

$P^{32}$ 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.

# 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 | $P_2O_5$ | 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 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

UNIVERSITY OF MINNESOTA EXTENSION

# Thank you

# Questions?