Soil Phosphorus and Potassium Dynamics and Management

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Phosphorus in Soils

- Plant available P is a very small portion of the total in soils, total P in top 6-inch of Iowa soils is 400 to 1000+ ppm
  - Increased mainly by manure application
- Inorganic or organic
- Dissolved in the solution or in the solid phase (organic and inorganic forms)
- Both are much less mobile than N, but doesn't mean they don't move at all

Inorganic Soil P

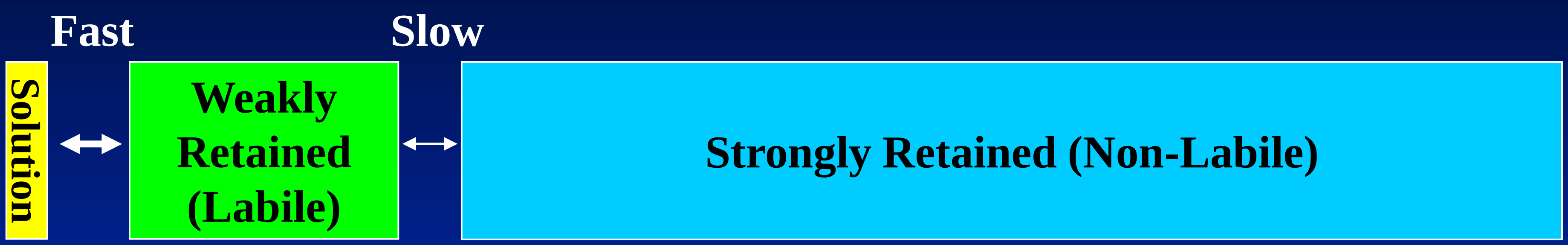
- Very little in the soil solution, most is weakly or strongly bound to soil particles
- In solution:
  - Orthophosphate P ions, mainly $HP0_4^{-2}$ and $H_2PO_4^-$, both absorbed by plants
- In the solid phase:
  - Ortho P adsorbed to mineral surfaces
  - Ca, Al, Fe phosphates in primary minerals or new ones resulting from weathering and fertilization/manure application

Organic Soil P

- Varies with soil organic matter content from 10 to about 80% of the total P
- Poorly known compounds
  - Humus and crop residues
  - Nucleic acids, phospholipids, phytate
- Its measurement is not useful for soil testing and for assessing crop P needs
  - Inorganic P reactions dominate, the P tied-up or released by organic matter reacts with the mineral phase

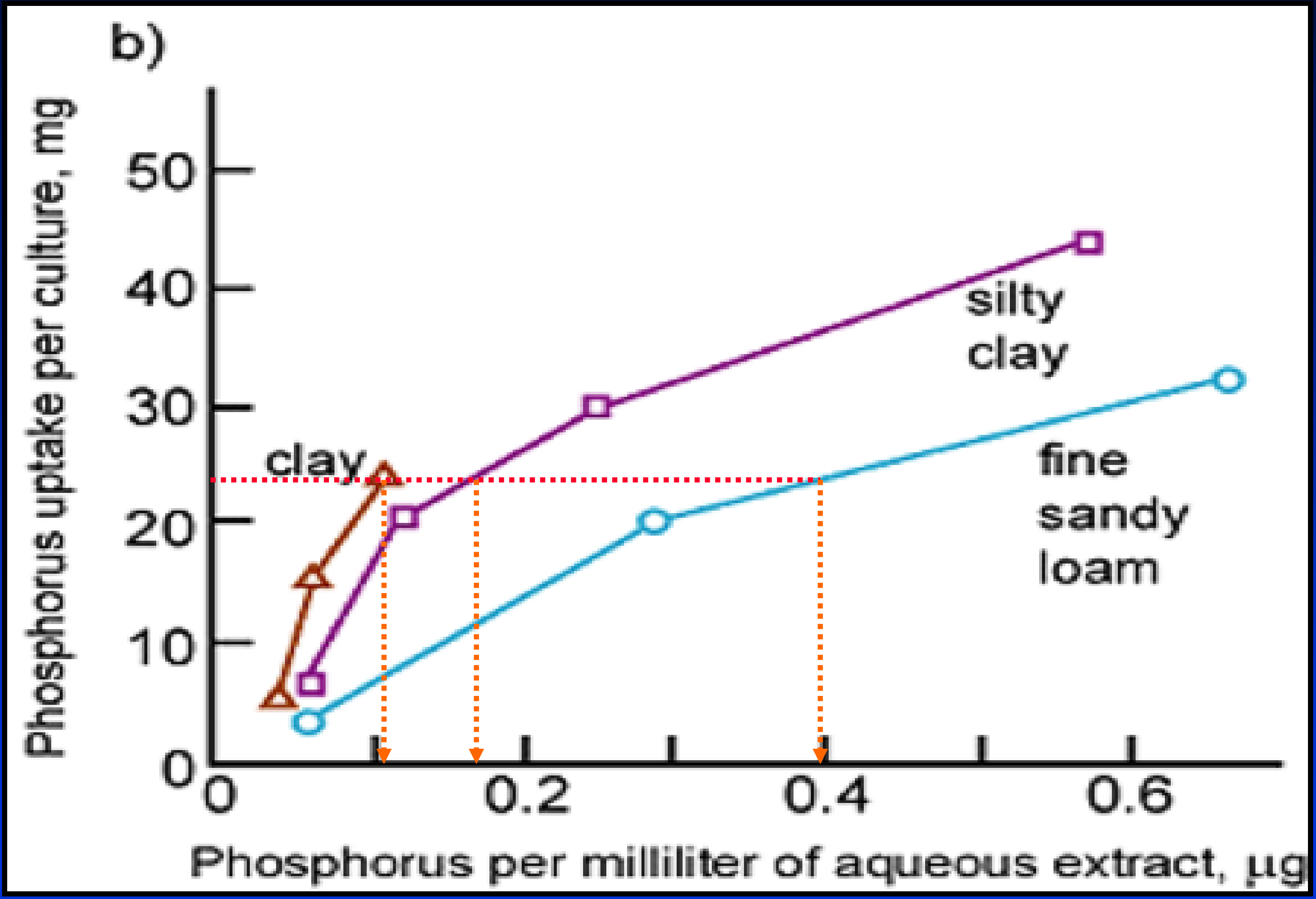
Schematic Pools and Reactions

- Solution: Dissolved simple inorganic or organic



- Labile P in the solid phase:
  - Solid phase P in a fast equilibrium with P in the solution
  - Adsorbed to mineral surfaces or as chemical compounds
- No clear limit between labile and non-labile P
  - Different degrees of solubility and potential availability
  - Soil have high retention capacity by various mechanisms and different strength, not necessarily “fixation capacity”

Importance of “Labile” P



Inorganic Phosphorus Sources

- Most fertilizers have P soluble in water and readily available for crops, the water solubility is about 90 to 100% in:
  - Mono-calcium P, $Ca(H_2PO_4)_2$
    - Simple superphosphate (has sulfur)
    - Triple (or concentrated) superphosphate
  - Monoammonium P (MAP), $NH_4(H_2PO_4)$
  - Diammonium P (DAP), $NH_4(2HPO_4)$
  - Potassium phosphate $K(H_2PO_4)$

Inorganic Phosphorus Sources

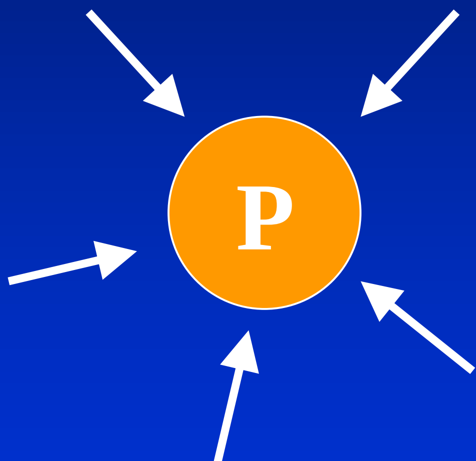
- Sources in which P isn't all water soluble but hydrolyzes or dissolves shortly after application
  - Polyphosphate in 10-34-0 and others
  - Dicalcium P in feed and manure.
- Rock phosphate: No water soluble P, but is partially soluble in dilute acid, and may become available over time
  - Sooner in acid soils, good source for forages and pastures

Composition of P Fertilizers

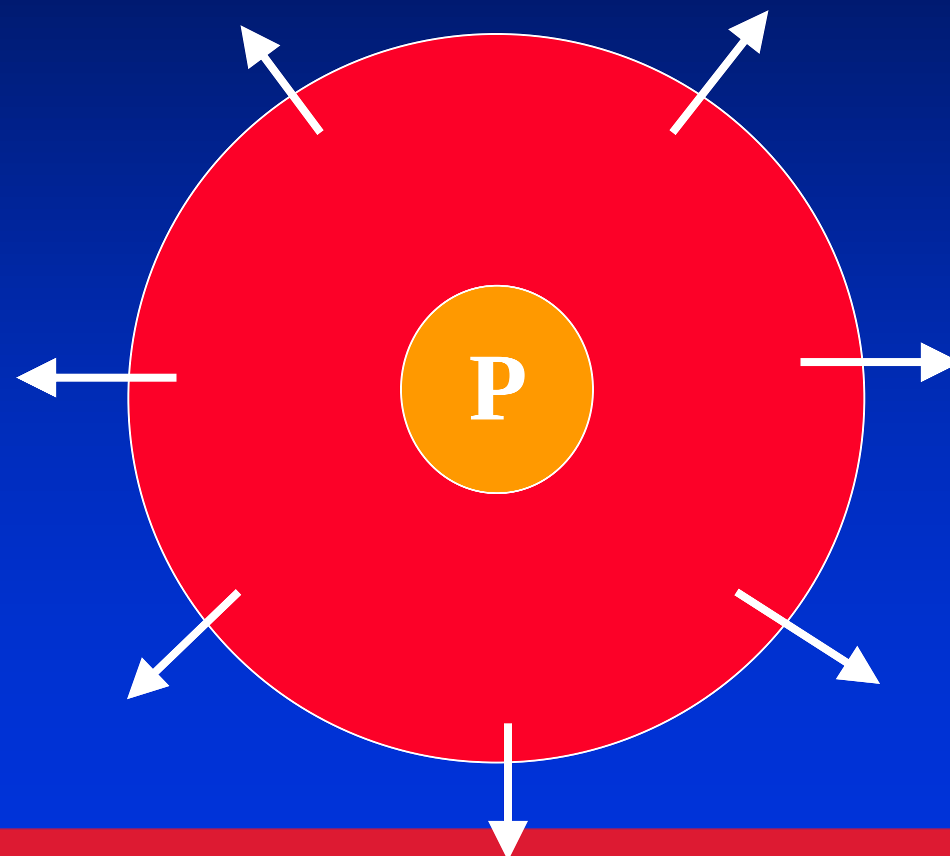
- Fertilizer P grade labels: Solubility of P in 1 *M* ammonium citrate
- About the same as water solubility for
  - Triple superphosphate: 45-53 % P_2O_5
  - DAP: 16-21 % N, 46-53 % P_2O_5
  - MAP: 11-13 % N, 48-55% P_2O_5
  - Liquid fertilizers
- Rock phosphate has no water soluble P
  - 2-15 % soluble in ammonium citrate
  - 30-35 % total P

Reactions of MAP, DAP, Super Triple

Water moves toward the fertilizer granule



A concentrated solution diffuses out
Very acid for Super Triple (pH 1.5)
Acid for MAP (pH about 4)
Alkaline for DAP (pH 8)



P Sorption and Precipitation Reactions

- Weak adsorption/desorption reactions of orthophosphate with surfaces of minerals
  - Clays, Al & Fe oxides & hydroxides
  - Calcium carbonate in calcareous soils
  - Adsorption sites can saturate near bands or in extremely high-testing soils
- Orthophosphate from dissolving Ca or NH_4 phosphates combine with other cations abundant in the soil solution
  - In Iowa soils mainly Ca, Mg, and K

P Reactions in Soils Over Time

- Dissolved P decreases rapidly, most P becomes “weakly retained-labile” pool and crop-available for months or years
- Over time adsorbed P may be retained more strongly and phosphates of lower solubility may form
  - Al-P and Fe-P in strongly acidic soils
  - Ca-P of low solubility in calcareous soils
- Soil pH is restored, but the ammonium in DAP or MAP may acidify with high rates

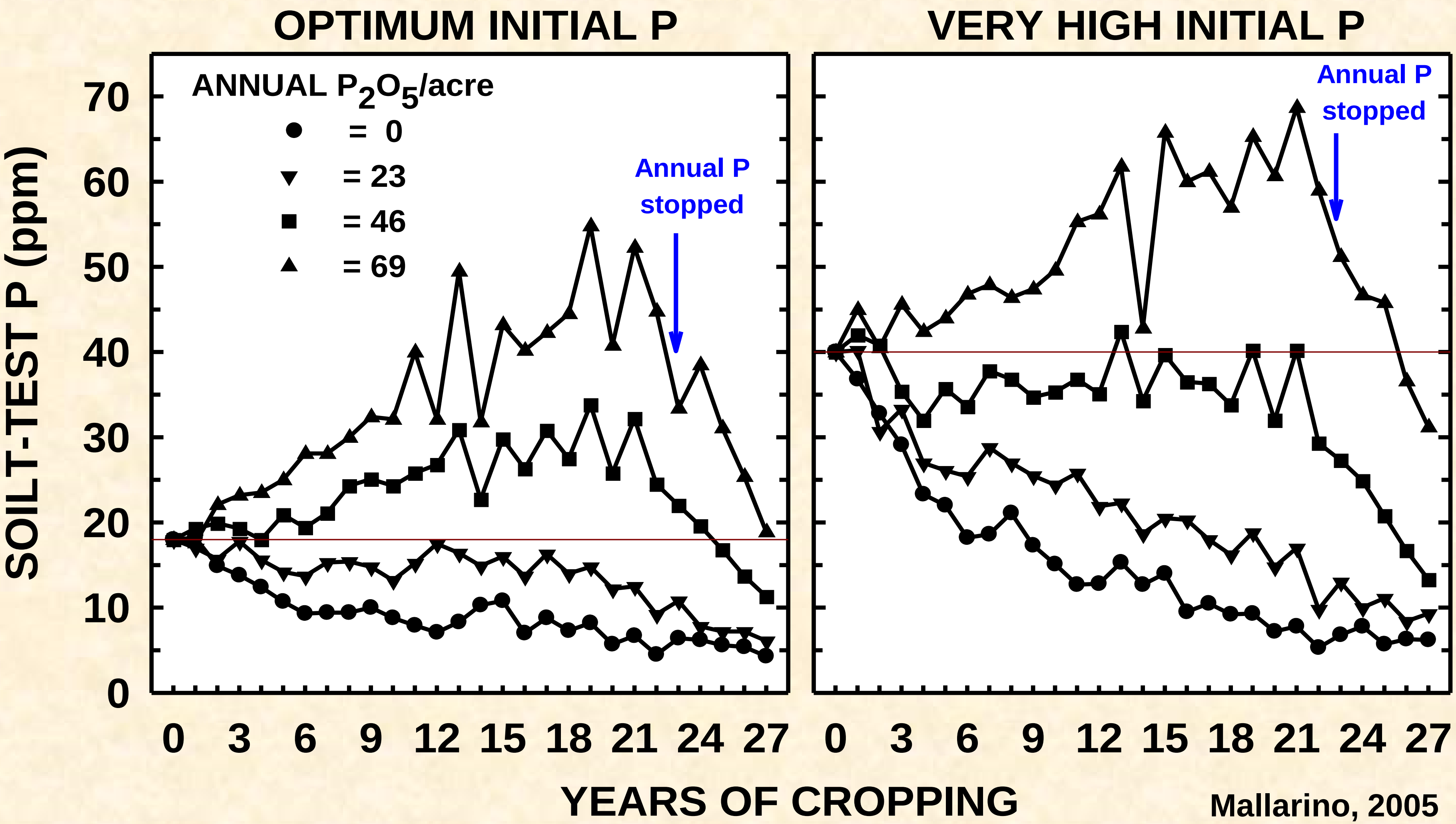
P Retention, Sometimes Fixation

- Soils with strongest P retention
  - Very fine textured (35-40+ % clay)
  - High Fe oxides/hydroxides
  - High % of kaolinite, amorphous clays
  - Extremely acid with exchangeable Al
  - Calcareous with high free $CaCO_3$
- Iowa soils retain, not necessarily fix P
  - Scarce soils with extremely acid pH, clay texture, or calcareous with high $CaCO_3$ content

Half-True Statements About P

- Low P fertilizer efficiency in
  - Acidic soils, maybe
    - Only with extreme acidity and very low organic matter; not in Iowa
  - Calcareous soils, maybe
    - Only with $CaCO_3$ higher than about 15%; not common in Iowa
- High P induces Zn deficiency, maybe
  - Only with very high P and marginal Zn
  - Not observed in Iowa or the NC region

Little “Fixation”: Can Buildup, Drawdown



Mallarino, 2005

K Content and Forms in Soils

- Plant available K is a very small portion of the total K in soils, total in top 6-inch of Iowa soils 2,000 to 10,000+ ppm
- K in soils or plants is inorganic, organic matter in soils or crops may retain K weakly but is no part of compounds
  - Free K cation in the soil solution
  - In the solid phase: rapidly exchangeable, nonexchangeable in the short term, in mineral crystal structures

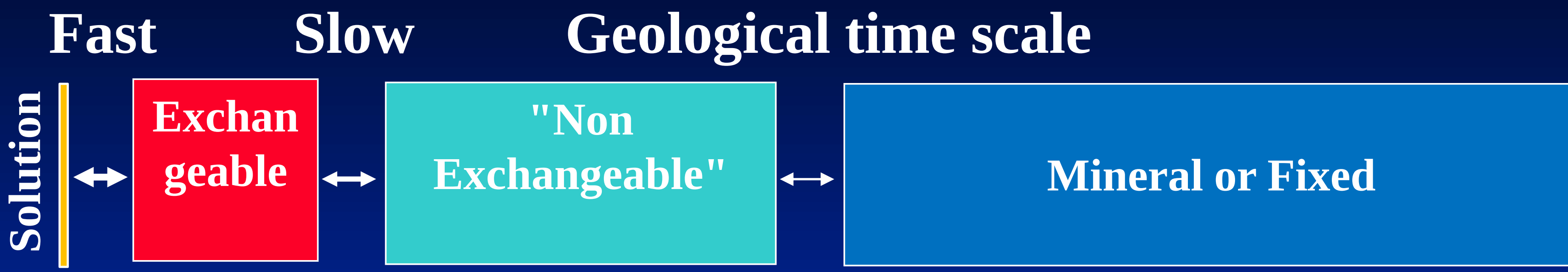
Potassium and Soil Clays

- The type and amount of clay in the soil influence K reactions (exchange)
- Clays are layered silicates, exchange sites in fracture borders and planar surfaces
- Vermiculite and some micas can retain K in interlayer “holes”
- K exchange reactions occur at various rates and strengths over time

K Content and Forms in Soils

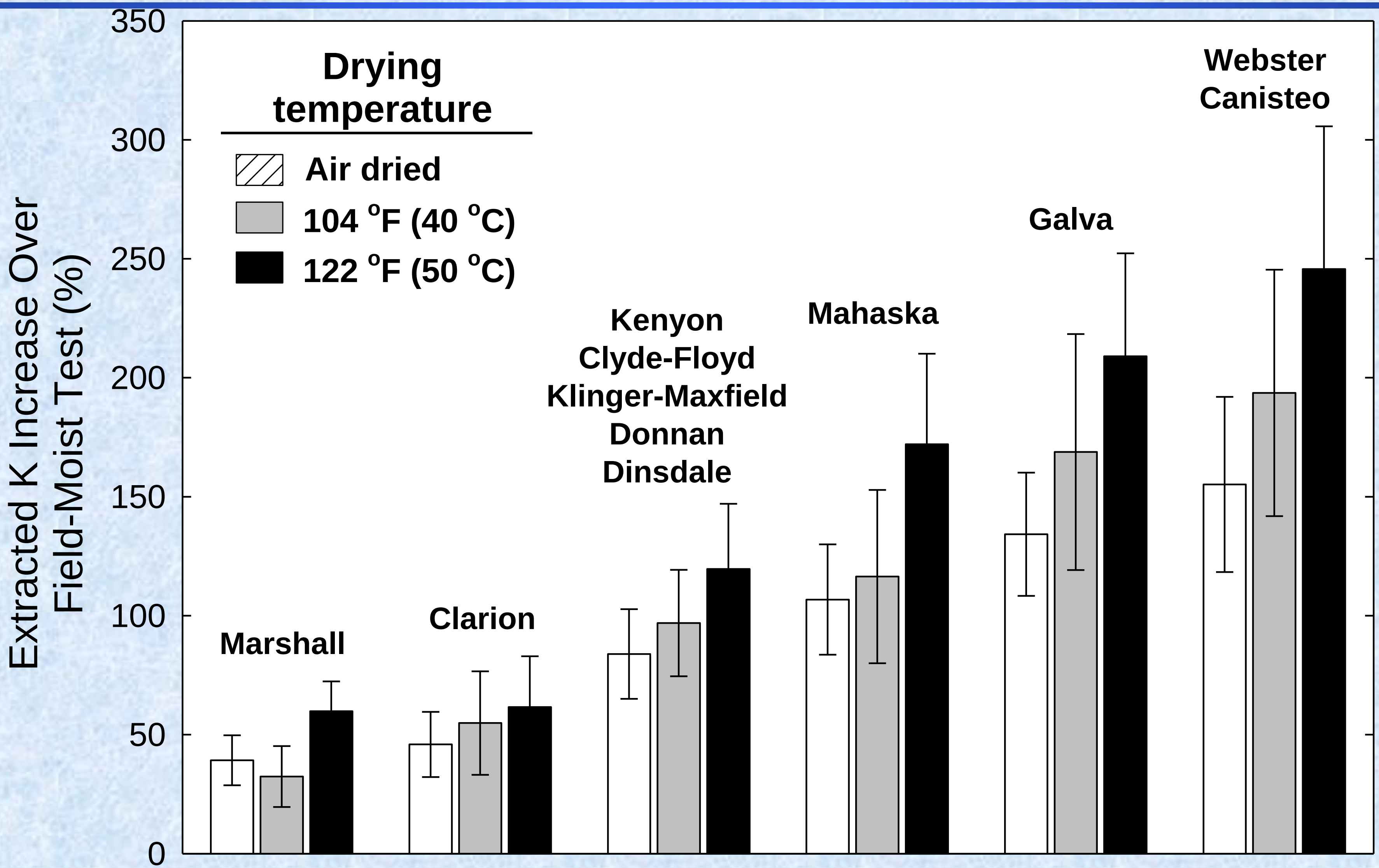
- Most common K fertilizer is potassium chloride (KCl) also called potash or muriate of potash, 0-0-60 to 0-0-62
- Some products contain
  - Potassium sulfate (K_2SO_4), 46-52% K_2O and 15-18% S
  - Potassium nitrate (KNO_3), 13-44-0
- All are soluble in water, the products dissolve and get free K^+ ions

Potassium Equilibrium in Soils



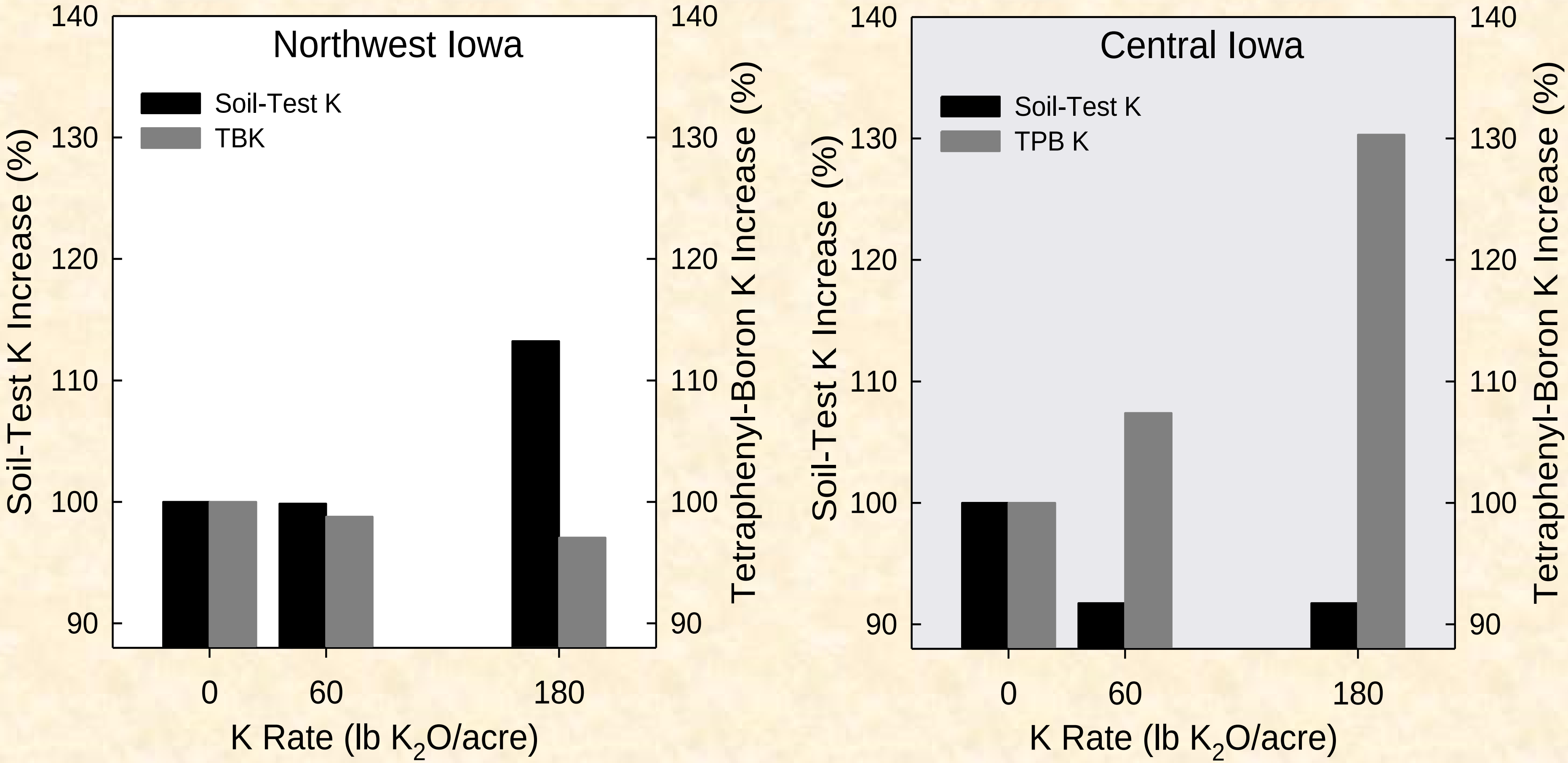
- Soil tests for crops estimate exchangeable K
- K removal by crops, soil moisture regime, and drying of soil samples greatly influence the equilibrium between exchangeable and non-exchangeable pools and soil-test K

Sample Drying Effect on STK



Barbagelata and Mallarino, 2006

Exchangeable - Nonexchangeable K



Clover and Mallarino, 2008

Potassium Retention or Fixation

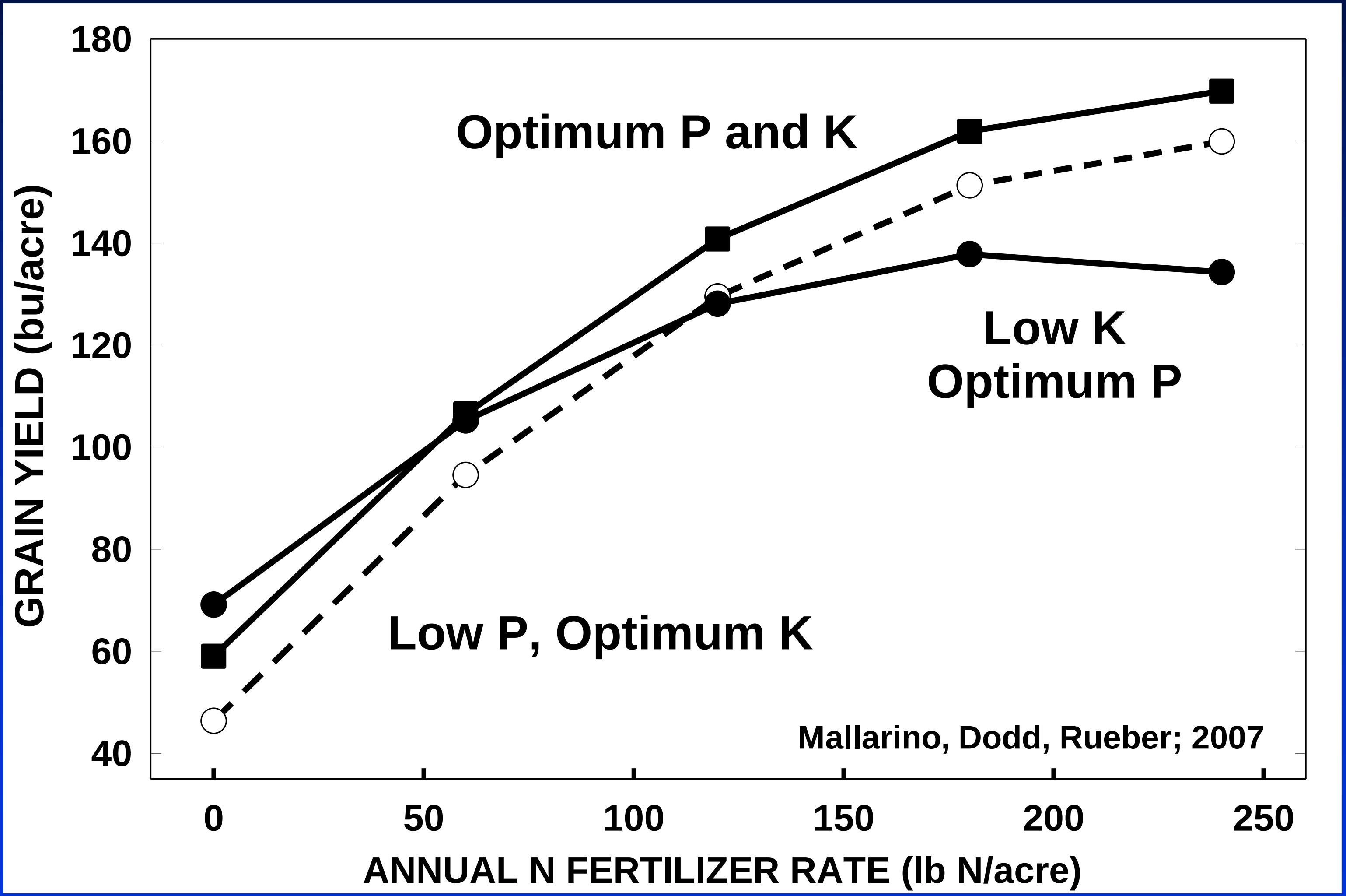
- K strongest retention:
  - Very fine-textured soils (35-40+ % clay)
  - High % of vermiculite clay
  - Smectites in lesser degree (bentonite, montmorillonite, nontronite)
  - Extreme water saturation and drying cycles in fine-textured soils
- No big problem in most Iowa soils, but studying effects of saturation/drying cycles in poorly drained soils

Half-True Statements About K

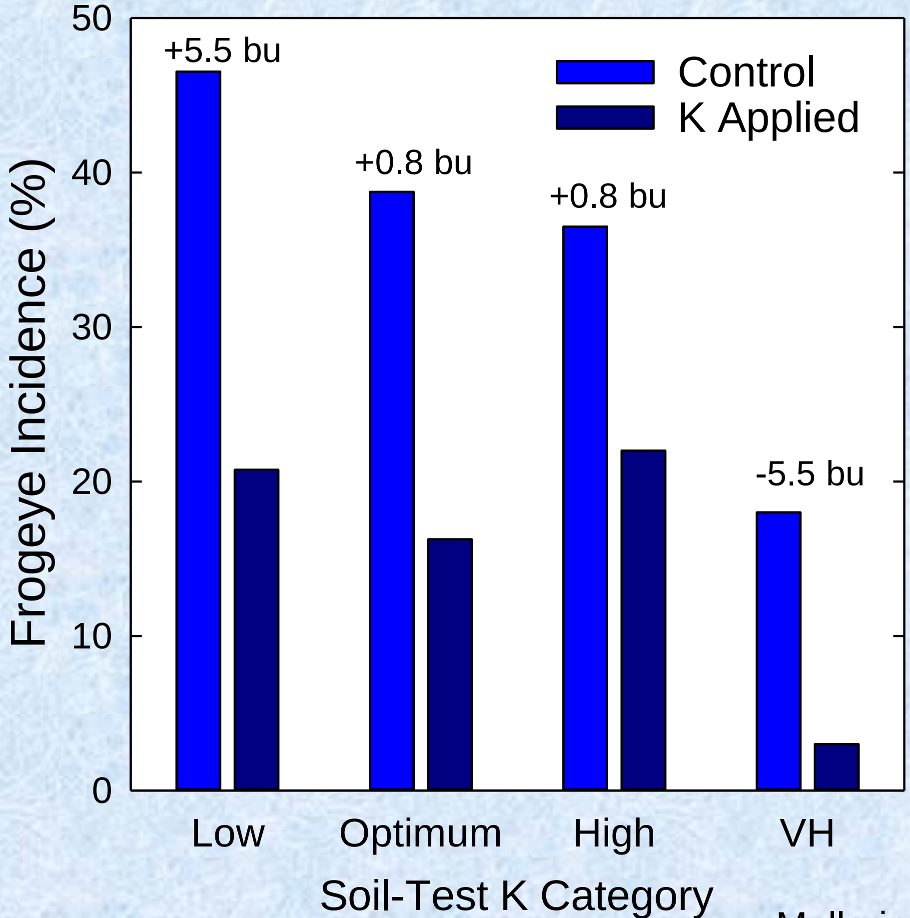
- Keep K balance with other cations:
  - No, but very different soils in some other states may need different calibrations of soil K testing methods
- K moves and leaches more than P:
  - Just a bit more in most soils, but K does leach a lot in very sandy soils
- K x N interaction in corn:
  - Yes, avoid K deficiency but don't need to apply higher than recommended K rates or maintain higher soil-test levels

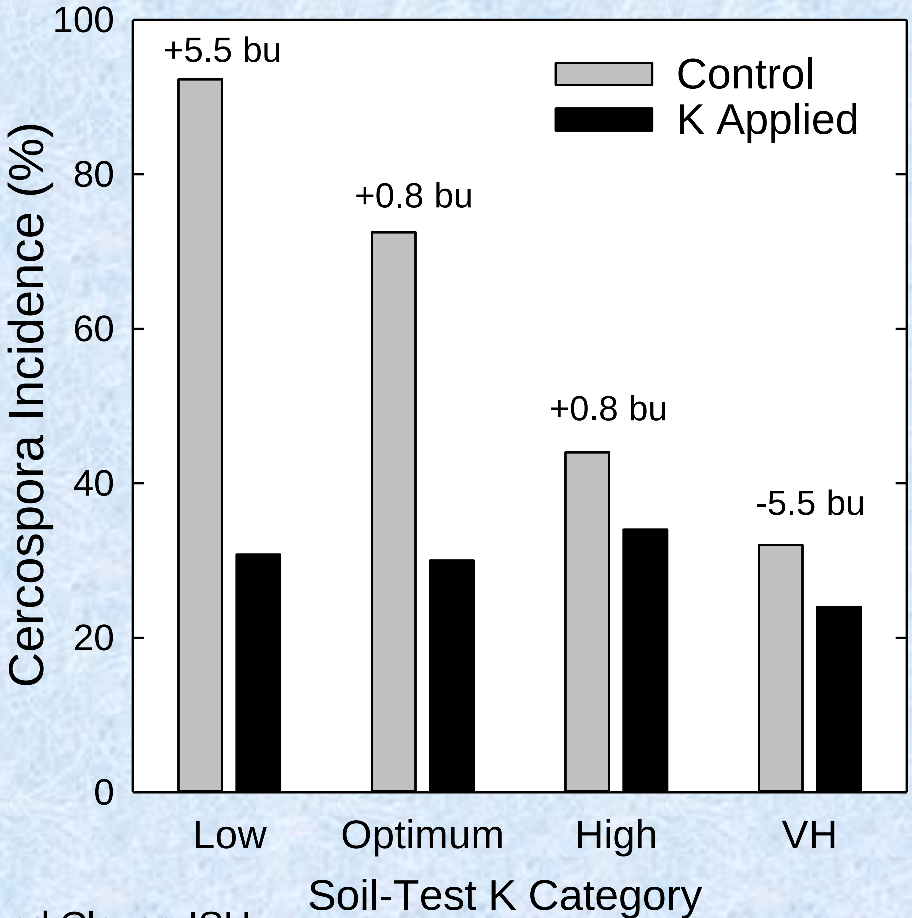
N x K Interaction in Corn

Long-Term Means, Continuous Corn Trial at Kanawha



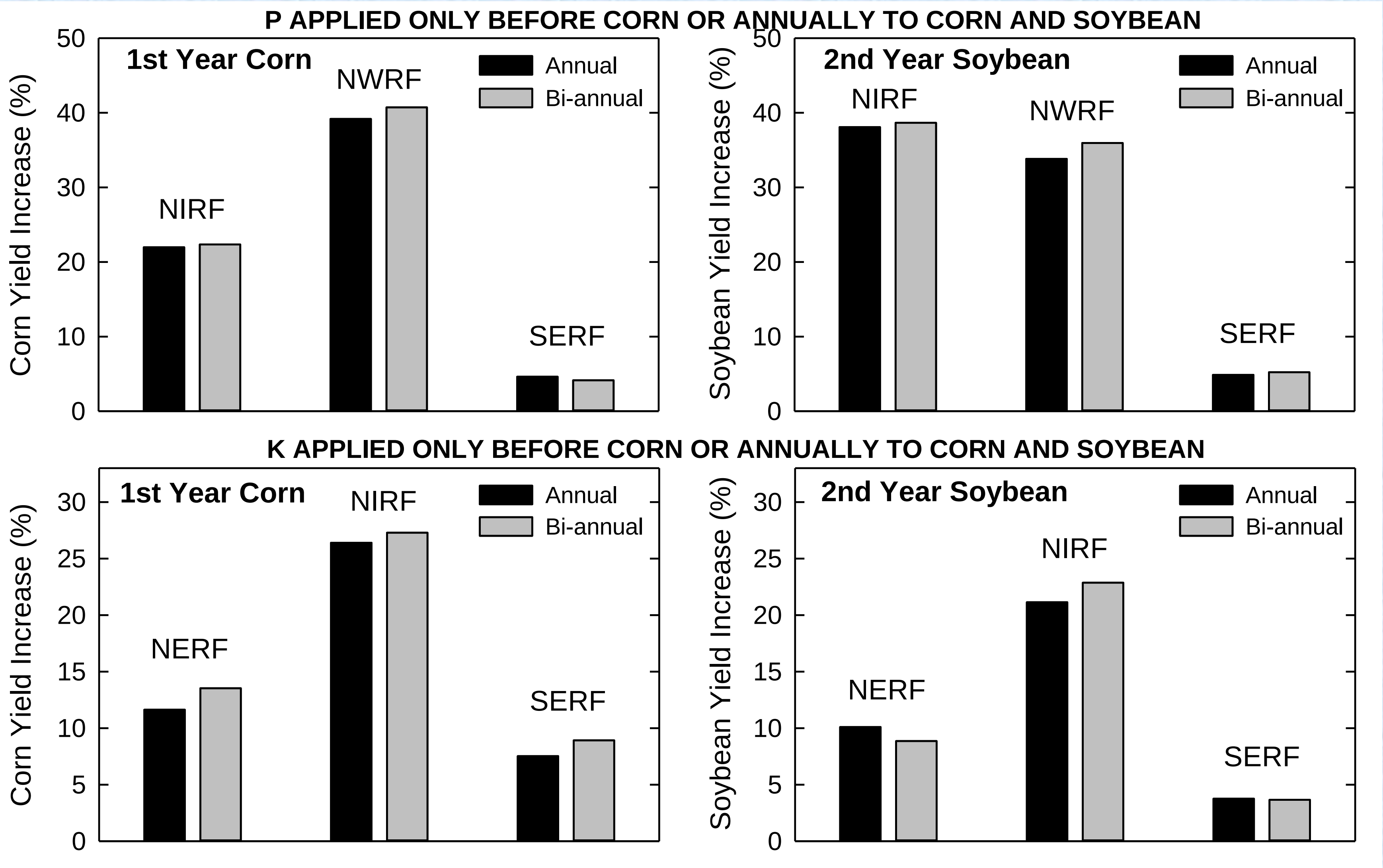
Potassium and Soybean Diseases





Mallarino and Clover, ISU

Annual = Bi-Annual P-K Application



Manure Phosphorus and Potassium

- Manure K is inorganic and crop available
- Manure P is 40 to 90% inorganic, highest values are for liquid swine manure
- Low water solubility of some organic (phytate, ADP/ATP, nucleic acids) and inorganic (dicalcium P) compounds
  - But most are soluble in dilute acid or alkali and hydrolyze in the soil by enzymatic and microbial processes
  - Phytase enzyme feeding reduces total P

Nutrients in Animal Manure

Manure can supply nutrients required by crops and replenish nutrients removed from soil by crop harvest. Since manure contains multiple nutrients, applications should

Manure has characteristics that make nutrient management different and sometimes more complicated than fertilizer. These include a mix of organic and inorganic nutrient forms; variation in nutrient concentration

The manure nutrient concentration varies considerably between animal species; dietary options; animal genetics; animal performance; production management and facility type; and collection, bedding, storage, handling, and agitation for land application. Use of average or "book" nutrient values can be helpful for designing a new facility and creating manure management plans but is not very helpful in determining specific manure nutrient supply or application rates due to wide variation in nutrient concentrations between production facilities. For example, a recent sampling across swine finishing facilities found a range in total N from 32 to 79 lb N/1,000 gal, P from 17 to 54 lb P_2O_5/1,000 gal, and K from 23 to 48 lb K_2O/1,000 gal. A similar or larger range can be found with other manure types. Nutrient analyses often vary greatly as storage facilities are

Manure P Availability: PMR 1003

Animal	N	P	K
	% Total Nutrient Applied		
Beef & Dairy	30-50	80-100	90-100
Poultry	50-60	90-100	90-100
Swine liquid	90-100	90-100	90-100

- Assume lower values for low-testing soils, but assume 100% to maintain Optimum soil P level
  - Some organic/inorganic P is not readily available but becomes part of the labile pool over time
  - Recognizes uncertainty in nutrient content and difficulty of uniform application

N-Based Manure and Soil P Buildup

- Manure application according to N may result in P build-up in the “soil bank”
- Corn needs in corn-soybean rotations:
  - swine, dairy, beef: small or no buildup
  - poultry: possible large P buildup
  - phytase may reduce total P 20 to 30% and doesn't change P solubility consistently
- Continuous corn or based on N removal by both corn and soybean grain:
  - Very large P buildup with all manures

Physiology and P & K for Growth

- Plants absorb much more K than P
  - Larger difference if expressed as elements
- P is especially needed early for cell division and multiplication and grain "sink" creation, so an early P deficiency is difficult to correct
- The amount absorbed for both nutrients increase exponentially until about R1 (silking) in corn and R5 in soybean

Plant P and K Uptake and Removal

Crop	P uptake Grain	P uptake Total	K uptake Grain	K uptake Total
	- lb P_2O_5/acre -		- lb K_2O/acre -	
180 bu corn	68	99	54	225
55 bu soybean	40	67	83	143
6 ton alfalfa	75		240	

% Removed with Grain

Crop	P	K
Corn	70	25
Soybean	60	60

Root Growth and P & K Uptake

- Fully developed roots fill 2 to 5% of soil
- Diffusion through soil water is the main mechanism of P & K uptake
  - Very slow 50 to 100 times less than in water) and through a few mm
  - Faster with high P, coarse texture, warm temperature, and moist soil
- Limiting root growth and water uptake limits P-K uptake: cold/wet, dry, loose, or compacted; root pests/diseases

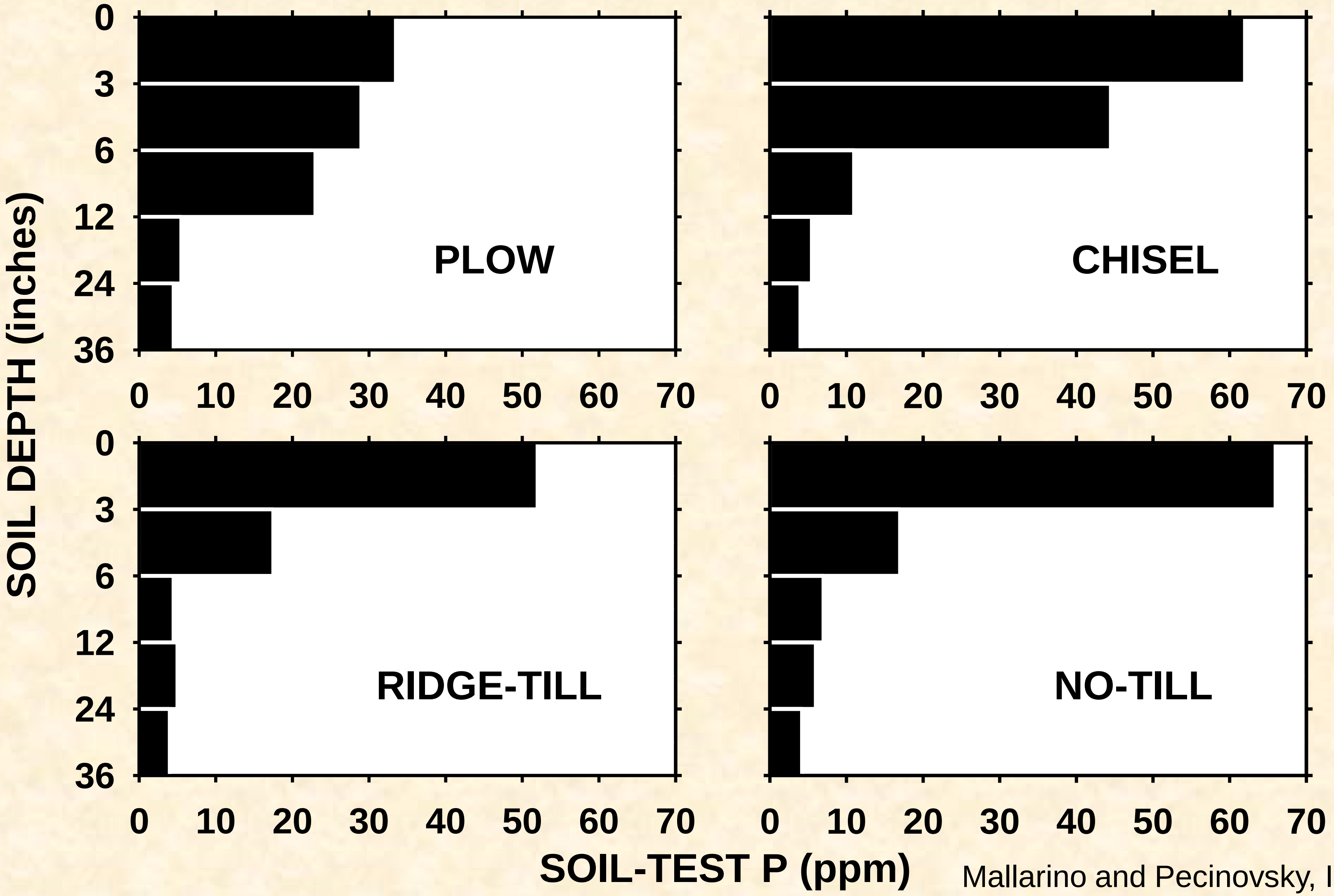
Conservation Tillage & Stratification

- No-till, ridge-till and ridge-till lead to stratification of P and K in the topsoil
  - Limited P and K movement
  - Limited incorporation of fertilizers.
  - Nutrient recycling from crop residues and from deep soil layers
- Stratification seldom is a problem in Iowa due to a humid climate and soils that allow for good root growth

Effect of High Residue Cover

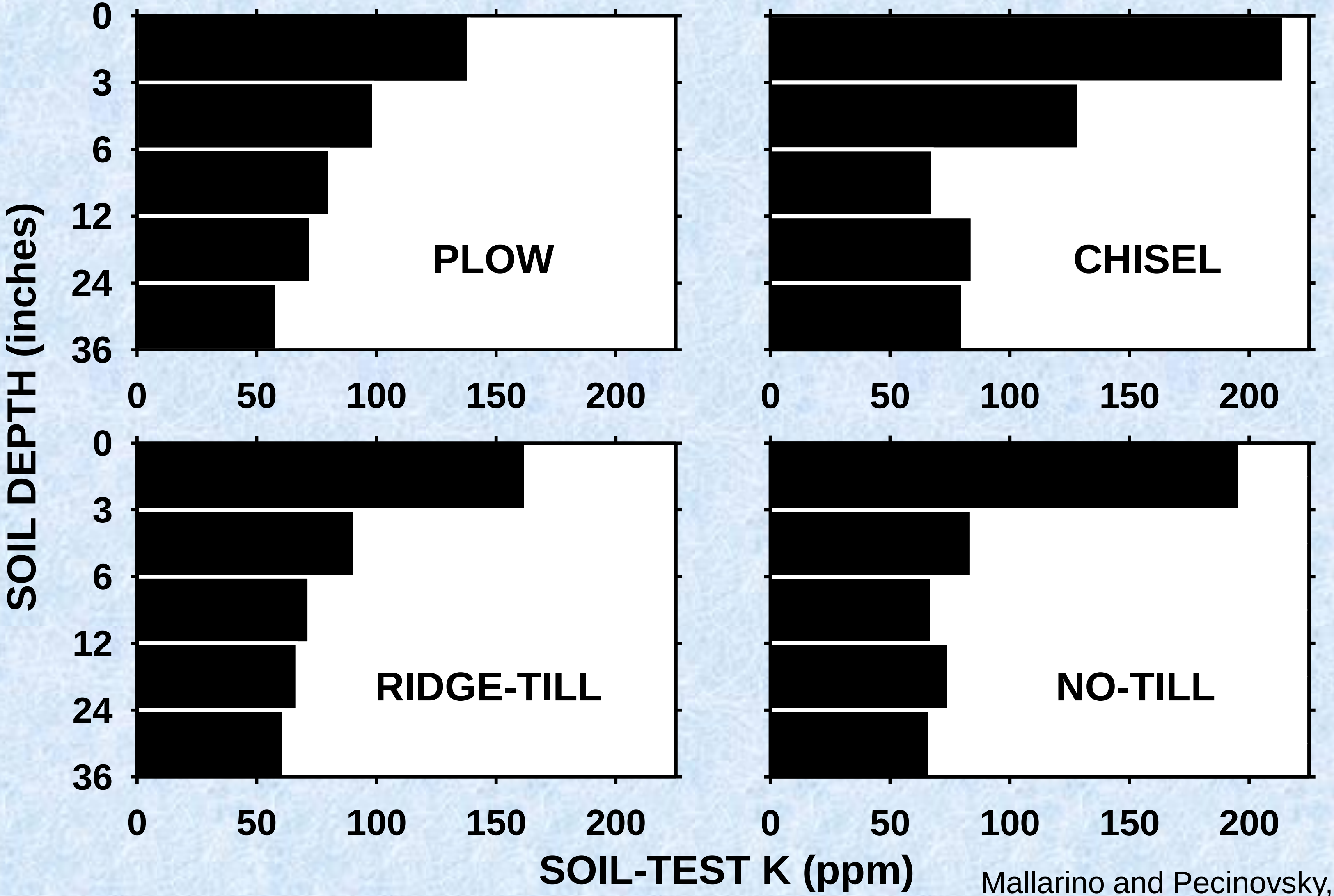
- Residues on the soil surface:
  - Lower soil temperature and higher soil moisture in early spring
  - Slower early plant and root growth.
  - Slower P and K diffusion to roots
  - But higher root efficiency later in the season especially with dry weather
- Starter N & P and zone tillage increase early growth, and maybe grain yield

P Distribution in the Soil Profile



Mallarino and Pecinovsky, ISU

K Distribution in the Soil Profile

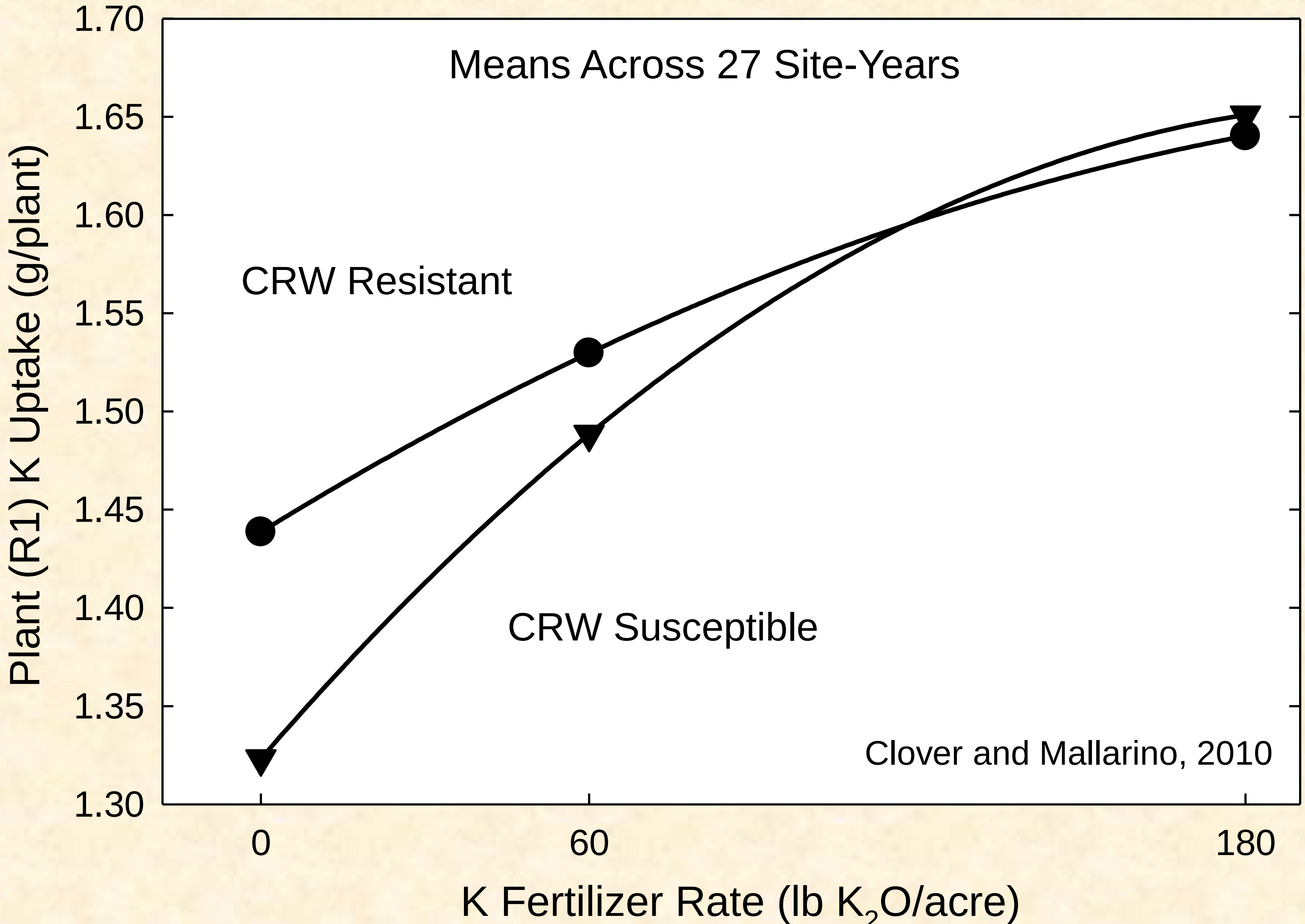


Mallarino and Pecinovsky, ISU

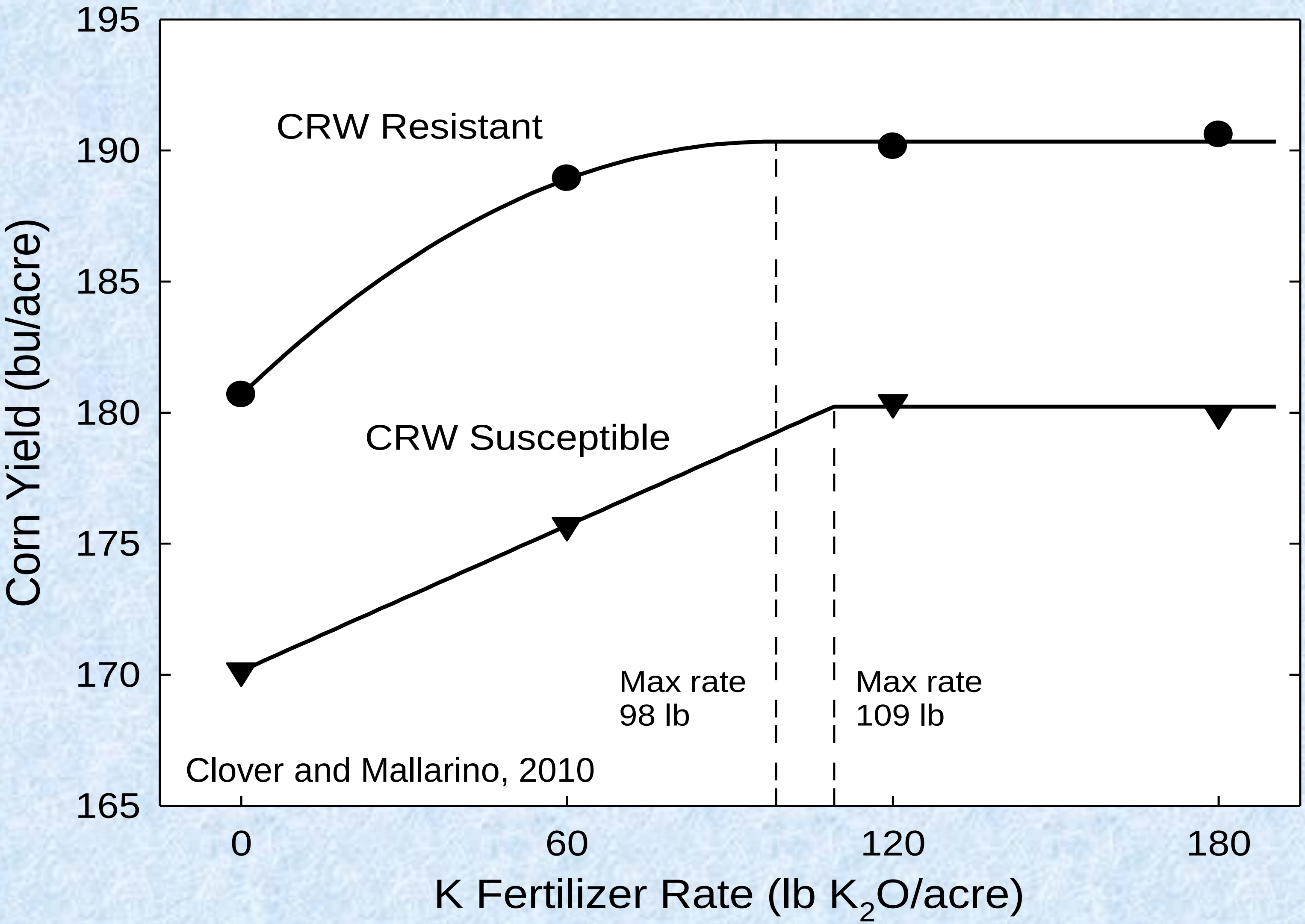
Rootworm Injury and K Uptake

Clover and Mallarino, 2010

Corn Rootworm and Plant K Uptake



RW Resistant Hybrids and Yield



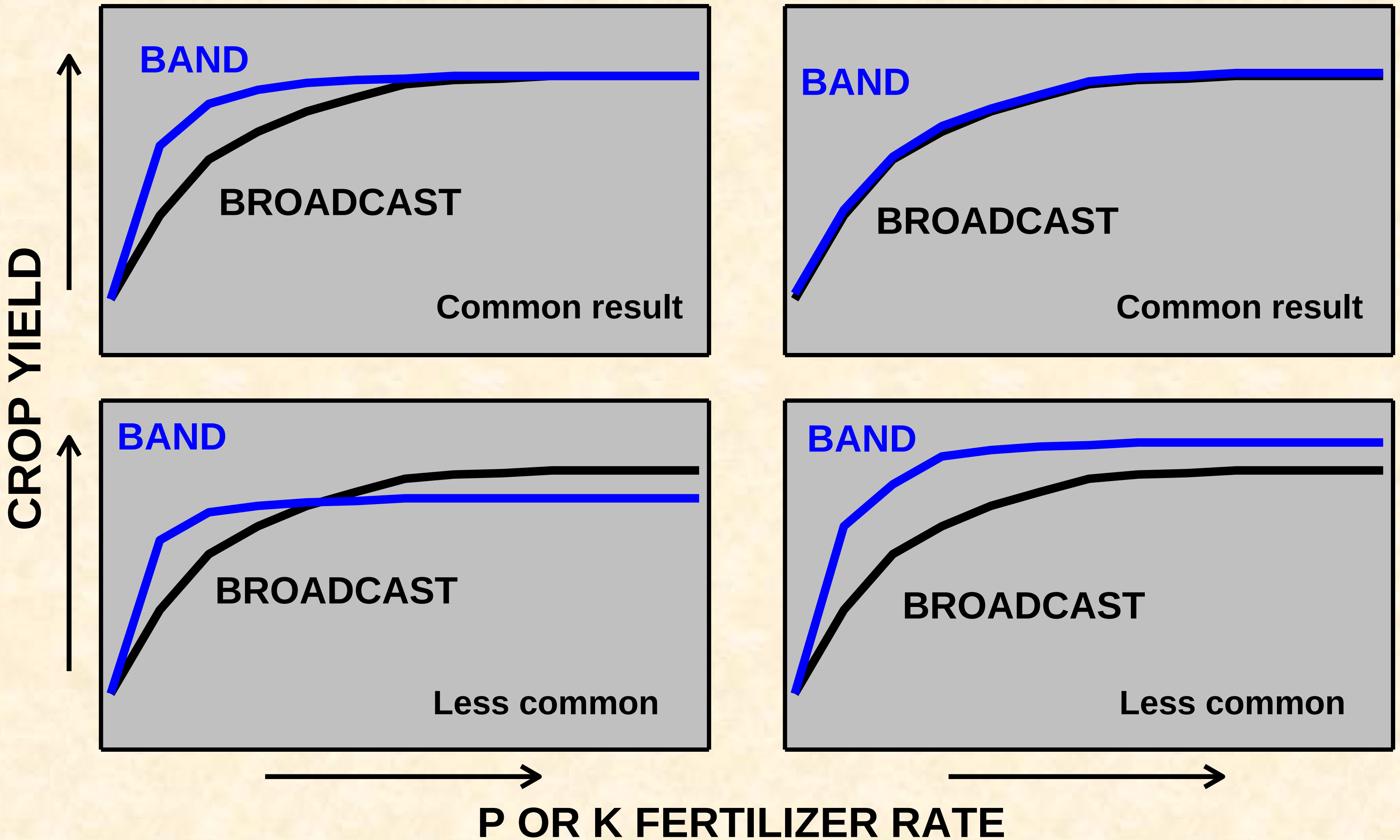
P and K Placement Issues

Dep banding and strip tillage in Southwest Iowa
Mallarino, North, Bordoli, Borges; ISU

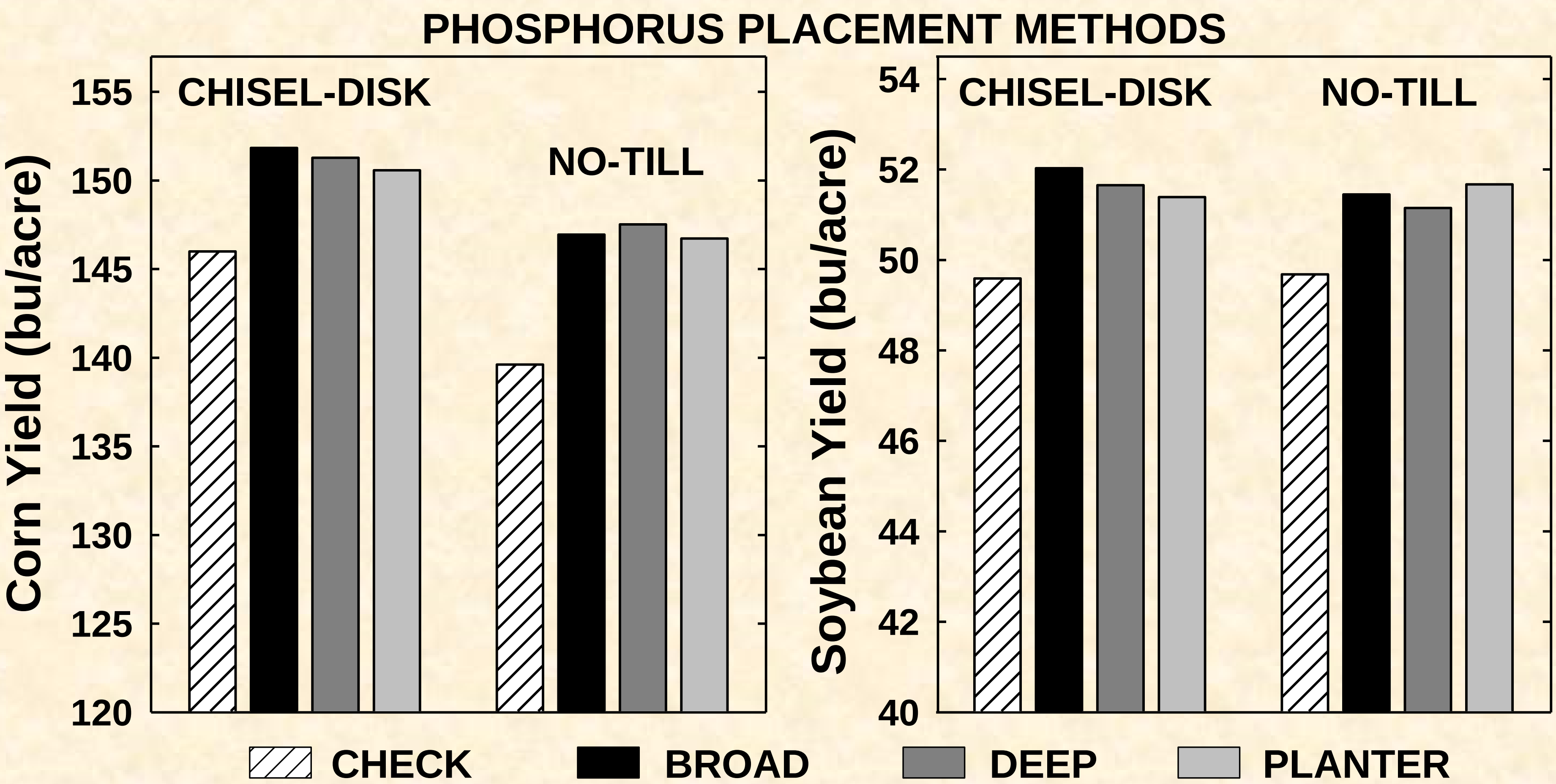
Theory About P and K Banding

- Subsurface banding reduces the reaction of fertilizer with soil, nutrients near growing seedlings and may slow down changes to less soluble forms
- Subsurface banding can increase P & K efficiency in soils of very high retention capacity, cold/wet, or frequent dry surface
- But this doesn't mean P or K banding is always better than broadcasting

Possible Responses to P & K Placement

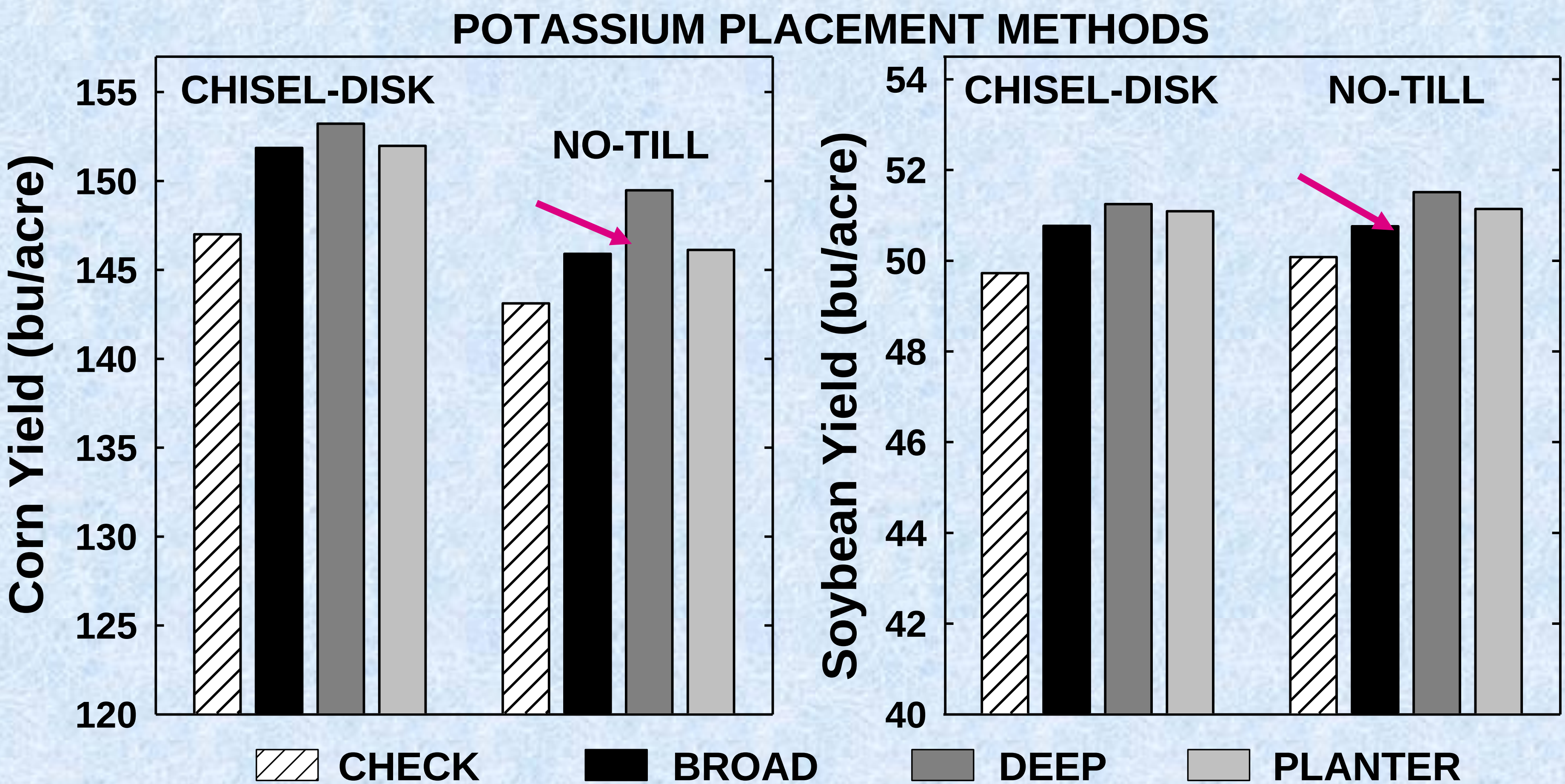


P Placement for No-Till



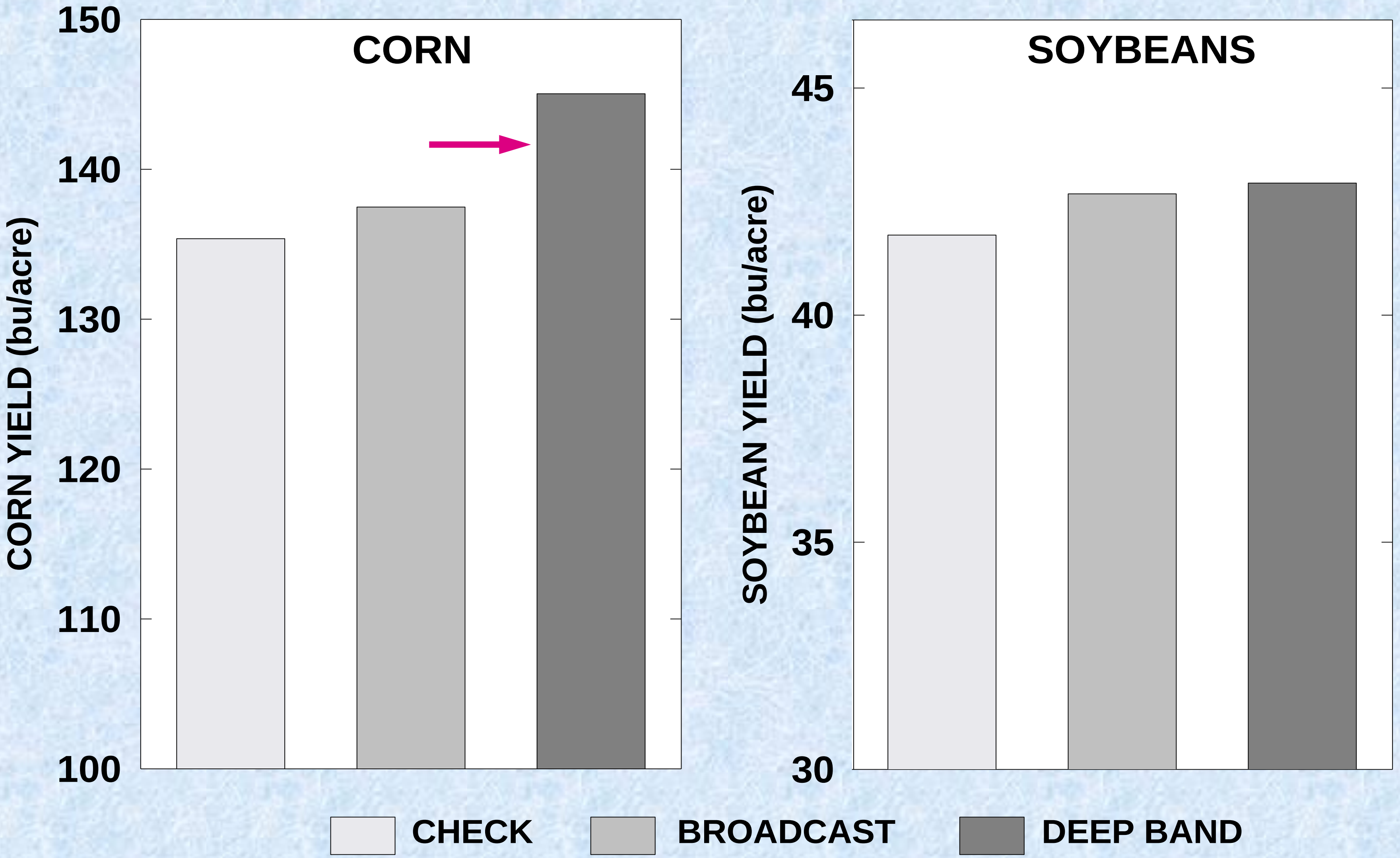
Mallarino, Bordoli, Borges, Barker. ISU

K Placement for No-Till or Strip-Till



Mallarino, Bordoli, Borges, Barker. ISU

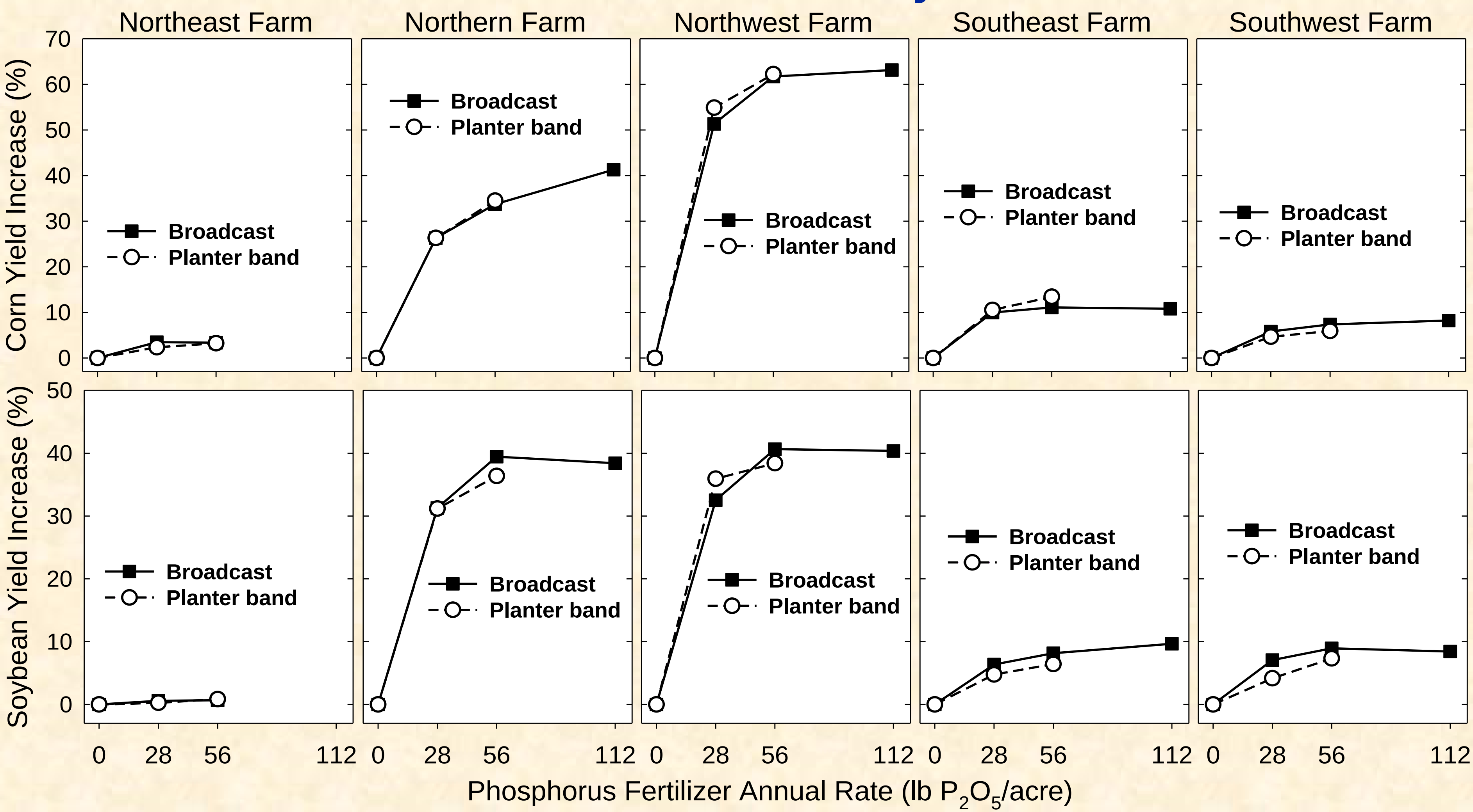
Need Deep K for Ridge-Till Corn



Mallarino and Borges, ISU

P Broadcast or Planter Band 2002-2014

No-Till Corn and Soybean



Mallarino, Oltmans, Jones, Thompson; ISU

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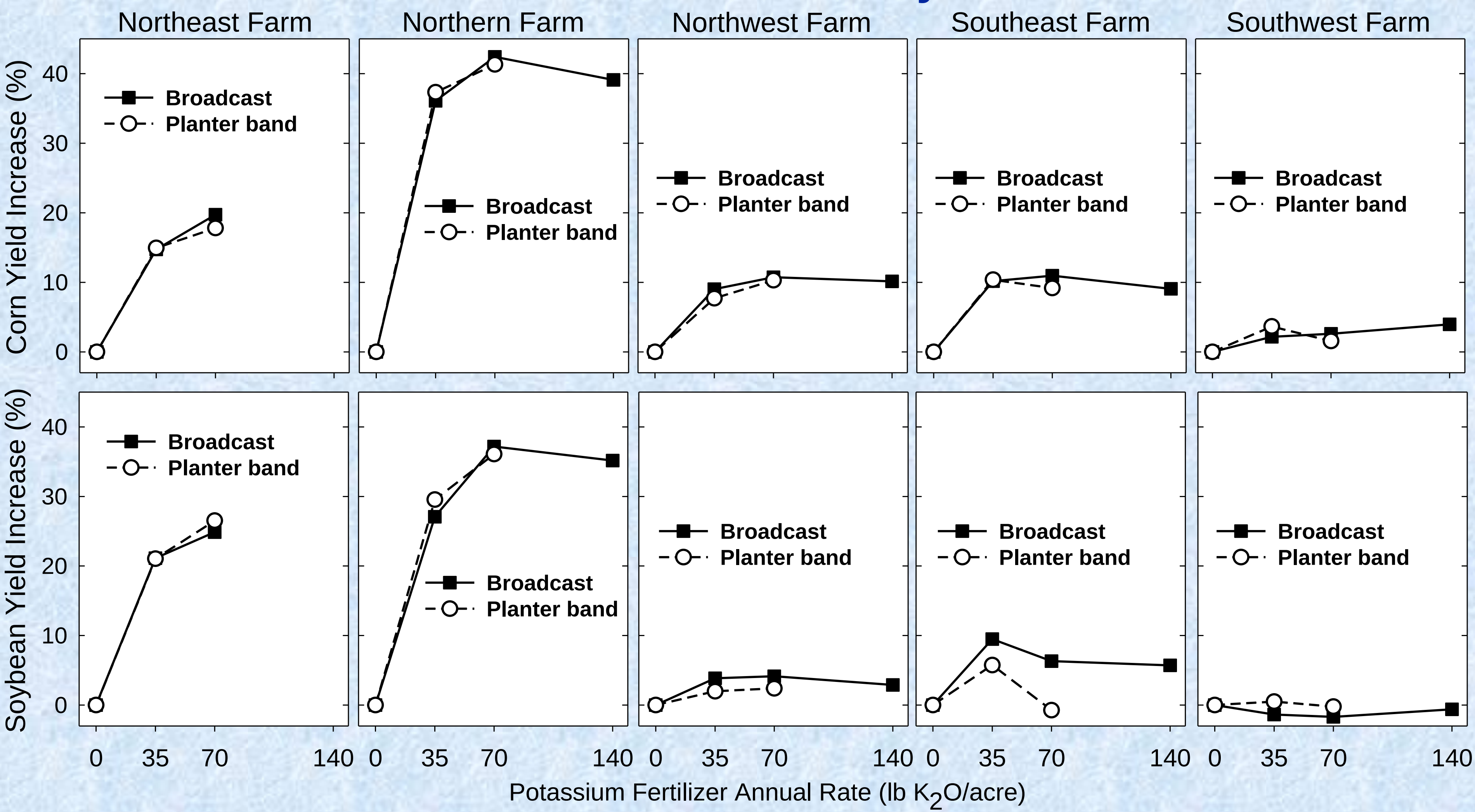


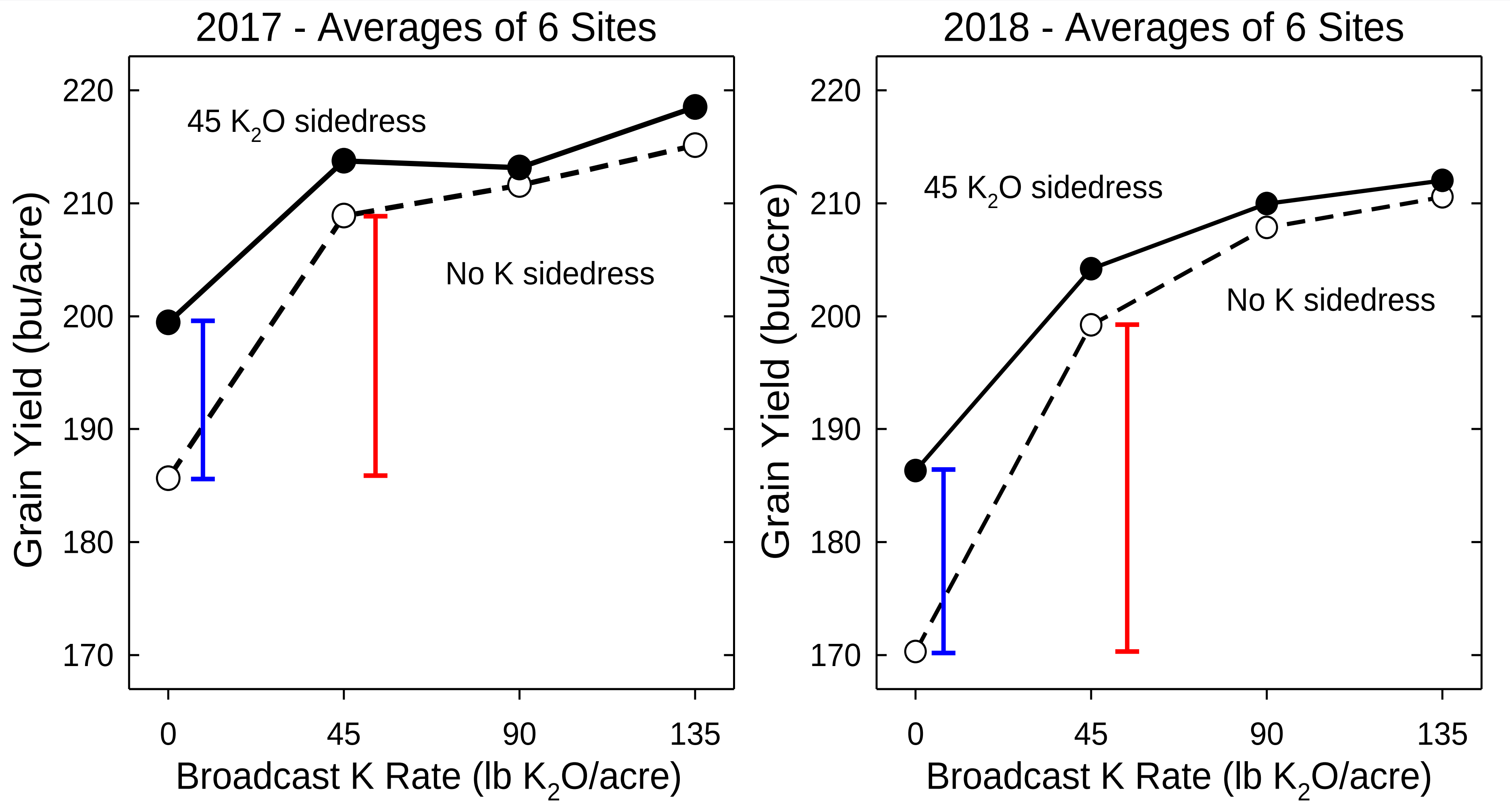
Iowa State University
Extension and Outreach

Mallarino, Oltmans, Jones, Thompson; ISU

No Large Response to P Banding

- Banding always increases early growth but seldom increases grain yield:
  - Soils not extremely low in P and with low or moderate P retention
  - Humid region, good root growth
  - Broadcast P long before planting
  - Long season adjustments
- Banding can be better than broadcast with very low soil P and deficient rates, or through a starter effect

Liquid K Sidedress for Corn?



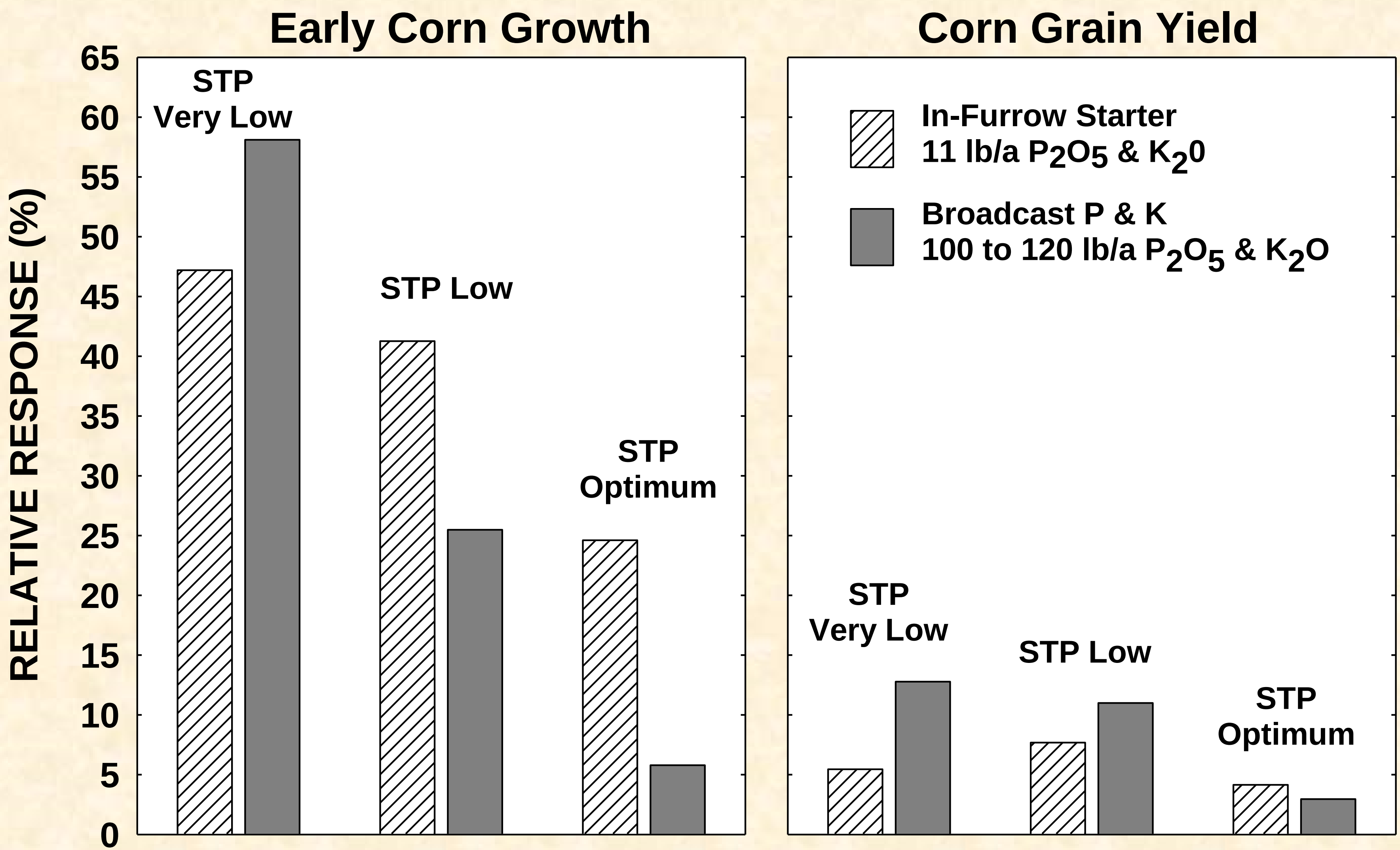
Mallarino, Thompson; ISU

Starter Fertilizer for Corn

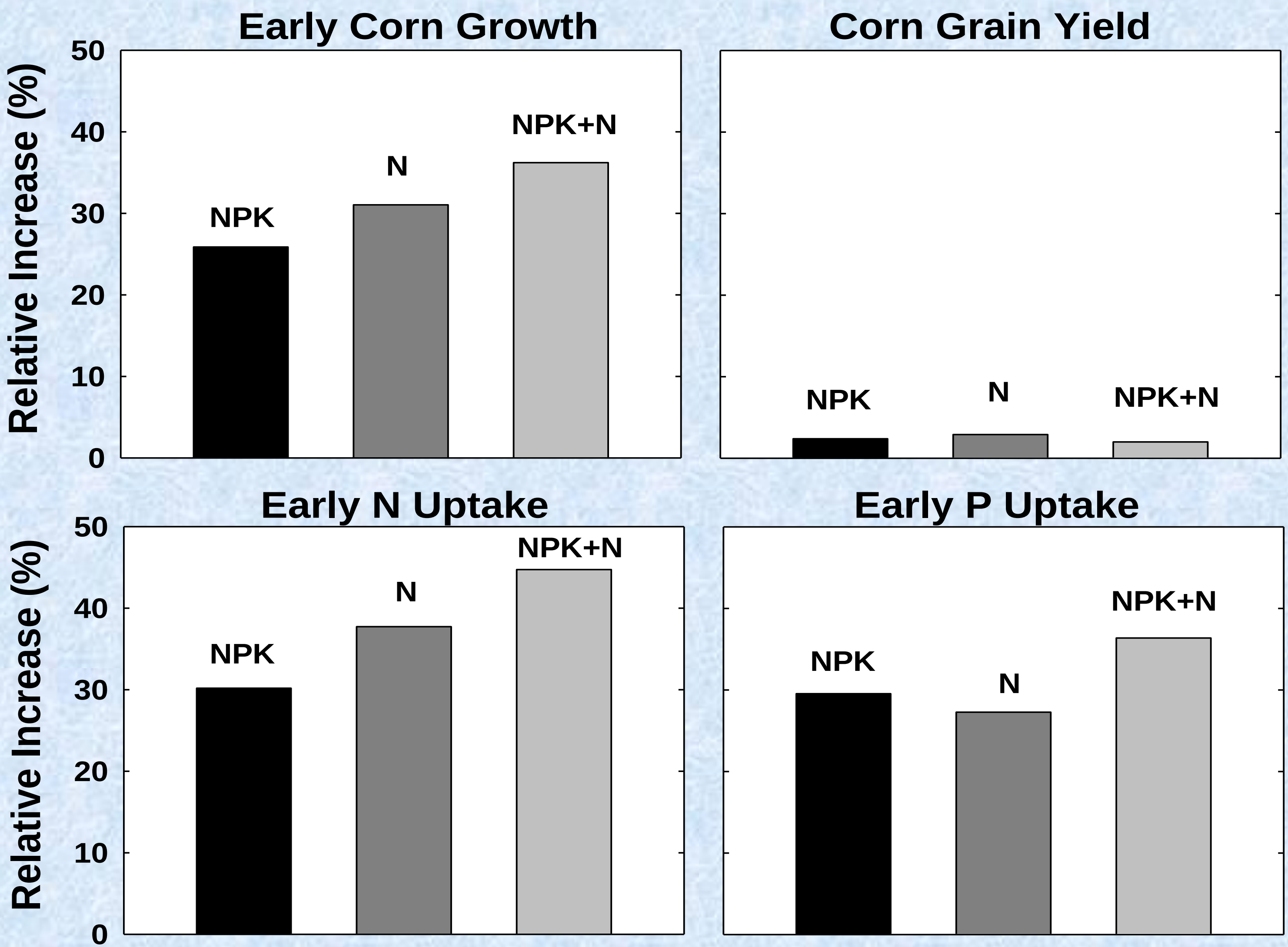
When Would Starter be Needed?

- Cold and wet soil in spring may limit
  - Early root growth and seedling growth
  - Reduced P and K diffusion through soil solution and root activity
  - Conditions more likely in poorly drained soils and thick residue cover
- Very late planting dates with full season hybrids, may speed-up development and grain drying

P Banding Effects: Yield and Growth



Starter P-K or N Effect?



Mallarino and Bermudez, 2004

Iowa Placement Recommendations

- No placement differences for P with any tillage system, other than starter for corn in some conditions
- Deep K placement
  - A must with ridge-tillage
  - Sometimes with no-till and strip-till, no consistent or large advantage
- Subsurface P banding can reduce P loss from fields, good for water quality

Soil Fertility Web Site
http://www.agronext.iastate.edu/soilfertility/

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