Is there a soil P credit? Lessons from Illinois

2023 ALTA Winter Meeting

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West Lafayette, IN

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Developing a phosphorus (P) credit to support Illinois farmers' management of P

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Postdoc
Currently: research scientist

Dr. Jordon Wade
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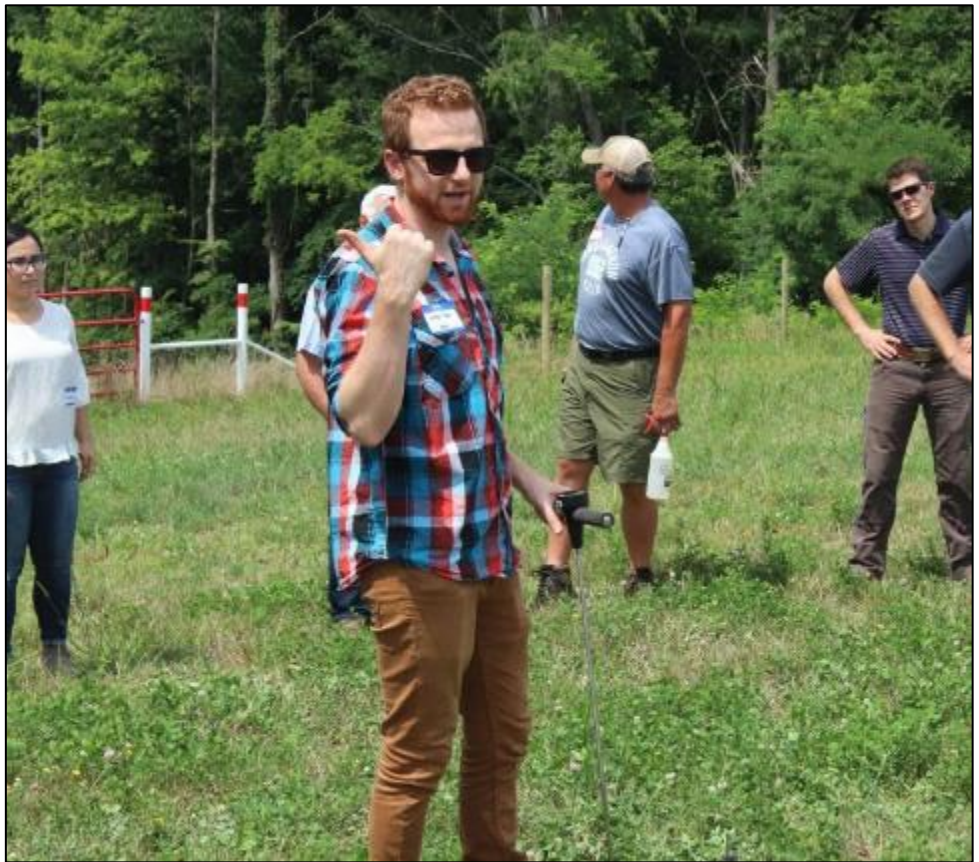
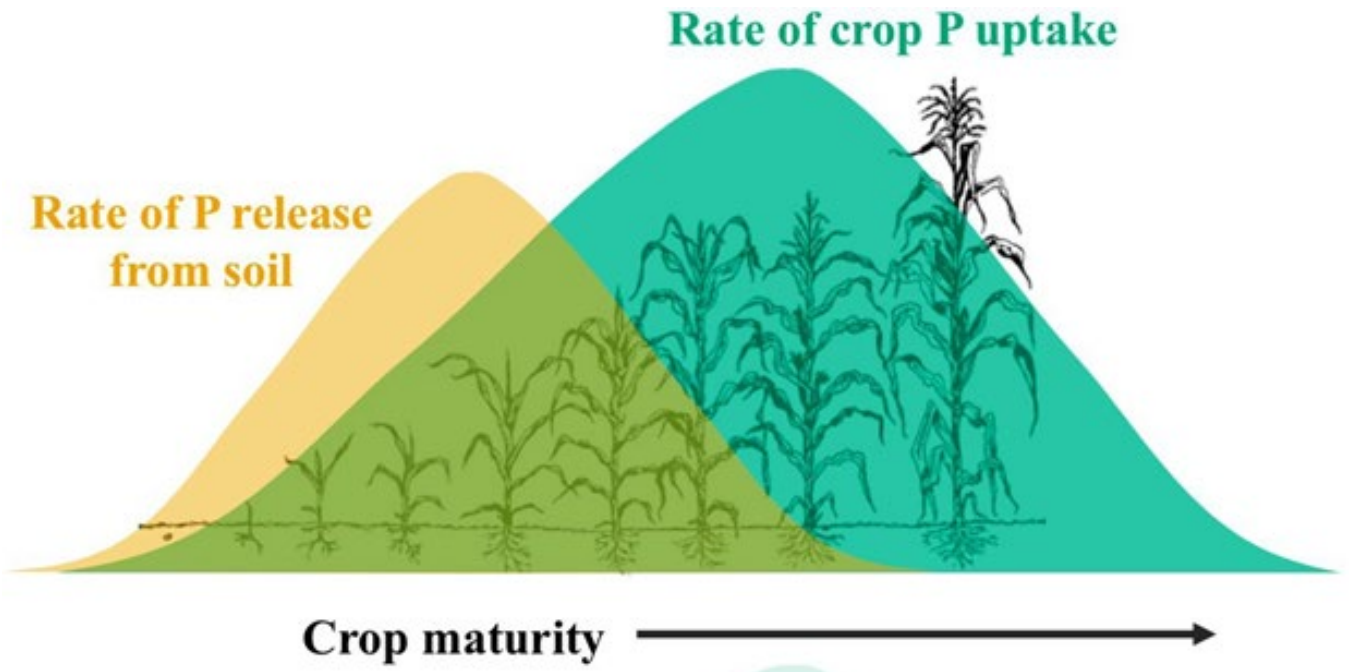
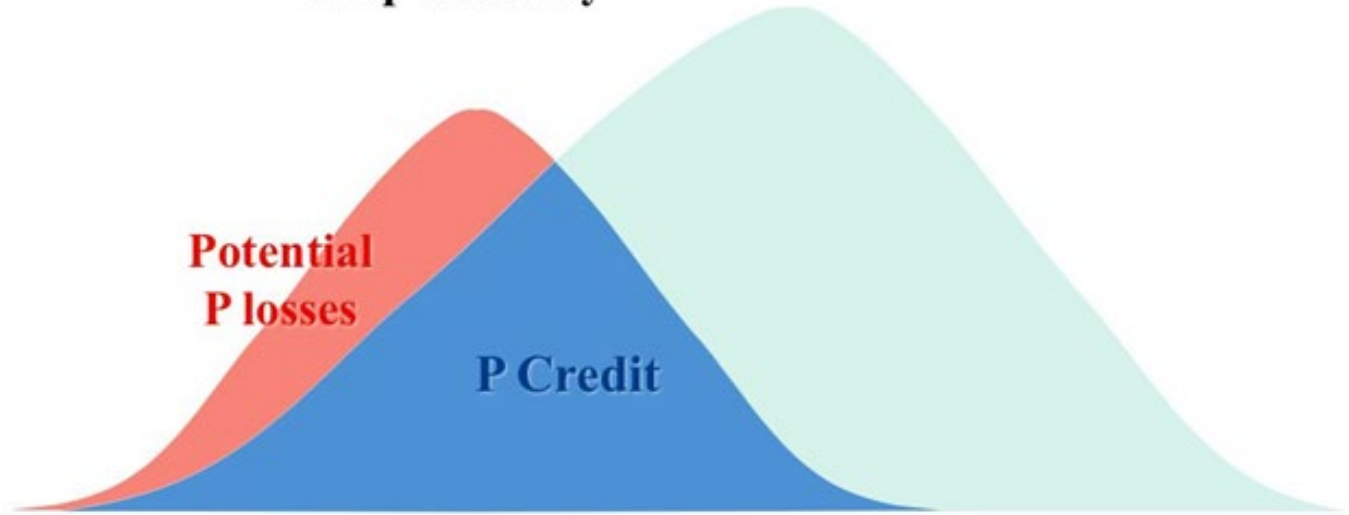
Currently: assistant professor at U. Missouri



How much P mineralizes from OM in Illinois production systems?



A soil P credit can help fine-tune P fertilization recommendations to increase nutrient use efficiency…..



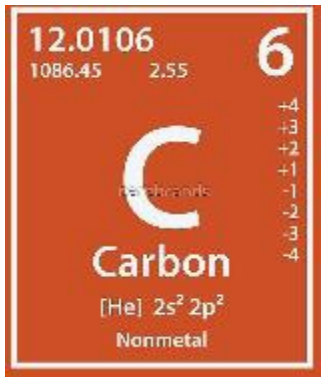
….and make the most of our soils' natural capital

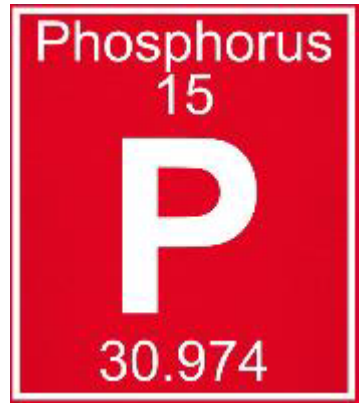
Nutrient credits from SOM

Soil organic matter (SOM) is…

100:10:1(ish)

C:N:P





Because C-N are tightly coupled (~10:1), we can make broad rules of thumb for the soil N credit **based on OM**

Conservative estimate is ~20 lb N/ac for every 1% OM

Caveats (of course!):

- How much depends on weather, in particular **temperature**
- Specific conversion (%OM to lb/ac of N) depends on **soil type**

Credit Soil Organic Matter for Nitrogen

December 9, 2008

Gary Zoubek, Extension Educator
Aaron Nygren, Extension Educator

The percent organic matter of the soil is a factor used by the University of Nebraska-Lincoln to make fertilizer recommendations for nitrogen fertilization in corn. Farmers, particularly those with high organic matter in their soils, need to encourage their soil test laboratories or crop consultants to take into account the nitrogen from soil organic matter when recommending nitrogen for corn. When nitrogen rates are based on a realistic yield goal, soil nitrates, legume credits, and potential nitrogen release from organic matter, nitrogen recommendations are reduced and fertilizer nitrogen is saved.

Added profit: $18.75/acre

Based on 28 pounds of nitrogen saved at $0.67/pound per each additional percent of organic matter in the soil for a field with a yield goal of 200 bushels (see *Example 1*)

Mineralization

One nitrogen source that is often forgotten is the mineralization of soil organic matter. In well-aerated soils, the end products of organic matter decomposition include CO_2, NH_4, H_2PO_4, and H_2O residues and many other

P!

https://cropwatch.unl.edu/giving-proper-nitrogen-credi…umes-corn-and-milo-rotations

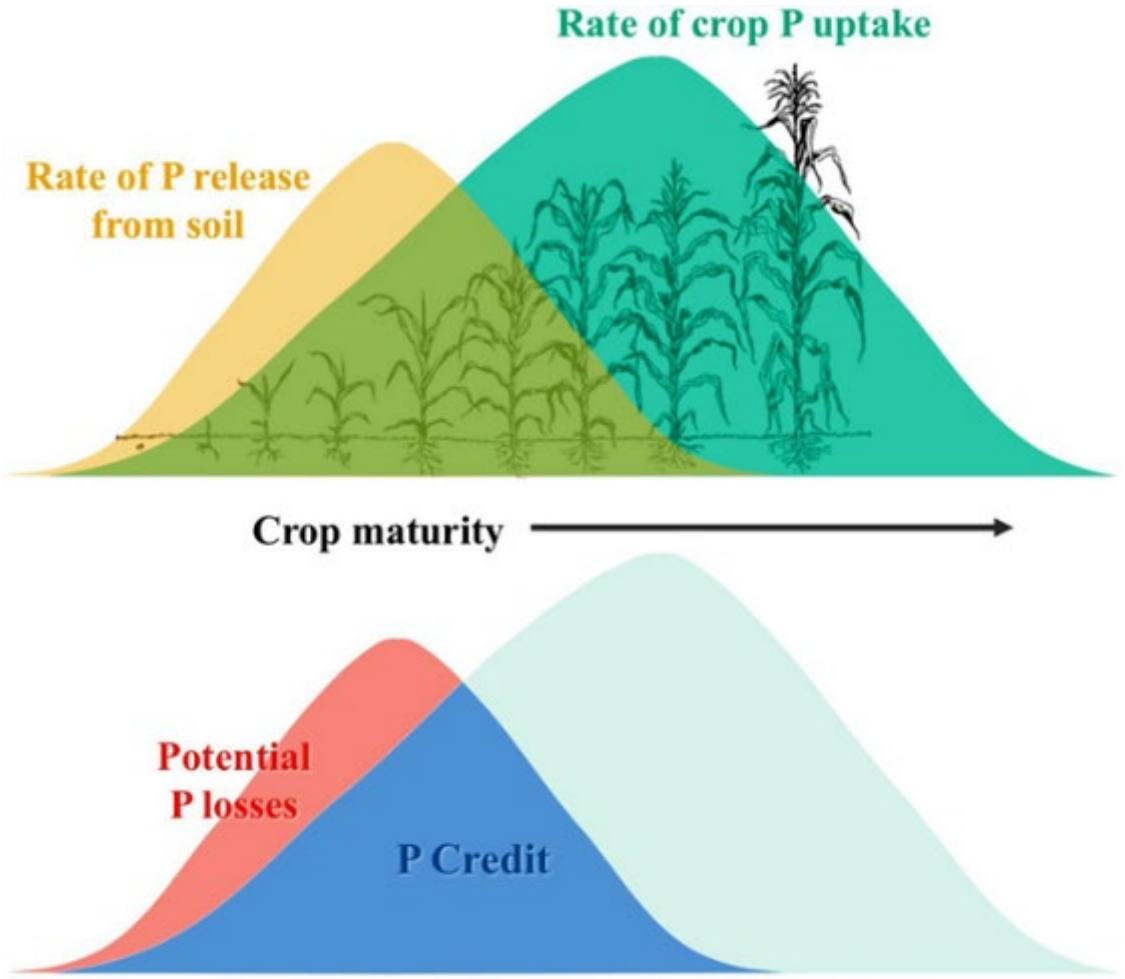
N and P are linked via C in soil organic matter (SOM)

Because C-N are more tightly coupled than C-P, **we aren't sure how OM% is related to a (likely) soil P credit**

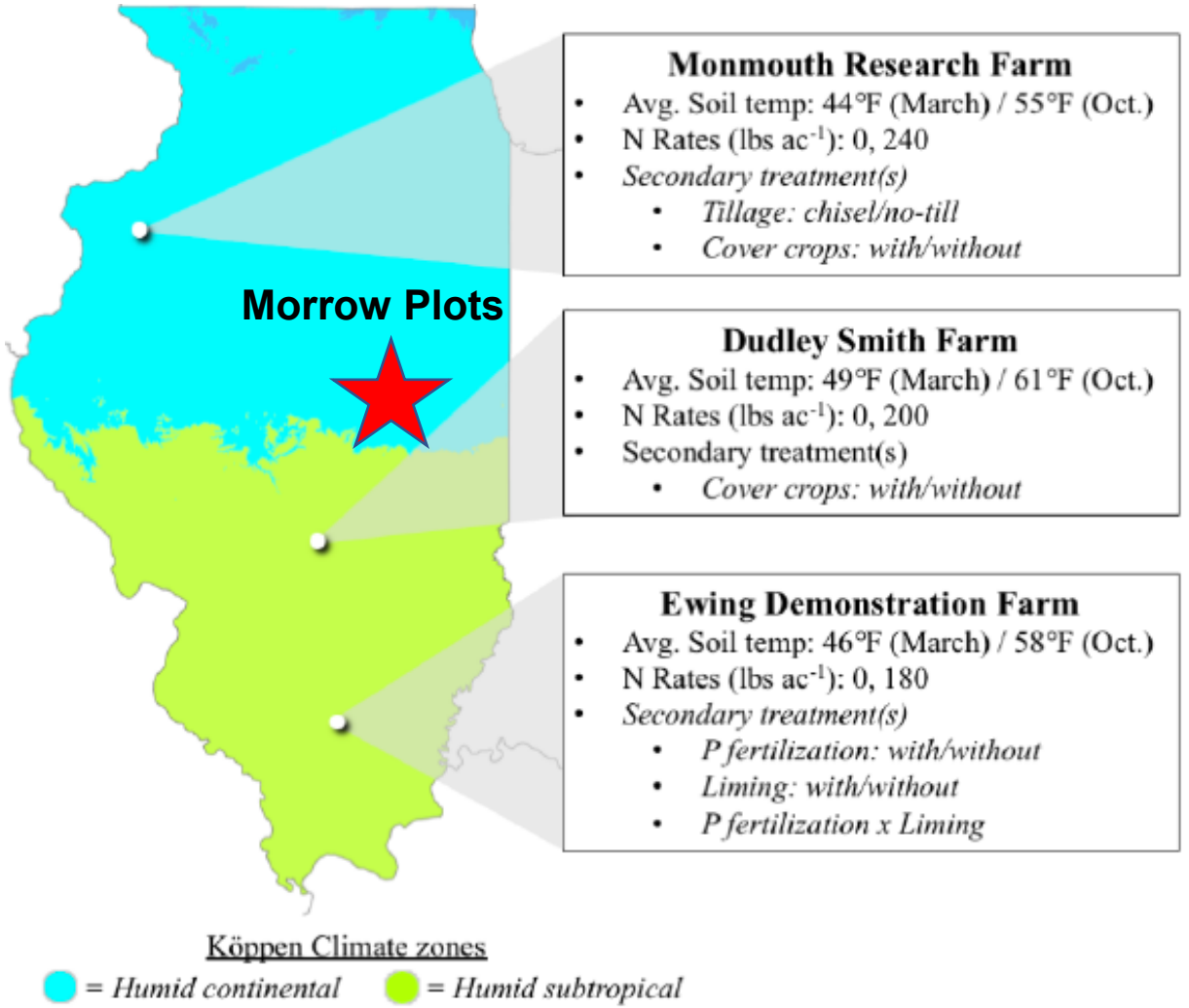
Top 6" of black prairie soils can hold up to 1200 lb/ac of P in **<u>organic form</u>**

→ Equivalent DAP value of $1,365

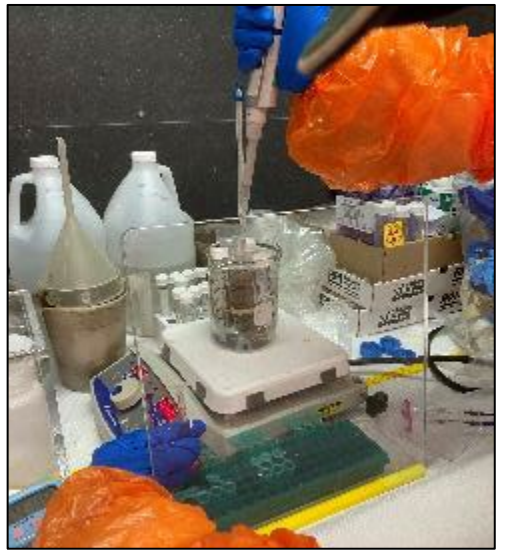
What is the range of a potential P credit for typical Illinois soils and managements?



Sites furnish gradients of soil and climate, and contrasts of management



Approach:
radioisotopic dilution

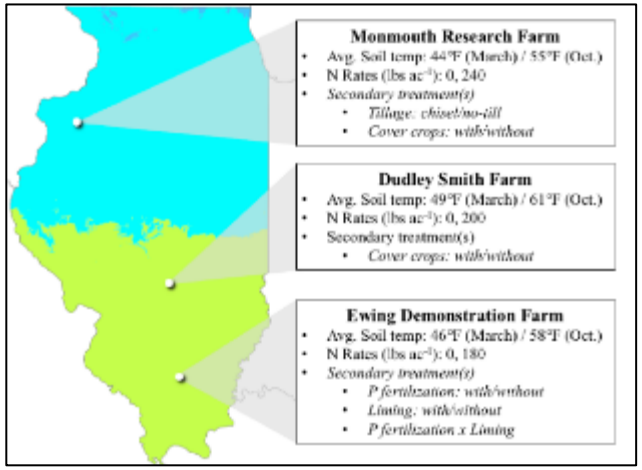


Soil sampling from diverse treatments and soil types

^{33}P method development

- Soil types of Illinois
- 5, 10, 20 °C set-up (41, 50, 68 °F)

P_{min} calculations



Model P credit: how much and why

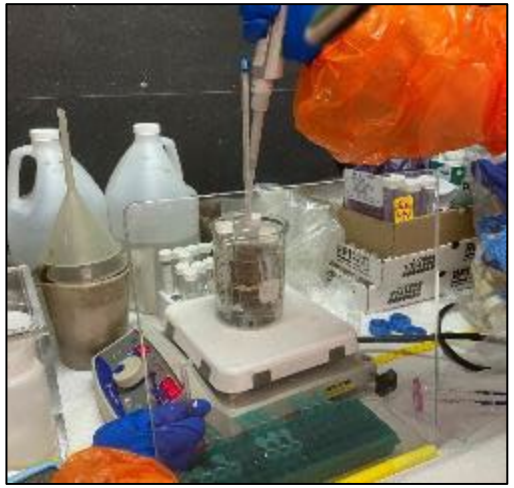
Phase 2: 2023 season

On-farm samples in Christian Co for P_{min}

Isotopic exchange kinetics (IEK) used to quantify P mineralization: rates and pool size

By measuring how much a pulse of 33-P is diluted by 31-P ('normal') generated by mineralization of soil organic P, we can infer P_{min}

Spike ^{33}P into soil



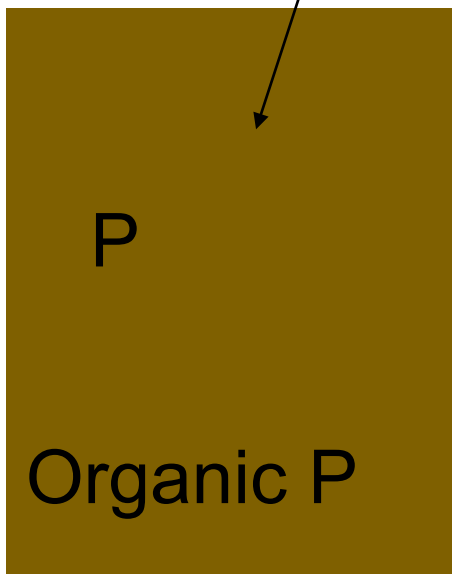
^{33}P ^{33}P ^{33}P

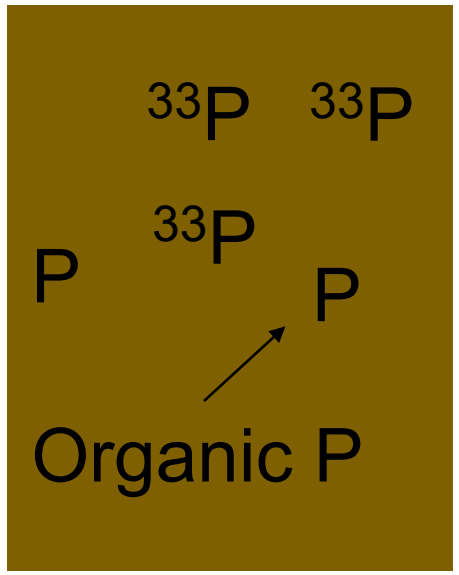
Non-labeled P mineralizes

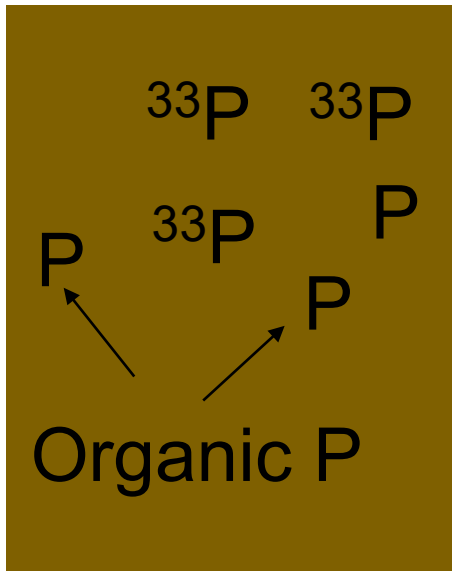
More dilution of ^{33}P with more P mineralization

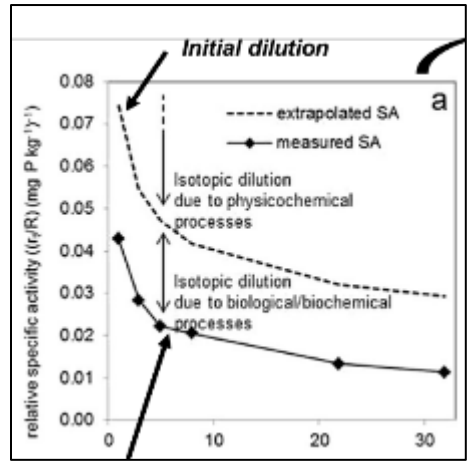
P_{min}

(lots of math)





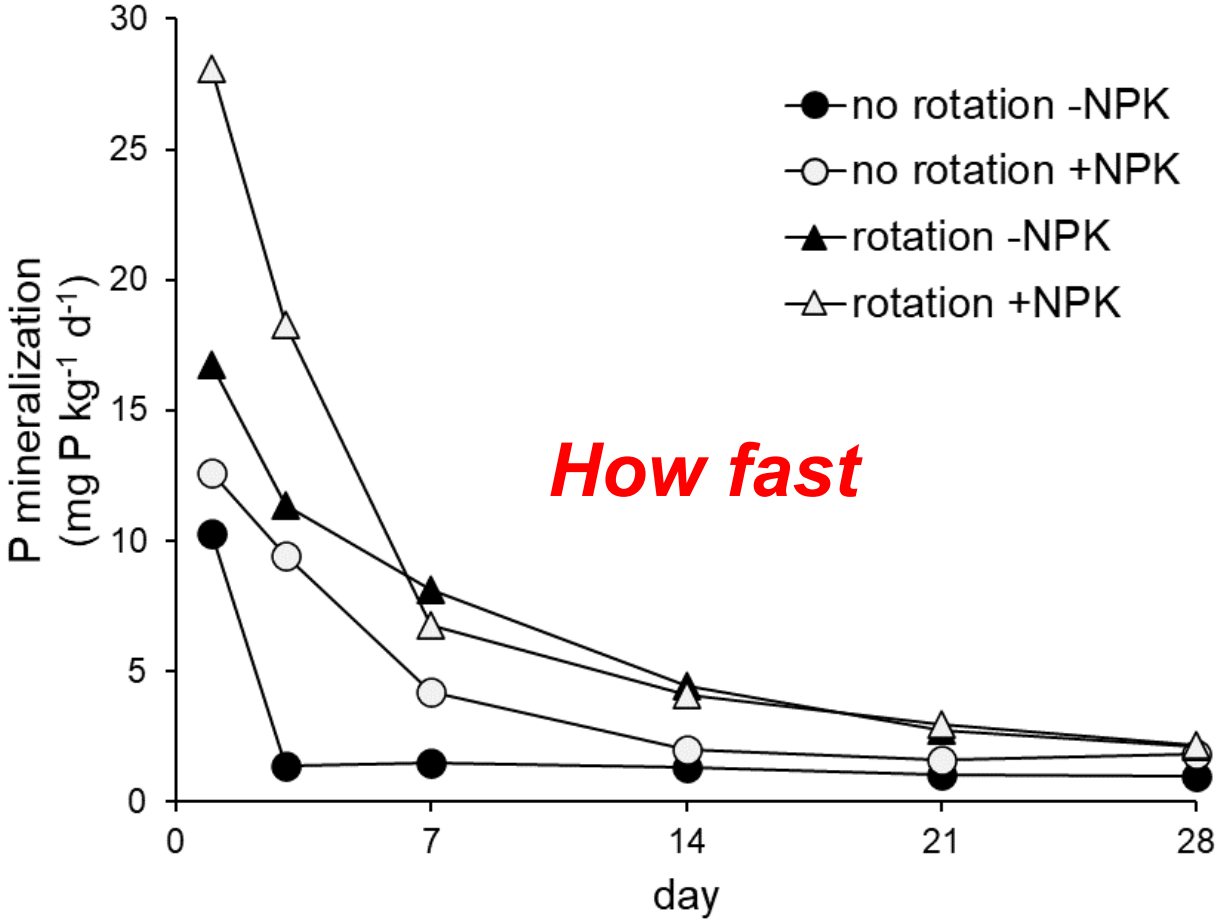




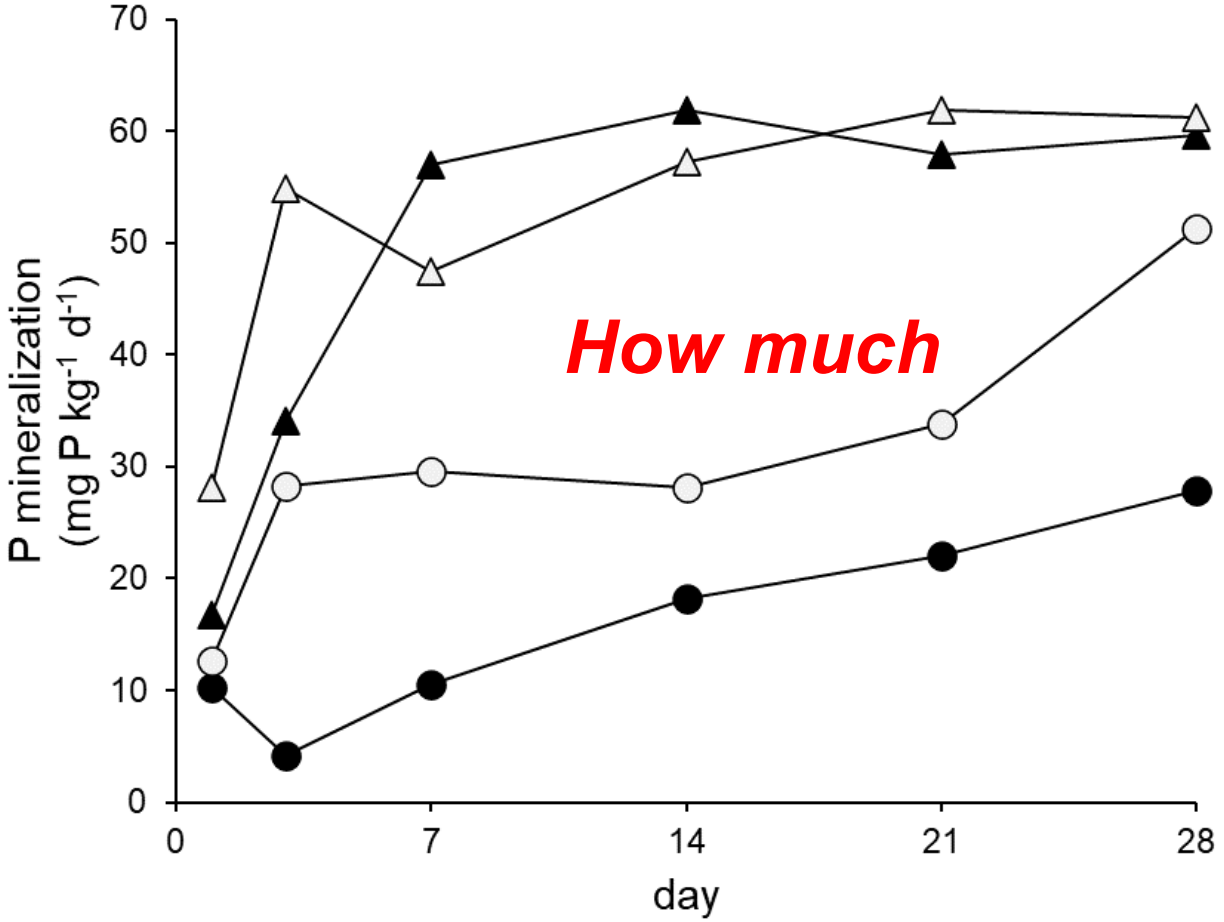
Rates vs pool size

- *How fast* versus *how much*
- P mineralization rates at days 21-28 used as steady state (mg kg^{-1} d^{-1}) = how fast
- Cumulative P mineralized over 28 days (mg kg^{-1}) = how much *could* mineralize

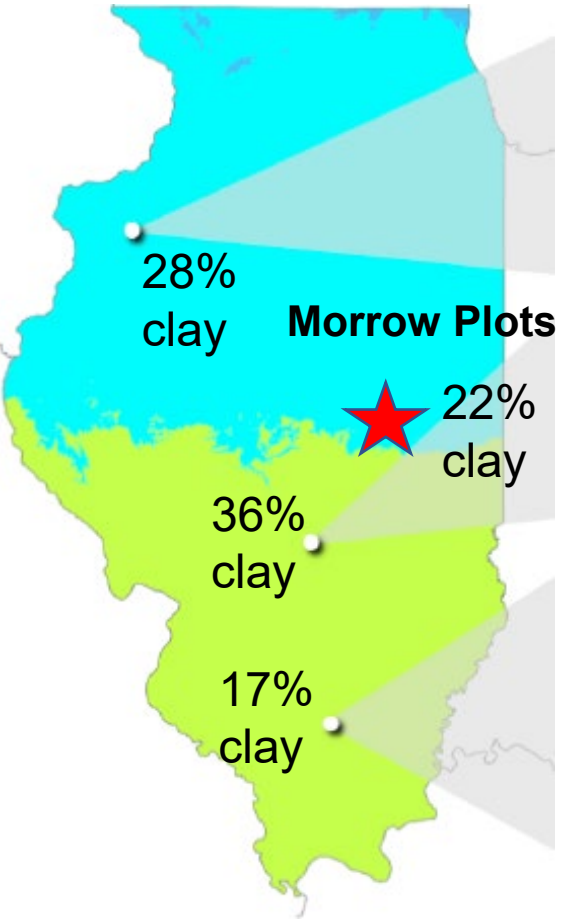
P mineralization rates



Cumulative P mineralized



Results: Most of the total P in surface soils is in organic form



Trial	Soil type	Treatment	Organic C (%)	C:N	pH	Total P (mg/kg)	Organic P (mg/kg)	Organic P (% of total)	Potentially min. P (mg/kg)	Potentially min. P (lb/ac)
Ewing	Alfisol	No lime, - P	1.0	9.4	4.6	233	190	81	12.1	24
Ewing	Alfisol	No lime, +P	1.1	9.3	4.7	556	488	88	53.3	107
Ewing	Alfisol	Lime, - P	1.0	8.7	5.3	203	192	94	14.1	28
Ewing	Alfisol	Lime, +P	1.3	9.4	5.0	568	497	87	59.2	118
Dudley-Smith	Alfisol	- CC, +N	1.7	11.3	5.8	666	419	63	34.8	70
Dudley-Smith	Alfisol	+CC, +N	1.8	12.0	5.9	732	444	61	30.9	62
Dudley-Smith	Alfisol	-CC, -N	1.8	11.7	5.8	762	452	59	56.9	114
Dudley-Smith	Alfisol	Pasture	2.0	11.1	6.3	546	376	69	43.9	88
Morrow	Mollisol	Corn-corn, -NPK	1.5	11.7	6.2	530	411	78	27.8	56
Morrow	Mollisol	Corn-corn, +NPK	2.1	11.3	7.4	654	479	73	51.2	102
Morrow	Mollisol	Corn-soy, -NPK	2.0	12.5	6.5	486	430	88	59.7	119
Morrow	Mollisol	Corn-soy, +NPK	2.7	12.8	7.1	796	512	64	61.3	123
Monmouth	Mollisol	Till, +N	2.3	12.8	6.9	638	501	79	100.6	201
Monmouth	Mollisol	No-till, +N	2.5	12.4	5.5	629	592	94	61.5	123
Monmouth	Mollisol	corn-soy, -N	2.7	12.4	6.9	636	539	85	57.0	114
Monmouth	Mollisol	corn-soy, +N	2.3	13.5	7.2	603	446	74	36.3	73
n/a	Mollisol	Forest	5.9	13.7	7.3	1358	1247	92	152.2	304
n/a	Mollisol	Prairie	3.3	13.9	7.2	702	540	77	45.8	92

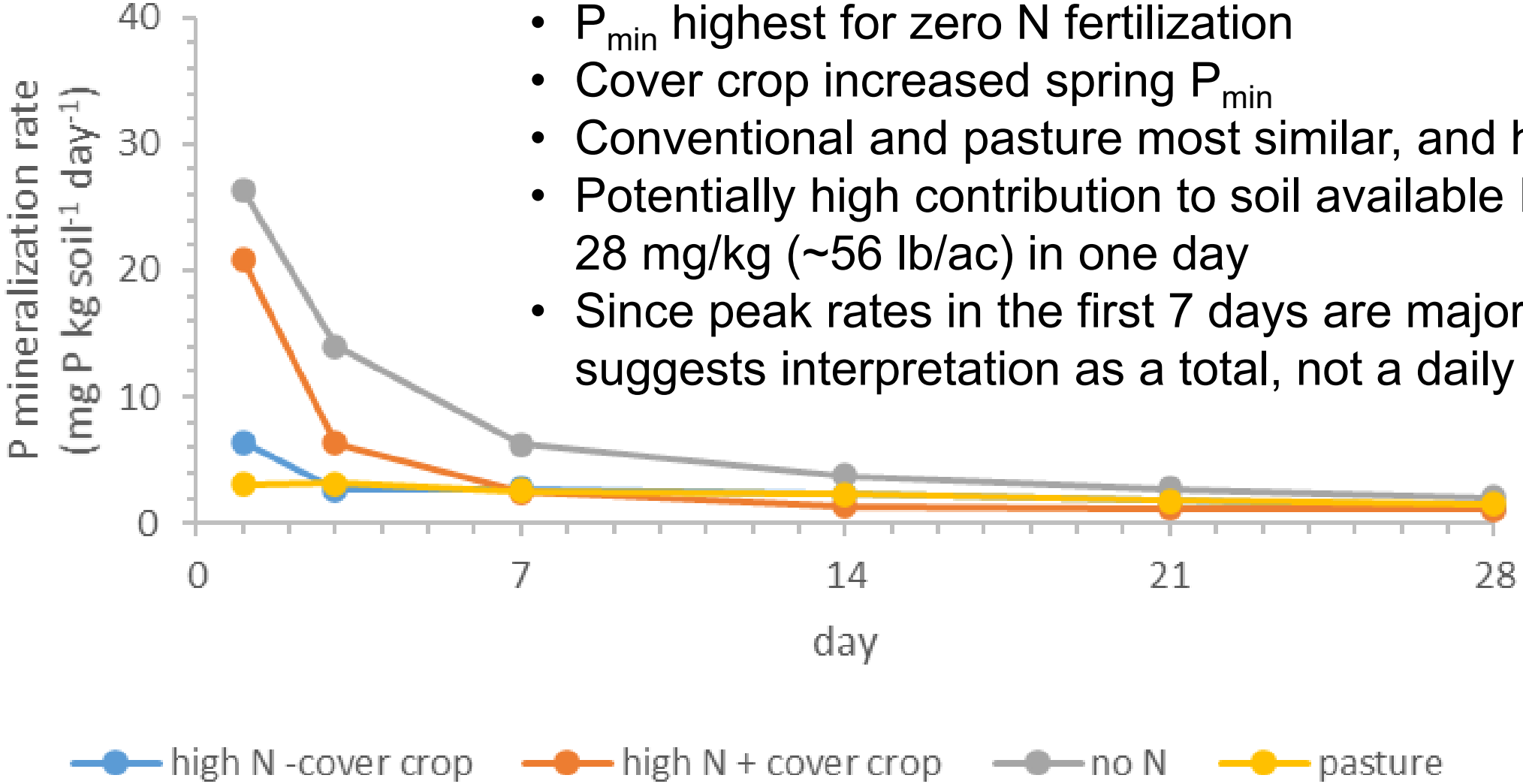
Major takeaways

- There is *a lot* of organic P in topsoil: 190-1247 mg/kg → 59 – 94% of total P
- Potentially mineralizable P in agricultural soils was 95 ± 43 lb/ac, nearly the same as in prairie soils (94 lb/ac)
- Assuming half of this potentially mineralizable P is mineralized in a growing season, soil P credit would range 12 to 100 lb/ac
- How much P is *actually* mineralized will….
  - …likely depend on weather, as for N mineralization
  - …timing of P mineralization and synchrony of P release from organic matter with crop need will determine contributions of soil organic P to crop uptake

1. Potential mineralization of P *can* be agronomically significant

Dudley Smith

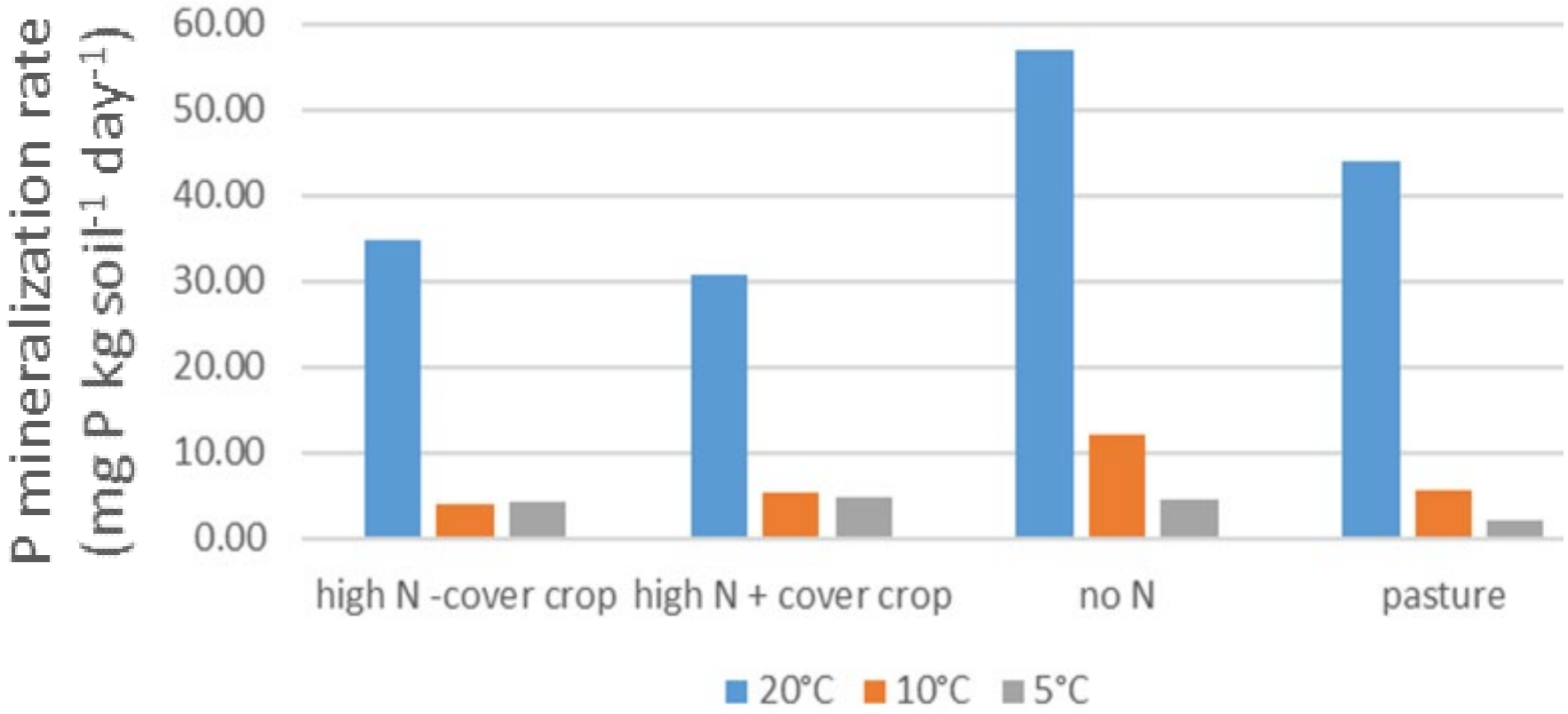
- P_{min} highest for zero N fertilization
- Cover crop increased spring P_{min}
- Conventional and pasture most similar, and had lowest P_{min}
- Potentially high contribution to soil available P = peak *rate* of 28 mg/kg (~56 lb/ac) in one day
- Since peak rates in the first 7 days are majority of P_{min}, this suggests interpretation as a total, not a daily rate



2. Mineralization of P is highly **temperature sensitive**

Dudley Smith

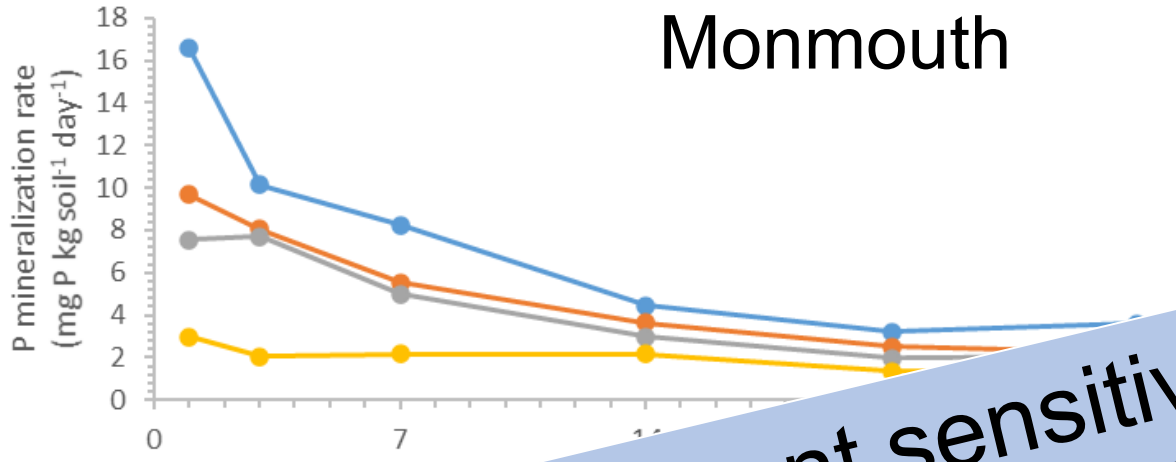
- P_{min} higher by 5-7x at 68°F vs 50-41°F soil temps
- Similar temp-sensitivity by management system (a good thing!)



(41, 50, 68 °F)

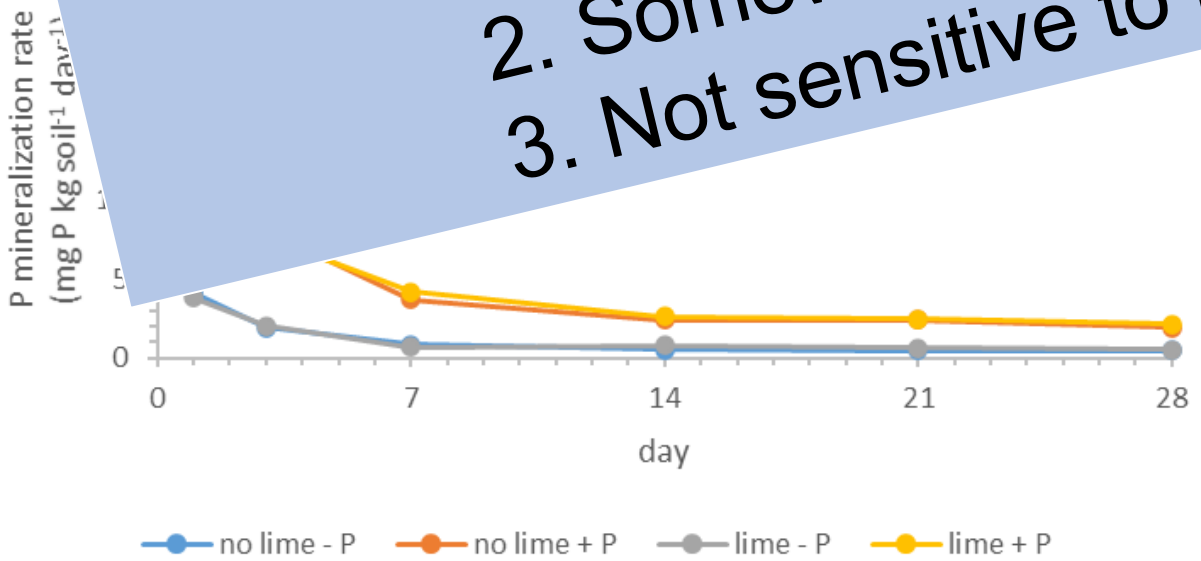
3. Mineralization of P can be **management sensitive**

Monmouth



- **Sable series**
- Like Dudley Sm
  high

Management sensitive
1. Most sensitive to tillage, P and N application
2. Somewhat sensitive to cover cropping
3. Not sensitive to liming

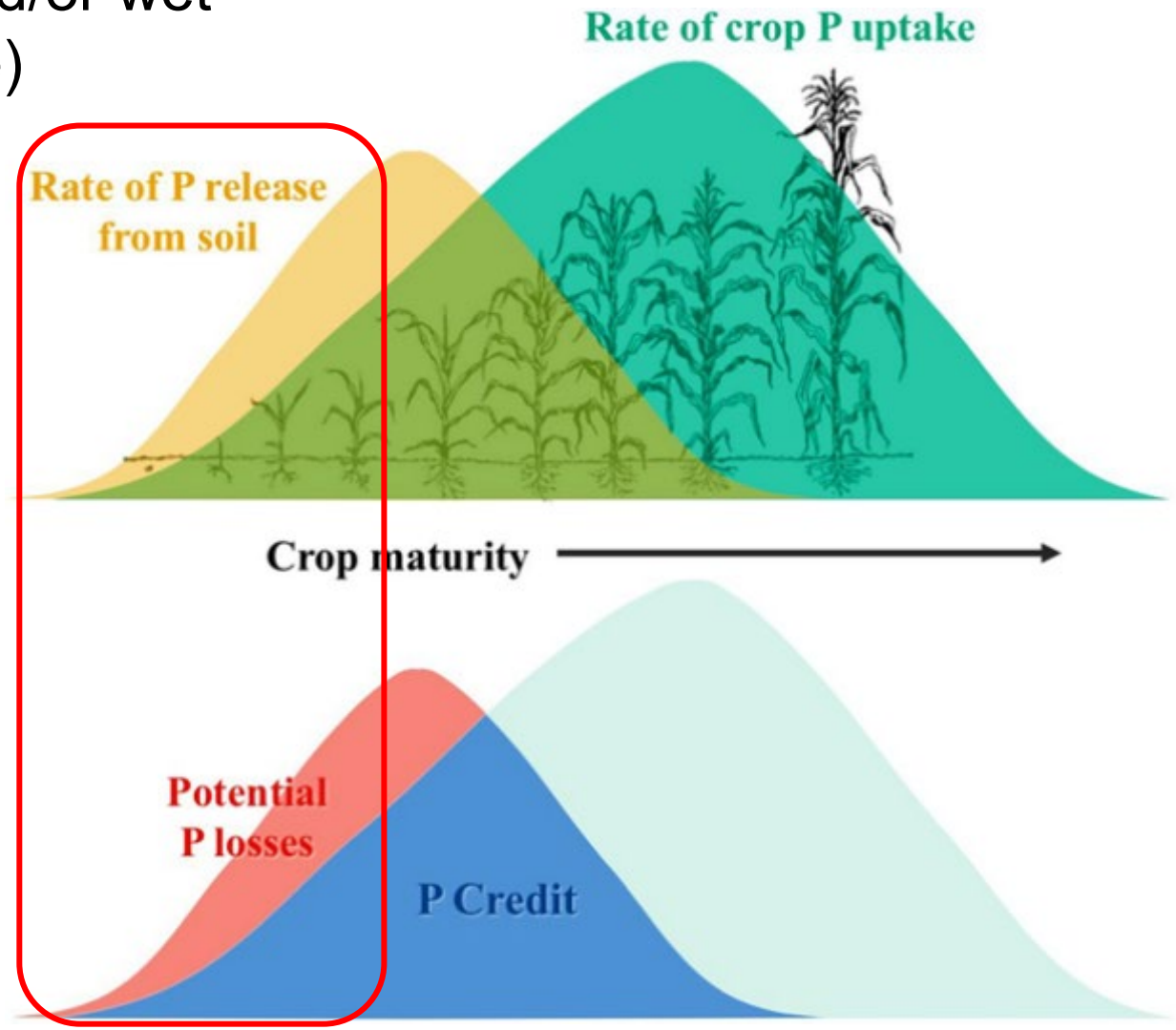


- **Cisne series**
- History of P fertilization entails higher P_{min}
- Negligible effect of liming

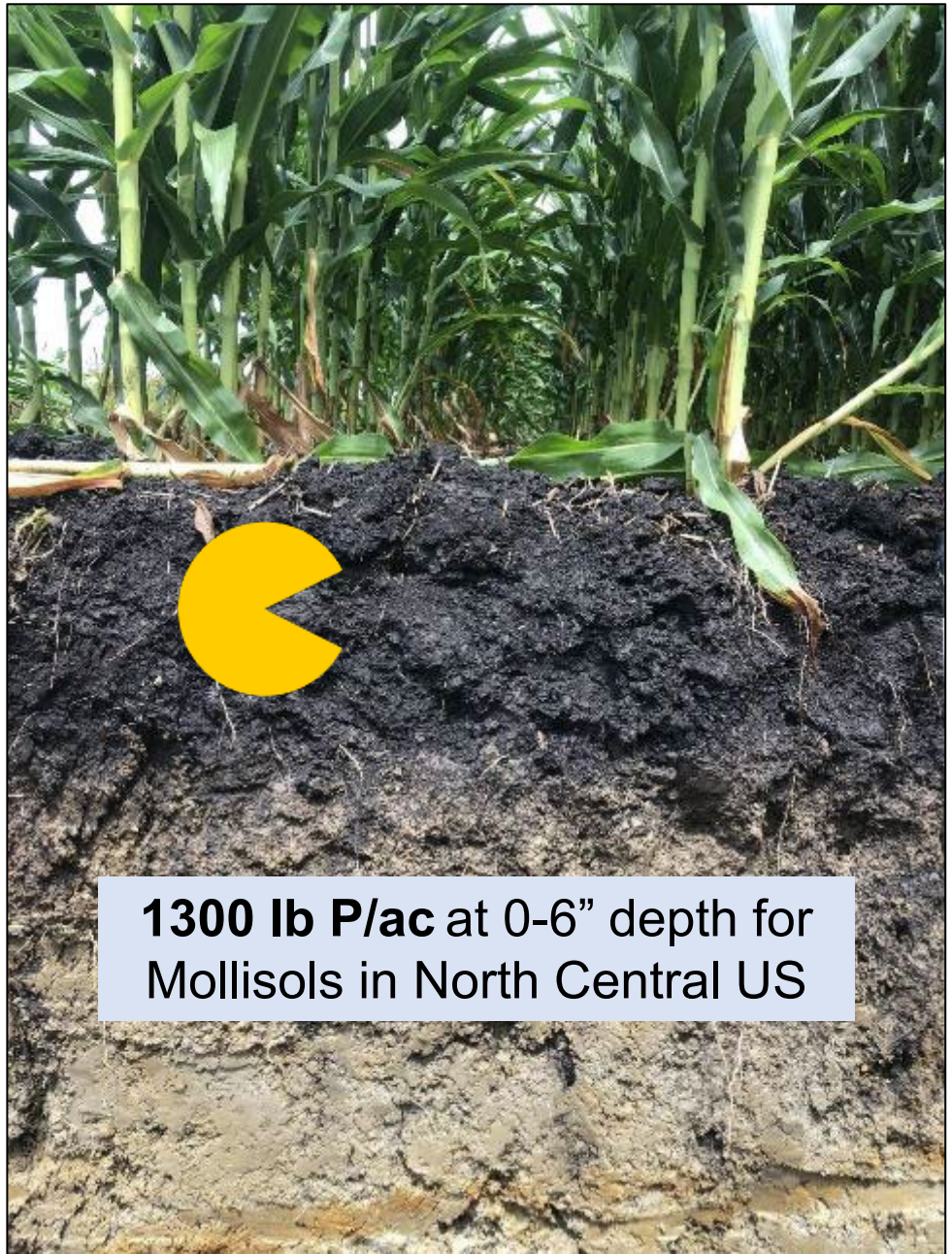
What could this mean for crop P uptake?

- P mineralization could be appreciable in early season
- Early season P deficiency: overly cool and/or wet weather (spring P effect, fallow syndrome)

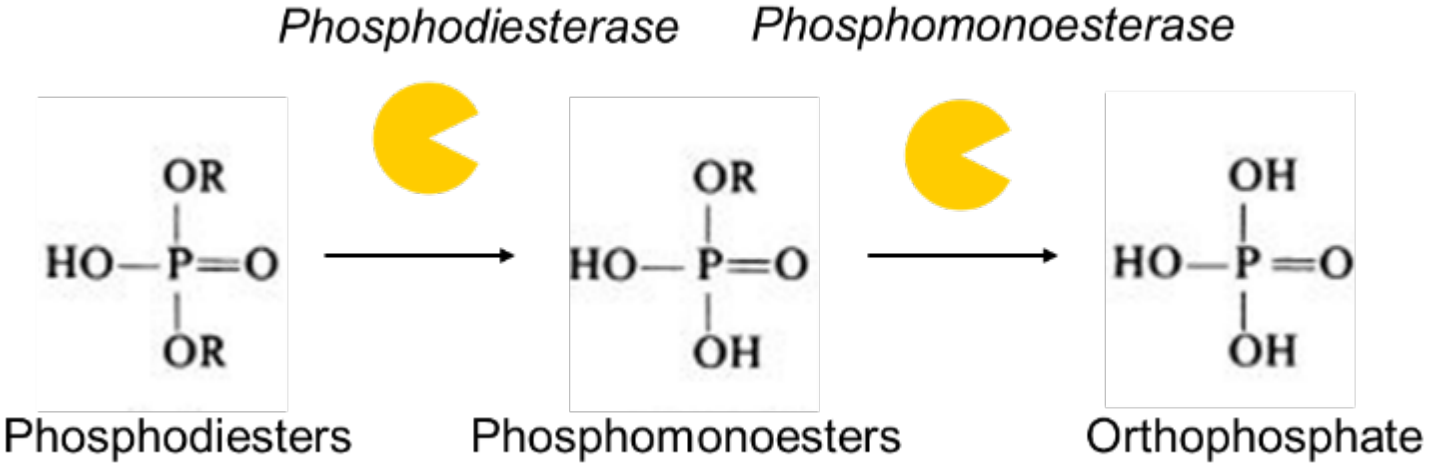
Dr. Dan Kaiser, University of Minnesota



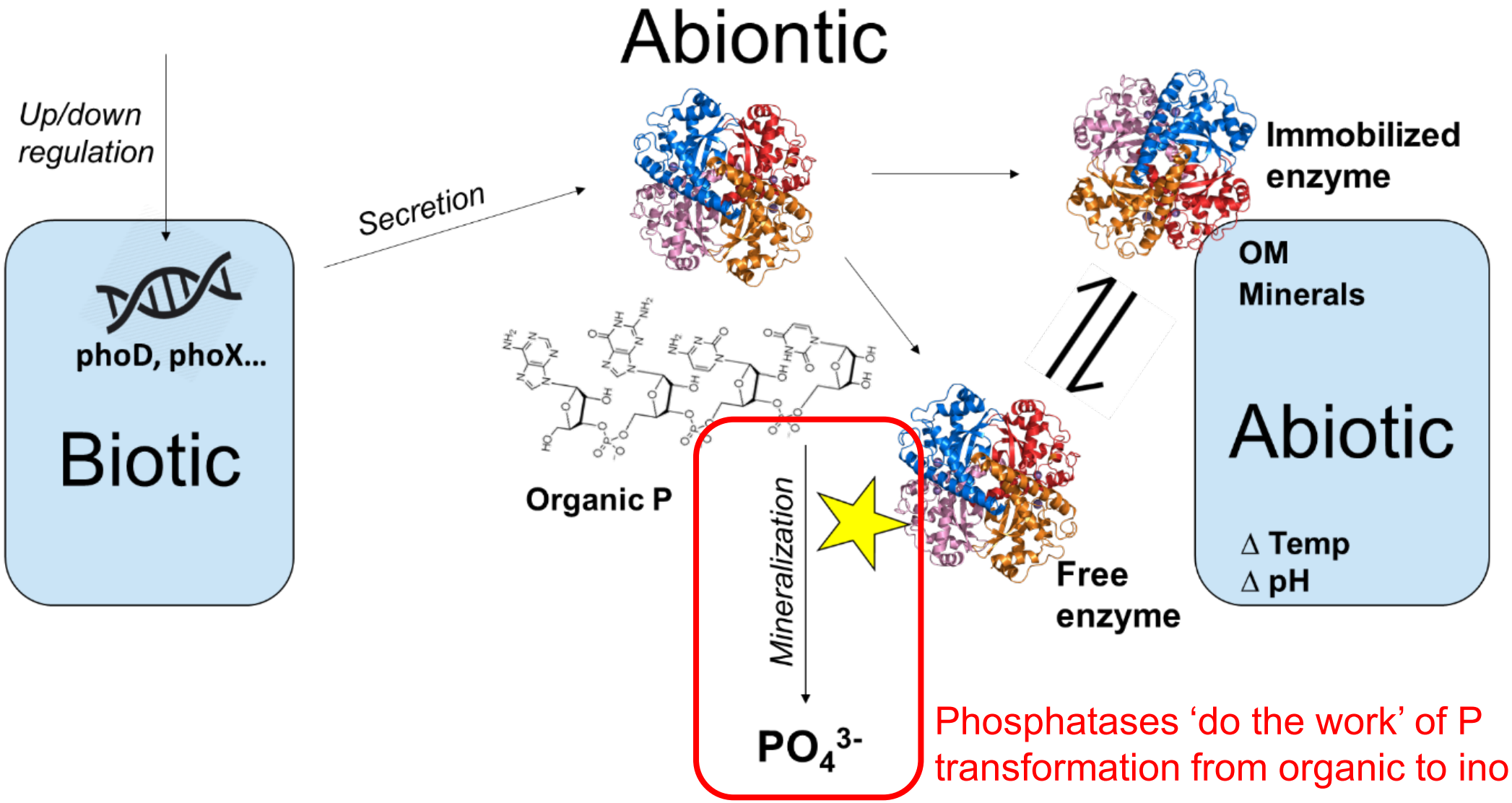
Can soil enzyme activities be used to explain the potential P credit?



- Extracellular enzymes in soils that “digest” organic matter to release P, as well as N and S
- Phosphatases catalyze the process of mineralization
- Phosphatases are recommended USDA NRCS soil health indicators



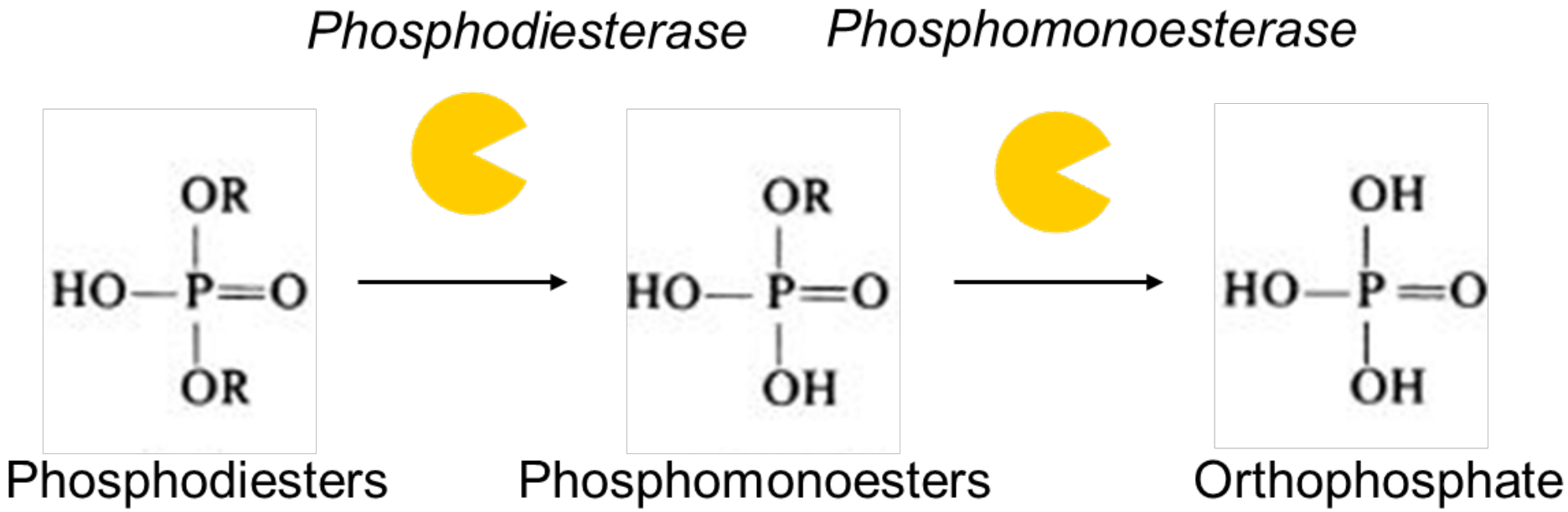
Phosphatases integrate biotic × abiotic



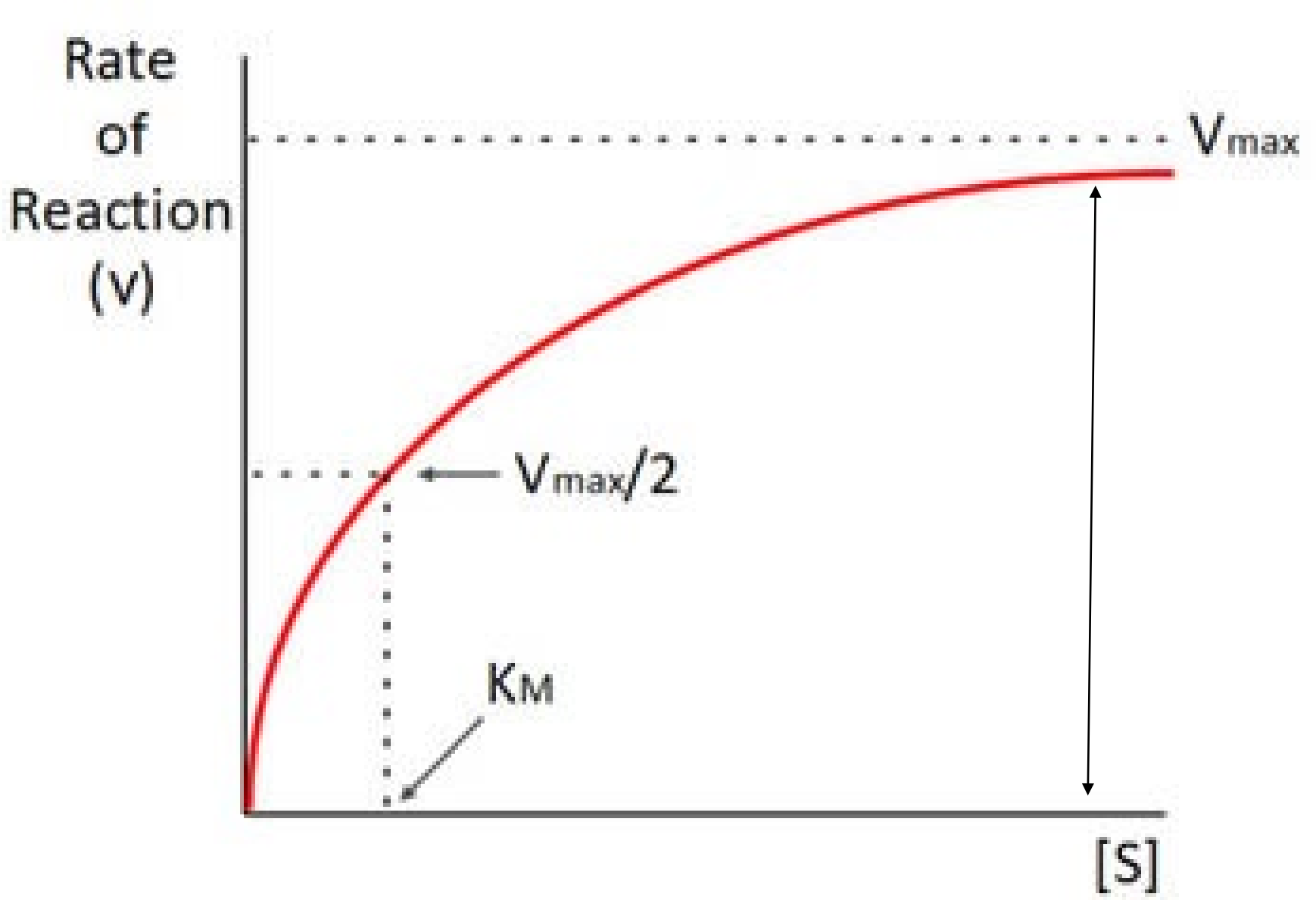
Phosphatases 'do the work' of P transformation from organic to inorganic P

Basics of phosphatases in the P cycle

- P depolymerization-mineralization: a two-step process catalyzed by two phosphatases
  1. Phosphodiesterase (E.C. 3.1.3)
     - 1st step, proposed to be rate-limiting
     - Not currently considered a soil health indicator; proposed in USDA NRCS Tech. Note 450-03
  2. Phosphomonoesterase (E.C. 3.1.4)
     - 2nd step, responsible for mineralization
     - (oddly?) generally highest activities of all hydrolytic enzymes assayed
     - USDA NRCS soil indicator, as “acid phosphatase” or “alkaline phosphatase”



V_{max} and K_m: kinetic properties of soil enzymes



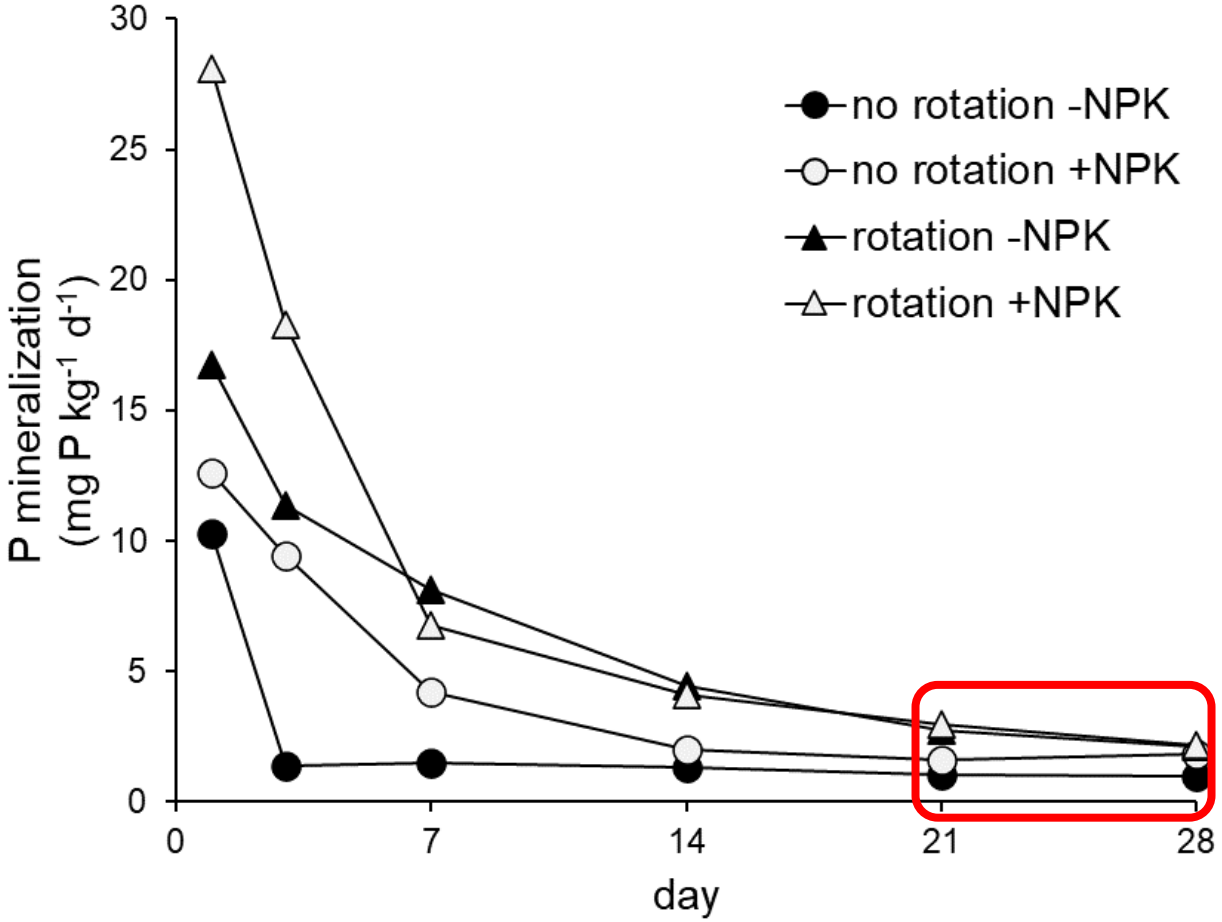
Most accurate, and thus comparable, measurements of enzyme activities

(μmol *p*NP g^{-1} h^{-1})

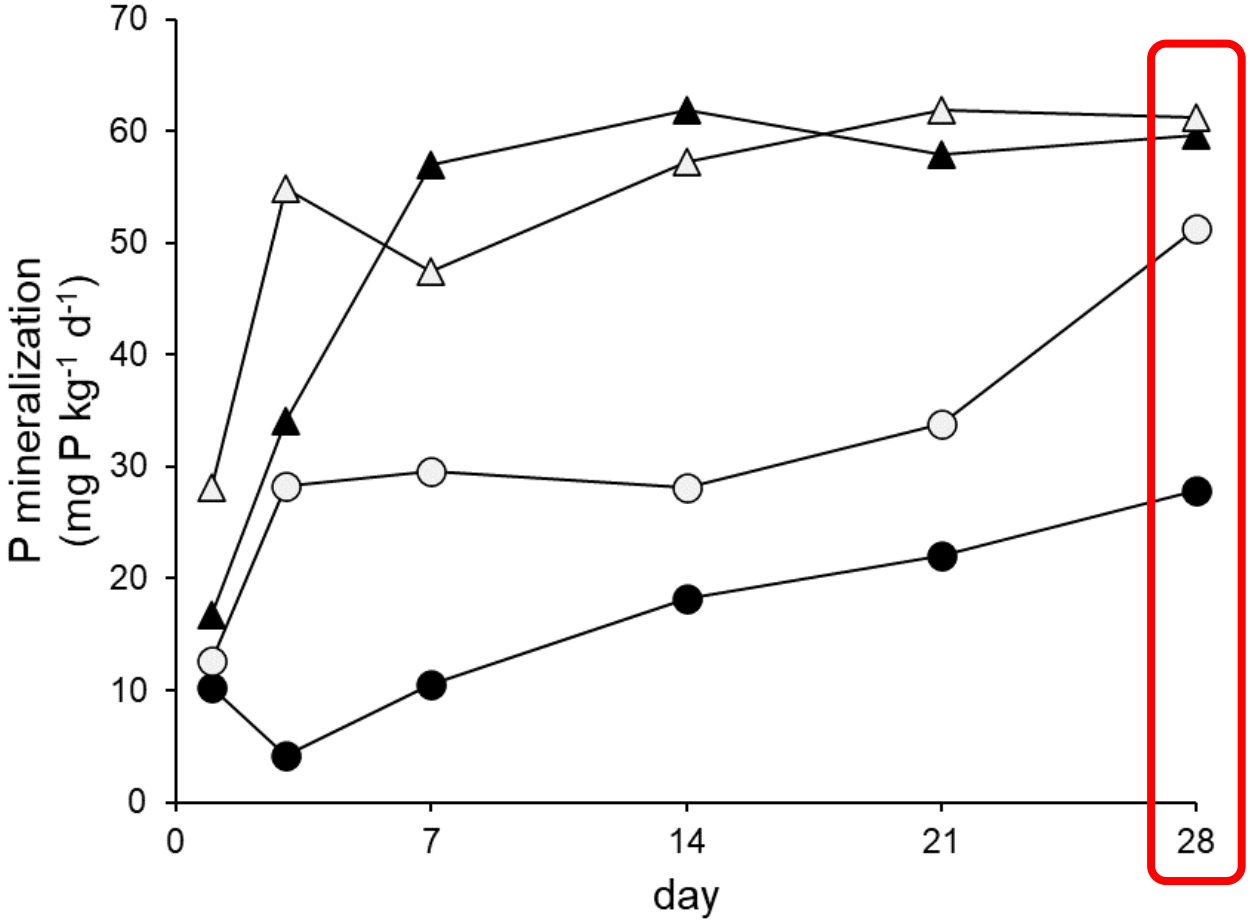
What metrices of P mineralization to use? Rate and pool size

- Phosphatase activity (V_{max}) and (K_m) measured at day 28
- P mineralization rates at days 21-28 used as steady state (mg kg^{-1} d^{-1})
- Cumulative P mineralized over 28 days (mg kg^{-1})

P mineralization rates

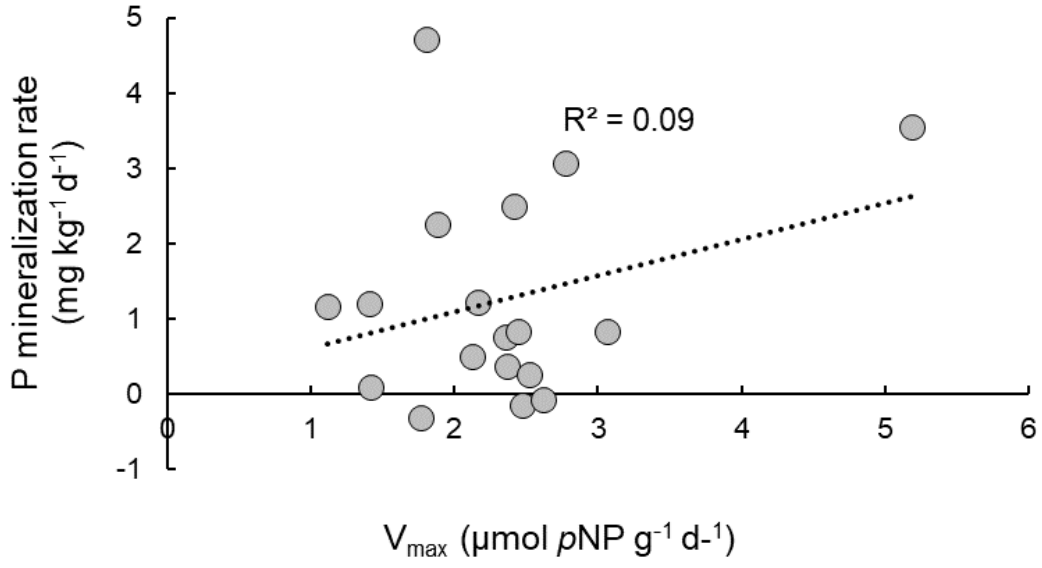


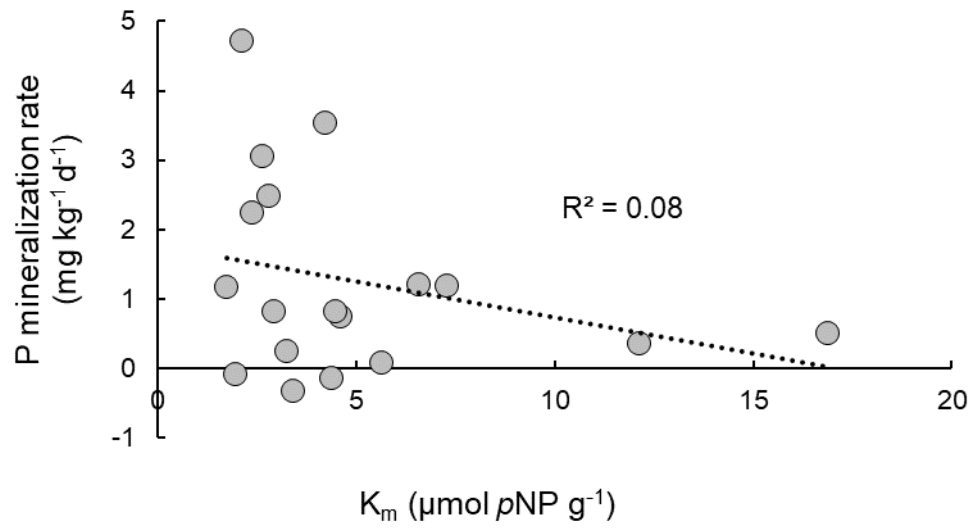
Cumulative P mineralized



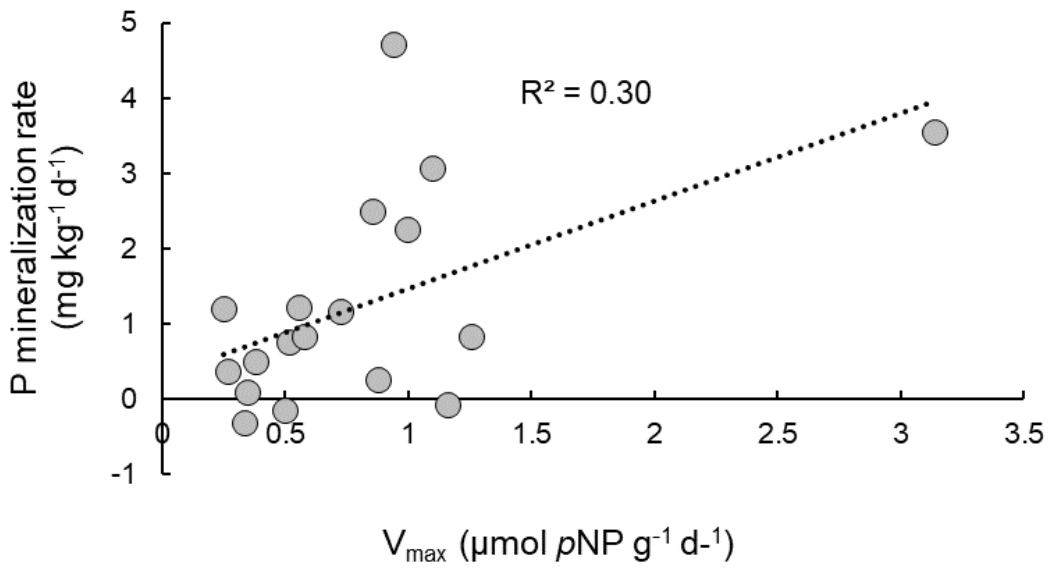
Phosphatase kinetic parameters and P mineralization (**rates**)

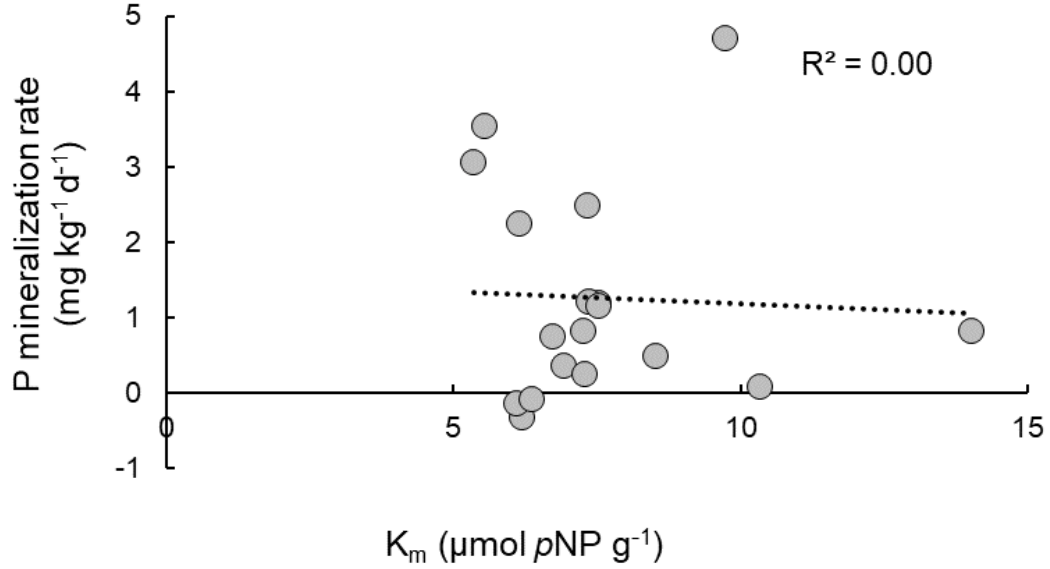
Phosphomonoesterase





Phosphodiesterase





V_{max}

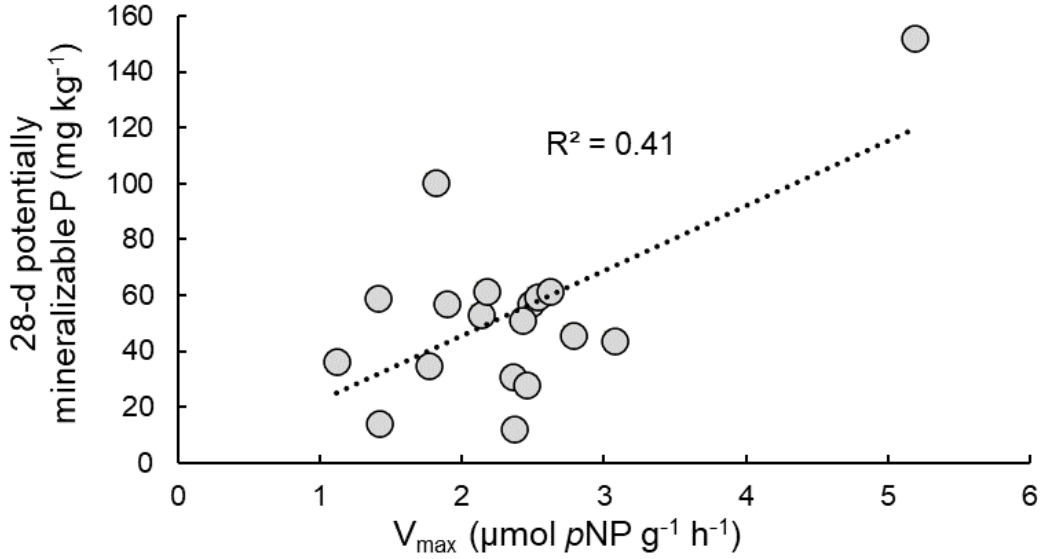
K_m

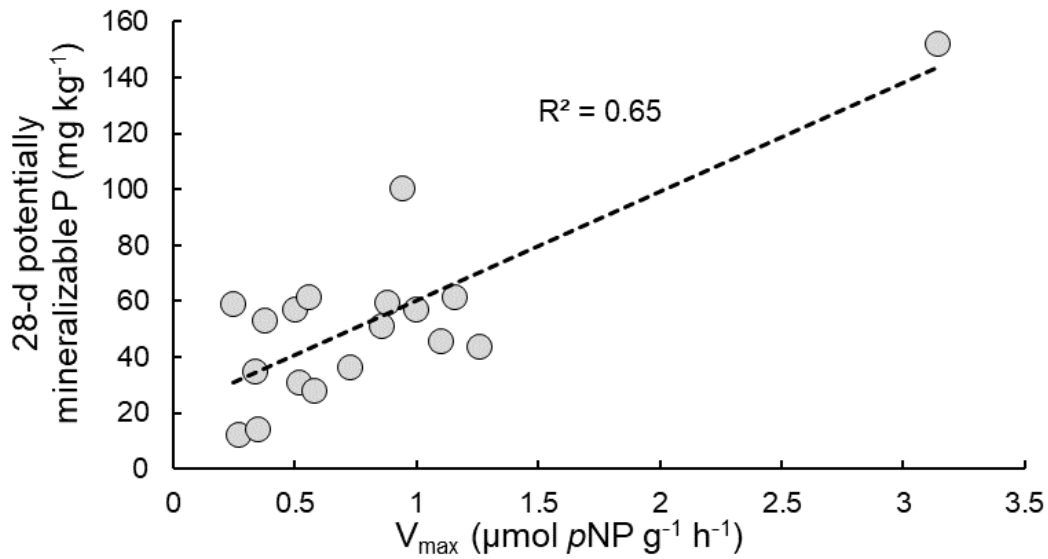
Phosphatase kinetic parameter and mineralizable P (**pool size**)

Phosphomonoesterase

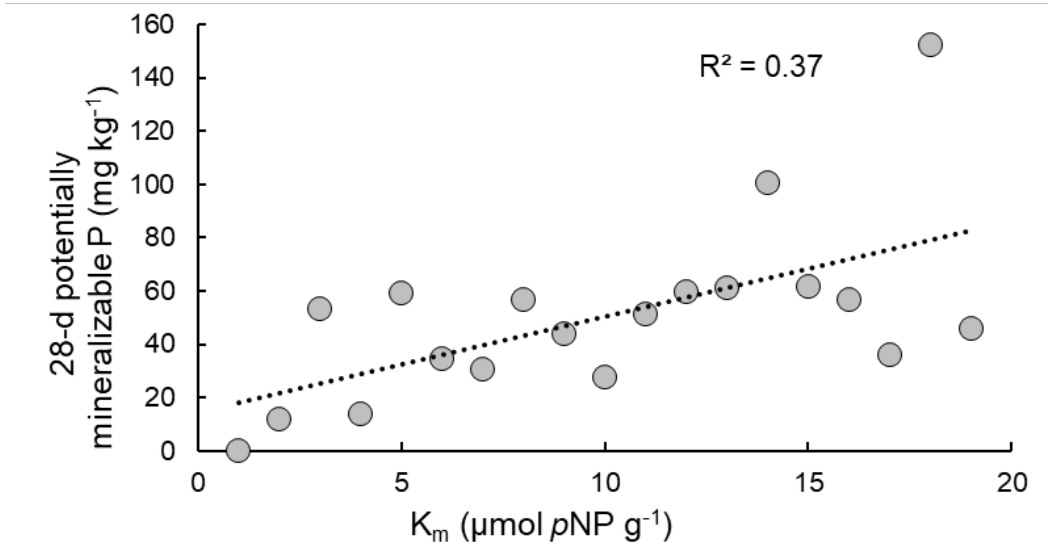
Phosphodiesterase

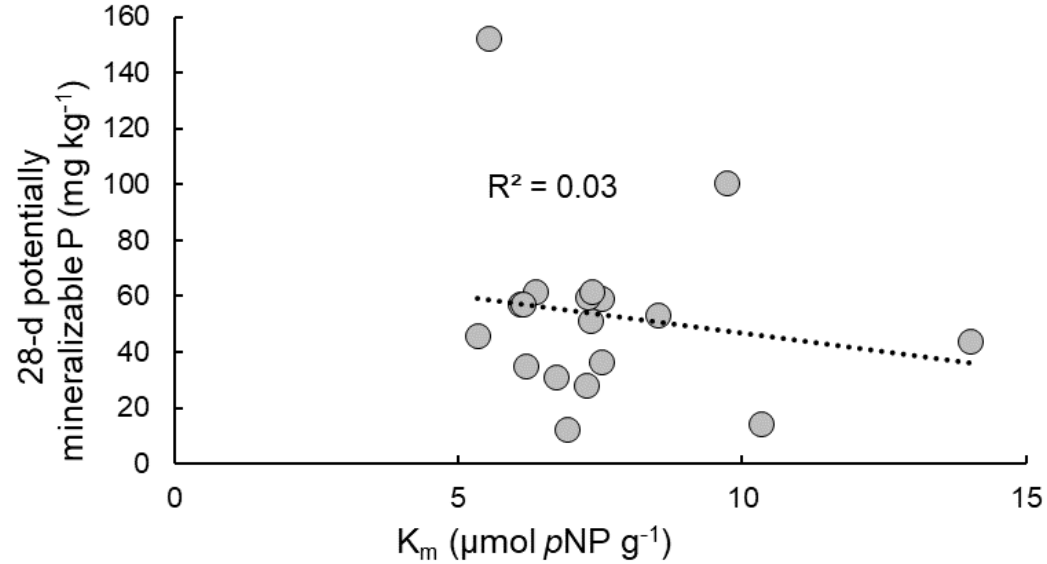
V_{max}





K_m





Enzyme activities taken literally do not make sense

- Assume a phosphomonoesterase activity of 2 μmol *p*NP g^{-1} h^{-1}

2 μmol *p*NP g^{-1} h^{-1}

For 24 hours ⇩

48 mmol P kg^{-1}

Convert to mass P ⇩

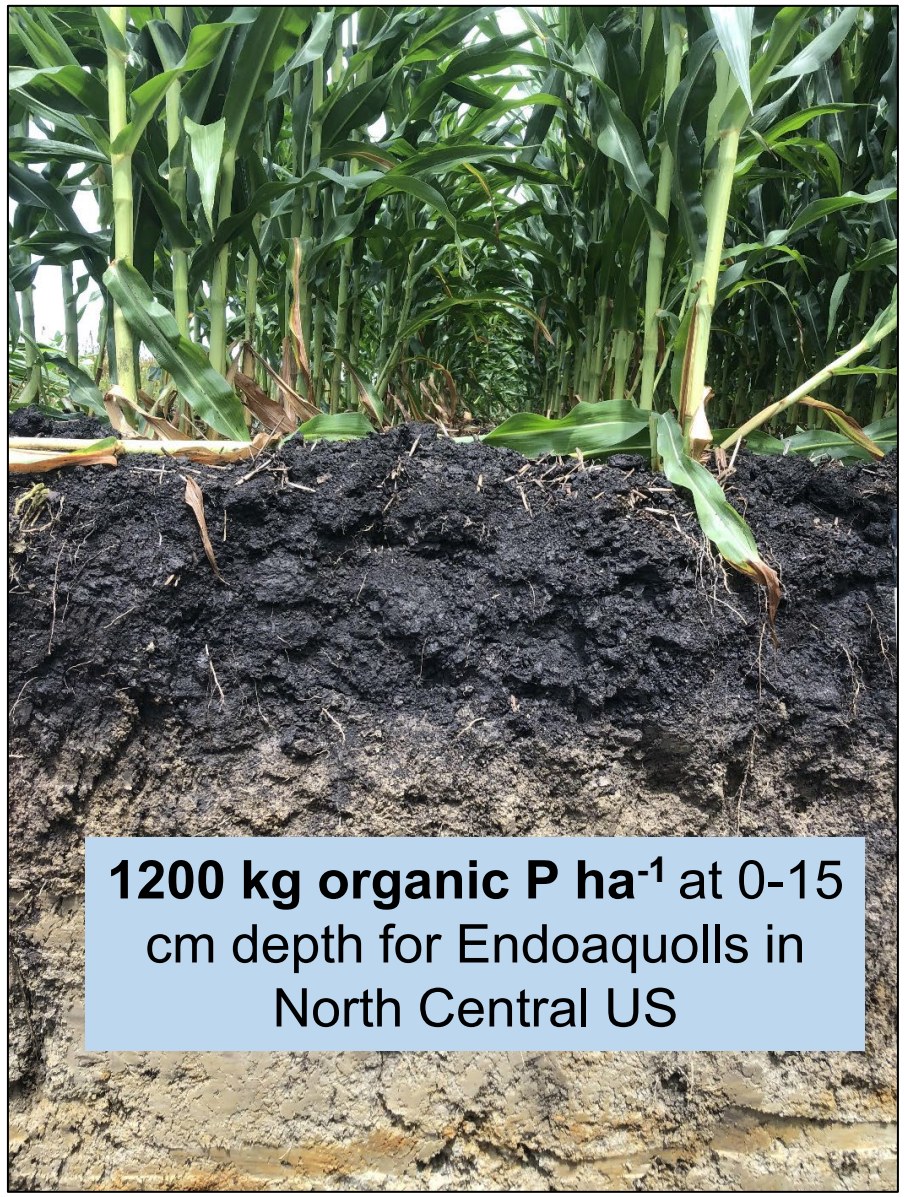
1,486 mg P kg^{-1}

Convert to per unit area ⇩

2,970 kg P ha^{-1} at 0-15 cm depth

⇩

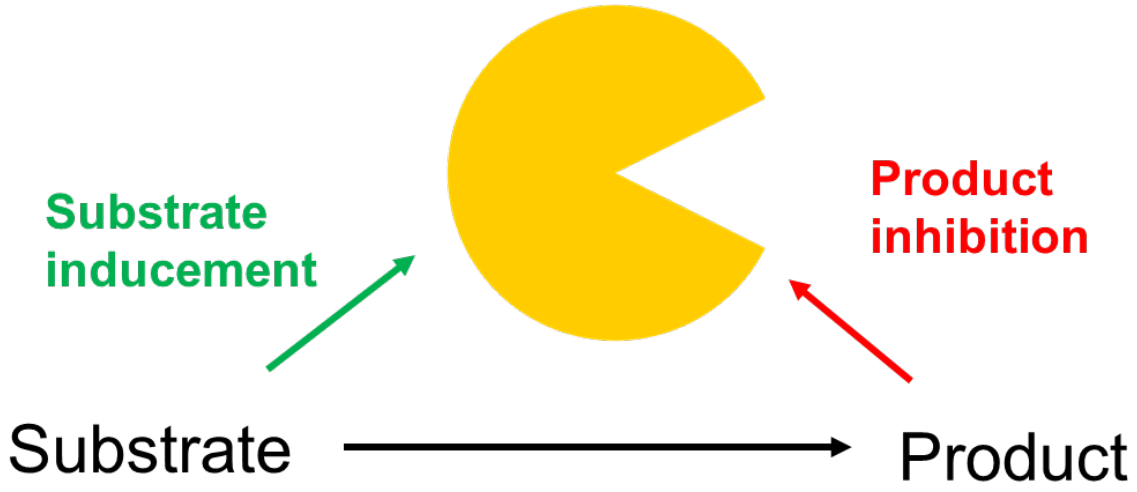
Less than one day's worth of organic P to be mineralized *if* measured activities operated in situ



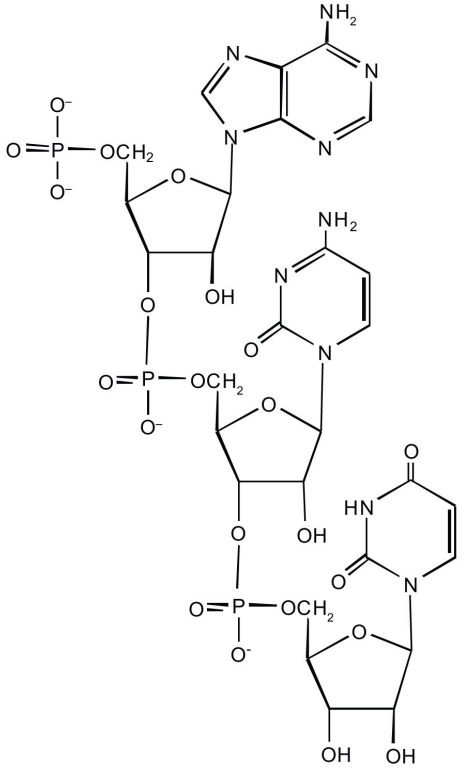
Additional potential explanations

- Does enzyme activity increase because there is a deficiency in the product, or because there are overall higher rates of nutrient cycling?

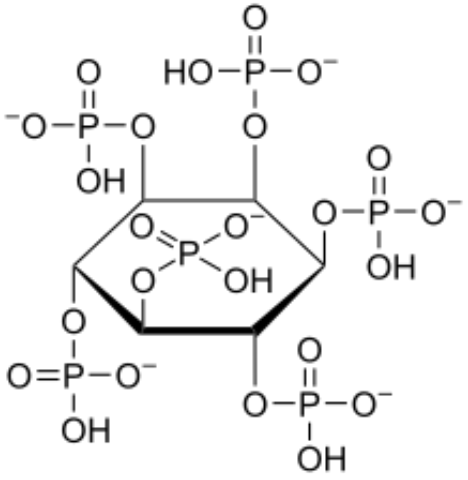
- Feedback inhibition and substrate inducement may operate in a tug-of-war



- Phosphatase can be produced in response to C deficiency: equally as C enzyme as much as P enzyme



Nucleic acid



Phytate

Takeaways

- Is there a basis for a P credit? **Yes**
  - Differs by soil type beyond 'just' OM, organic P and soil test P
- Across soils and managements, potentially mineralizable P was 5- to 7-fold greater at 68°F vs 50-41°F, indicating robust temperature sensitivity
- Potentially mineralizable P related…
  - …strongly to total soil organic P
  - …less strongly to total soil organic C, reflecting variation in C:P ratio of OM (23-62), which is
  - …unrelated to C:P ratio of OM
- "Phosphatases", soil enzymes that are a common soil health indicator, are somewhat related to potential P credit
  - V_{max} but not K_m
- Fundamental work is needed on how enzymes relate to nutrient supply power (P_{min} + N_{min}) to enable interpretation of activities


Questions?