Improving K rate recommendations by recognizing soil K pools with dissimilar bioavailability

Michael Bell[1], Philip Moody[2], Michael Thompson[3], Christopher Guppy[4], Antonio P Mallarino[3], Keith Goulding[5].

[1]School of Agriculture and Food Sciences, University of Queensland, Australia.

[2] Queensland Department of Science, Information Technology and Innovation, Australia.

[3]Department of Agronomy, Iowa State University, USA.

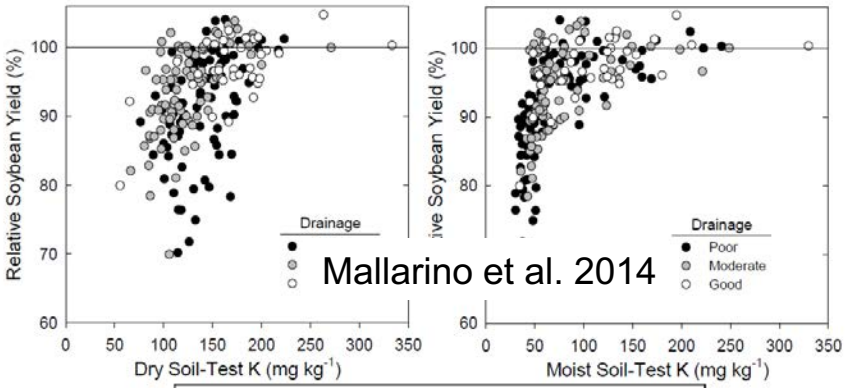
[4] University of New England, Armidale, NSW, Australia.

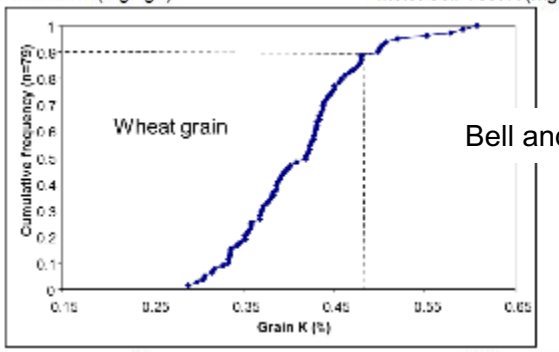
[5] Rothamsted Research, Harpenden, Hertfordshire, United Kingdom.

The University of Queensland Australia | Queensland Alliance for Agriculture & Food Innovation | Queensland Government | Iowa State University Department of Agronomy | une University of New England | Rothamsted Research

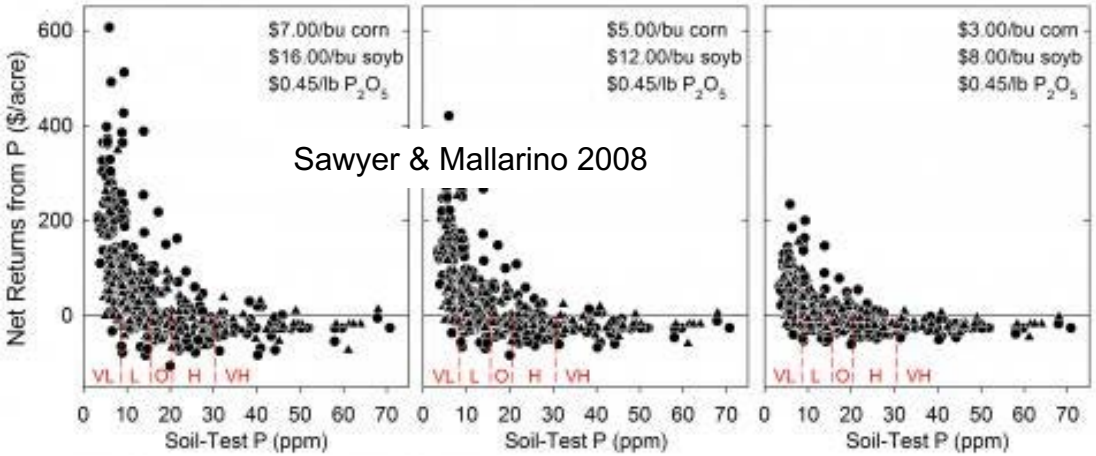
TO IMPROVE FERTILIZER RECOMMENDATIONS WE NEED…

1. The likelihood of a productivity response to applied nutrient
2. A crop-specific nutrient budget (the rate of removal in harvested product)
3. A benefit:cost analysis of the return from fertilizer investment





Bell and Klepper 2009



Sawyer & Mallarino 2008

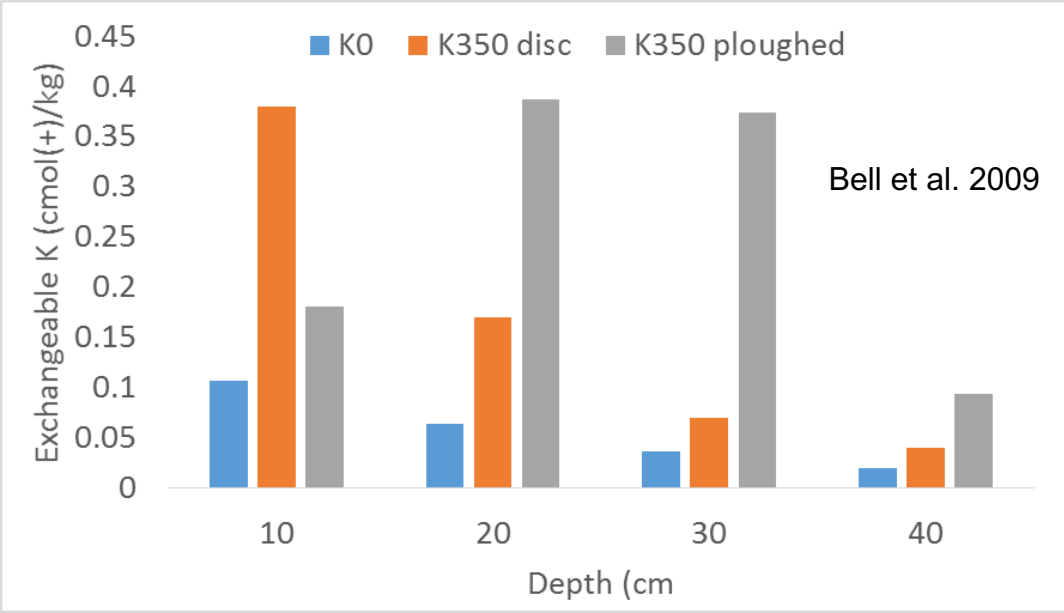
STEPS 2 & 3 ARE PRETTY STANDARD, BUT WITH K THE 1ST STEP IS THE PROBLEM!

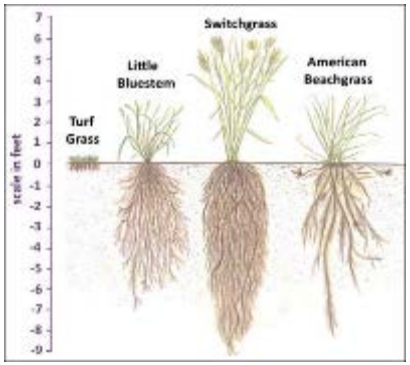
- There are real problems with reliable prediction of a K response.
- Issues are a combination of –
  - Soil sampling strategy (which depth increments need to be considered)
  - Sample handling
  - Analytical methodology
  - Interactions between soil properties (physical as well as chemical) and K application method on availability for crop uptake.
  - Stress (drought/frost) inducing K responses in otherwise non-responsive soils
  - A lack of regional and soil type-specific K research

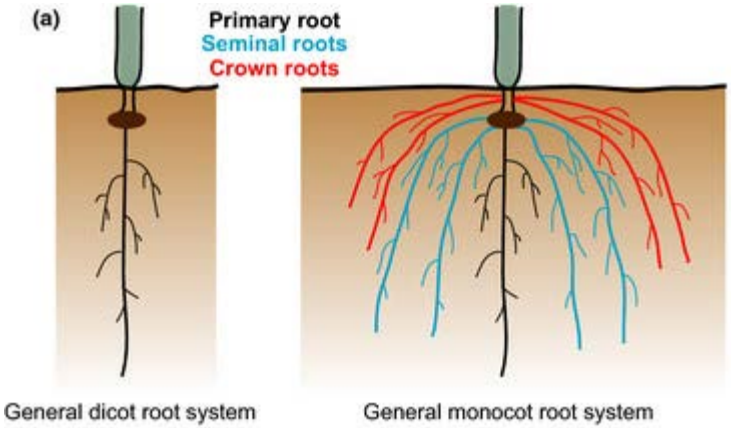
WHY IS THIS SO HARD?

There are a number of contributing factors –

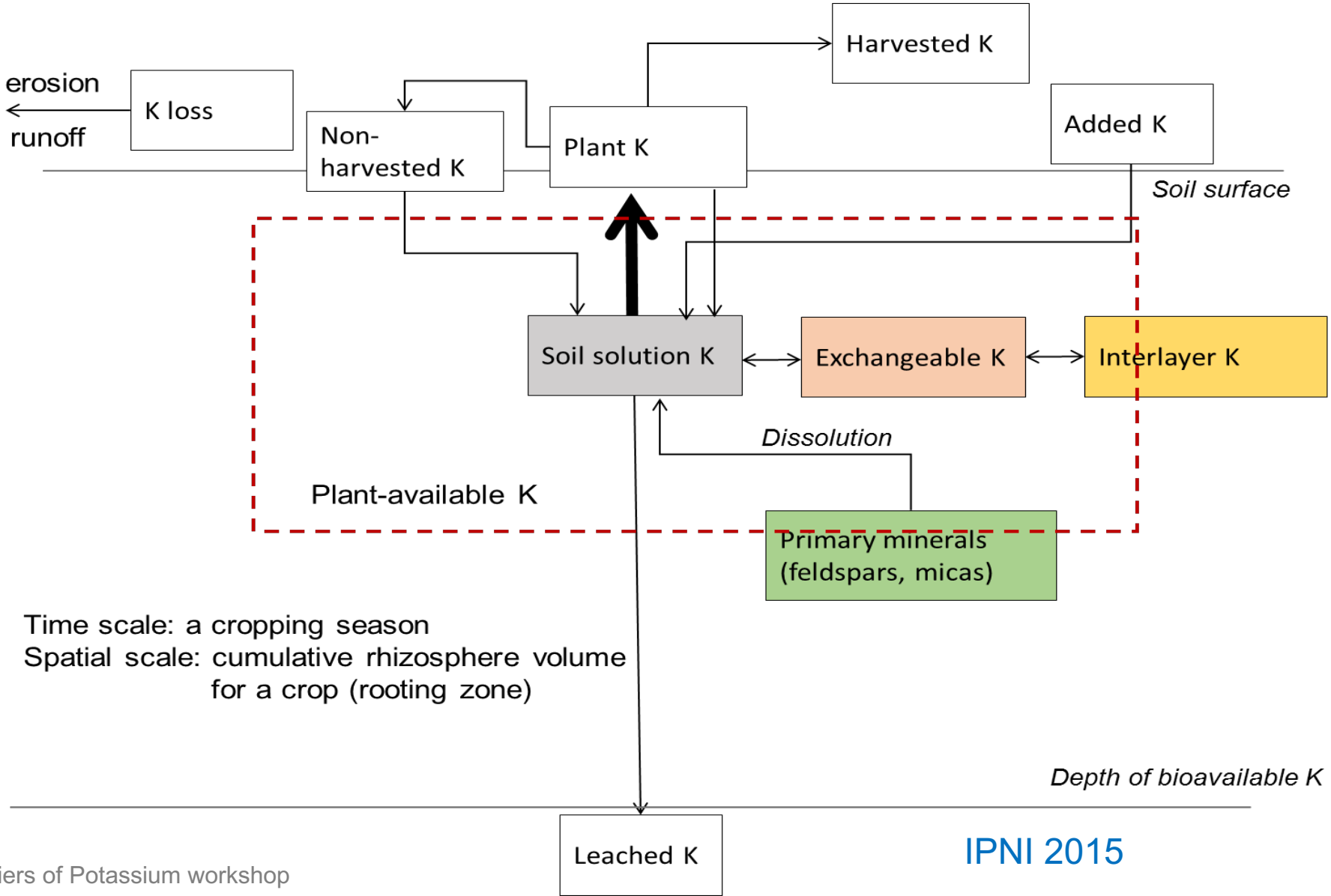
1. Dealing with an immobile nutrient, so fertilizer placement and root distribution combine to influence K acquisition.
2. Crop species (and genotypes) have different root systems, which may respond differently to fertilizers and management.
3. There are different pools of K in soils, with different (and in some cases unpredictable) bioavailability. All pools are not present in all soils.







THESE WERE THE POOLS AS DEFINED IN THE HAWAII WORKSHOP



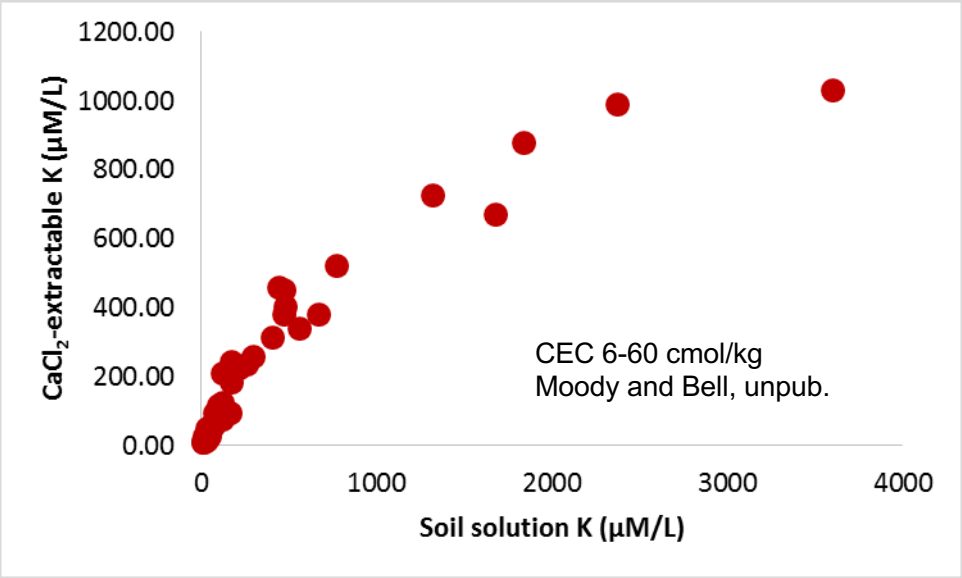
IPNI 2015

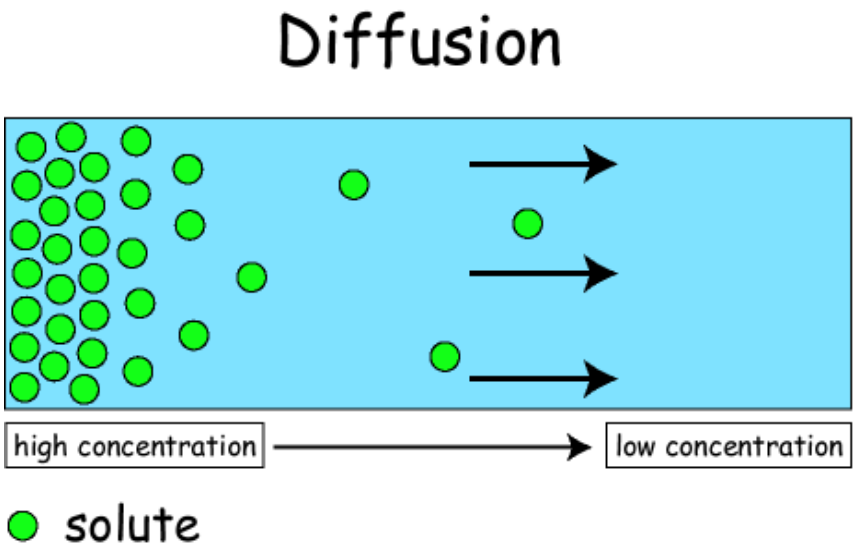
POOL CHARACTERISTICS AND FLUXES

- ***Soil solution K*** – small (0.1-0.2% total K) but most readily available for plant uptake. Quickly depleted without diffusion from surrounding soil solution, or replenishment from other K pools.
- ***Exchangeable K*** – larger pool (1-2% of total soil K) in rapid dynamic equilibrium with soil solution K. Quickly replenishes solution K depleted by roots. Still a small fraction of total soil K.
- ***Interlayer K*** – presence and behaviour dependant on mineralogy but can be a significant proportion of total K (1-10%). Fixation/release primarily governed by concentrations of K and competing cations in the soil solution.
- ***K in primary minerals*** – largest pool of soil K (90-98%). Release primarily by dissolution in response to low solution K. Plant root exudates and rhizosphere acidification can accelerate this process

SOIL SOLUTION K

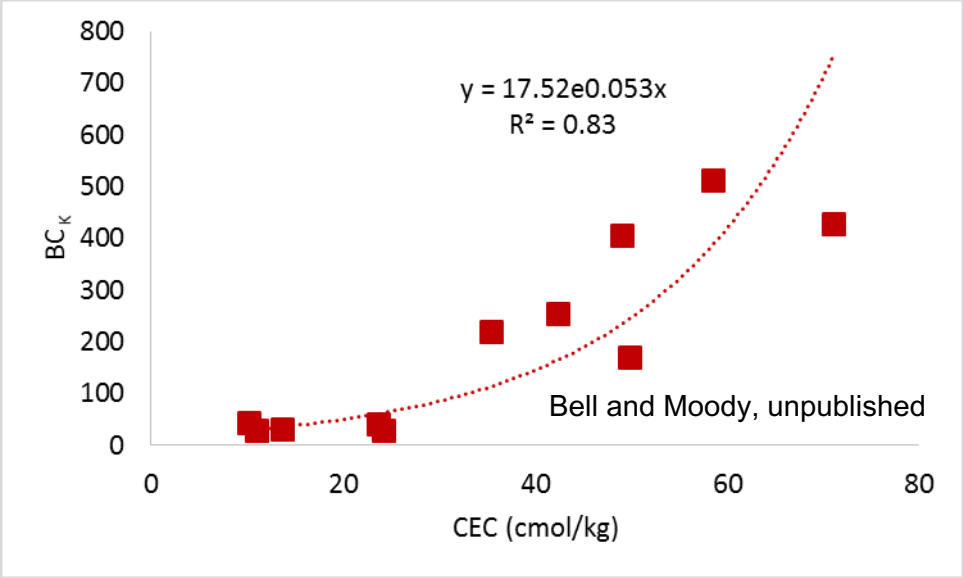
- Measurement methods well developed but rarely used to guide K fertilization strategies.
- Selective adsorption by clay minerals keeps solution K concns low (<1000uM), except in recently fertilized or high organic matter soils.
- Small quantities rapidly exhausted due to plant uptake.
- Key resupply processes
  - rates of diffusion from undepleted soil
  - quantity of readily desorbable K on exchange sites.

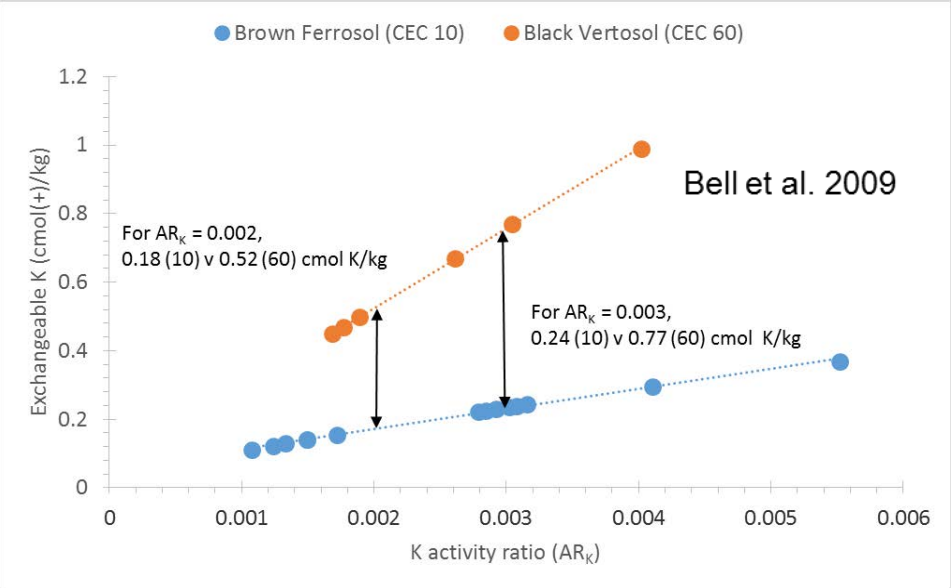




SOLUTION K - OTHER CONSIDERATIONS

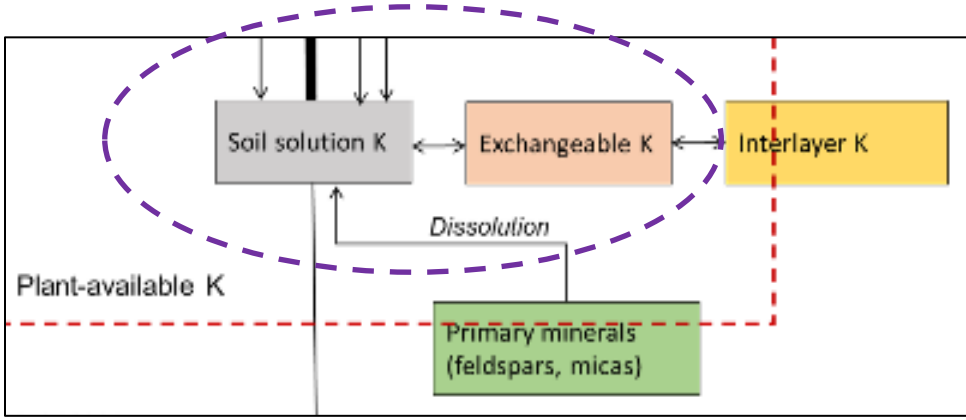
- Moderating effects of other major cations (Ca, Mg & Na) on the replenishment of K from exchange sites are complex
- CEC impacts capacity of soils to buffer soil solution K (BC_K), at least in mineral soils.
- High CEC soils better able to buffer K removal …<u>but</u> have lower AR_K and less efficient root uptake. Will require higher K rates to increase AR_K.
- The implications of these trade-offs for plant K acquisition are still not well understood.

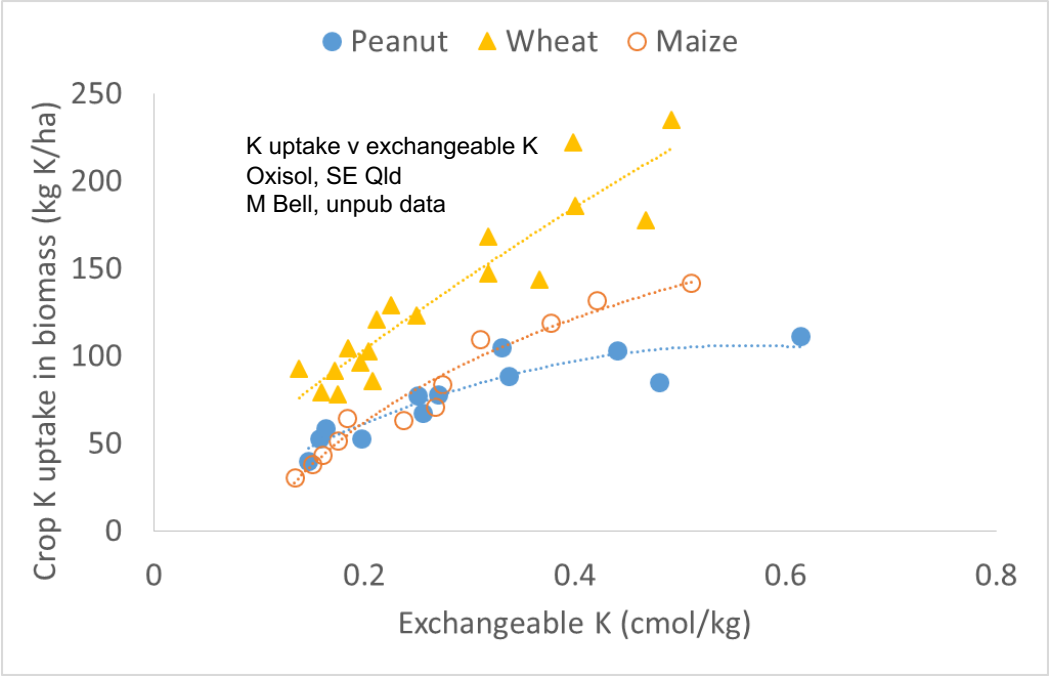




EXCHANGEABLE K

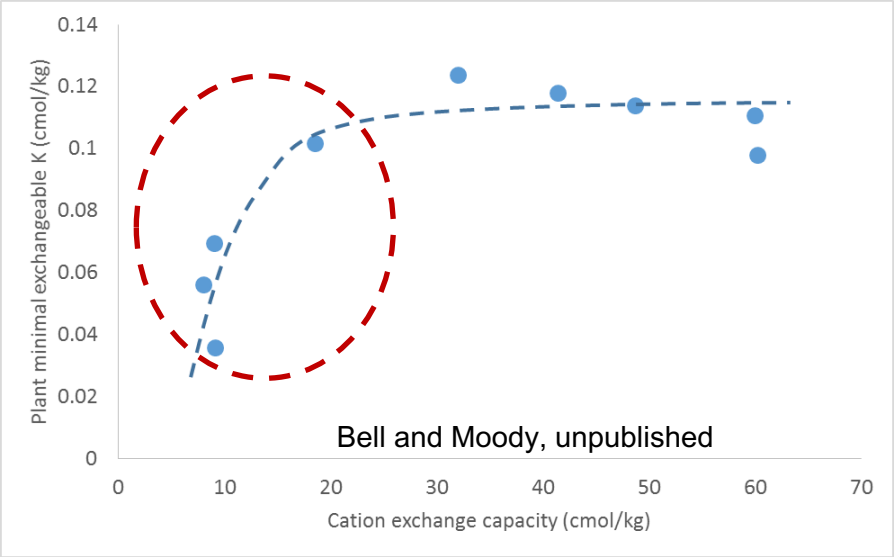
- The basis of most fertilizer K advice.
- Typically measured by displacing K^+ with NH_4^+.
- Short extraction times do not allow for significant contributions from slow release K pools.
- Is a good indicator of plant available K for a narrow range of mineralogies and locations.
- Difficulties arise when extrapolating to other soil types....

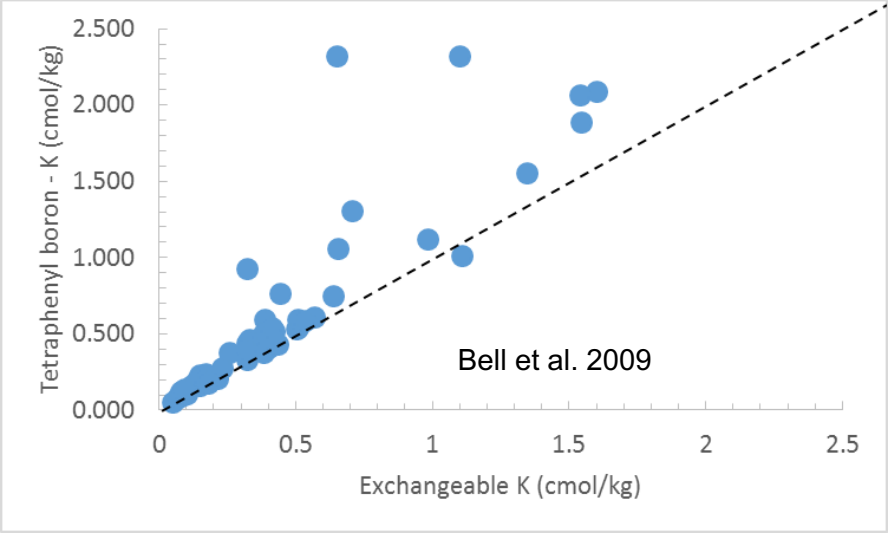




EXCHANGEABLE K – OTHER CONSIDERATIONS

- Not all exchangeable K may be extractable by plants, and the quantity increases with CEC (Schneider et al. 2016) - at least up to CEC 25.
- Soils with bioavailable mineral or interlayer K can significantly confound the relationship between exchangeable K and plant K uptake.
- No wonder we talk about 'site-specific' soil test K – crop response relationships!

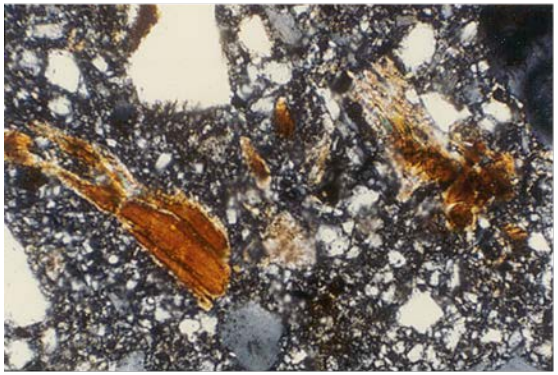


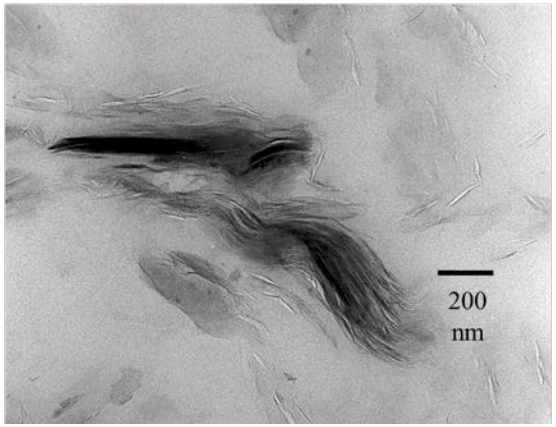


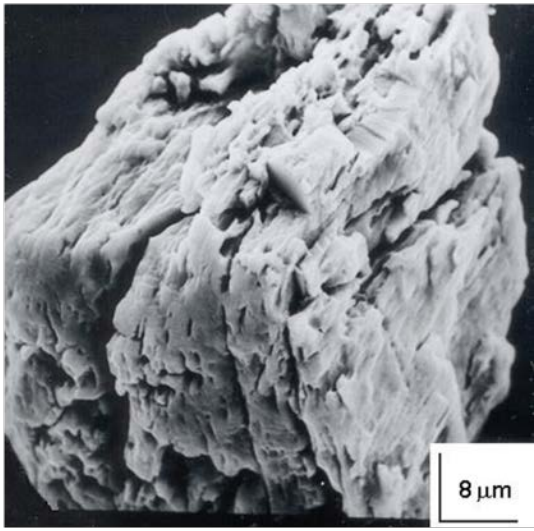
PRIMARY MINERAL K

- Main forms in soils are micas (biotite and muscovite) and feldspars (orthoclase and microcline).
- K is released by dissolution of the mineral framework during weathering, and release of interlayer K as layer charge declines.
- Low solution K concentration is a driver for K release. Acidic conditions and root exudates will accelerate release rates.

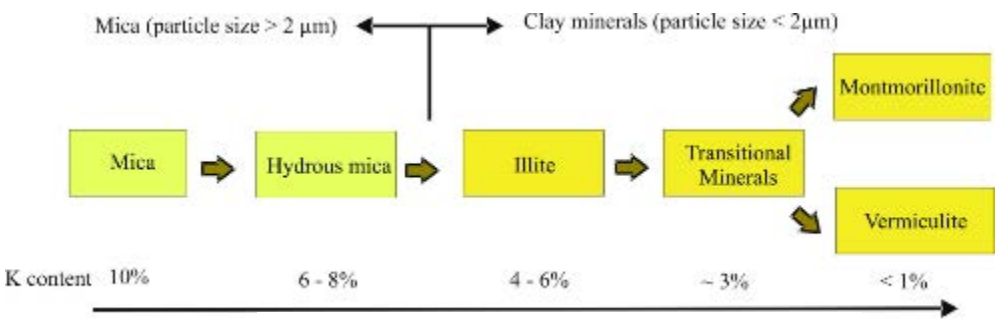
Weathered Micas







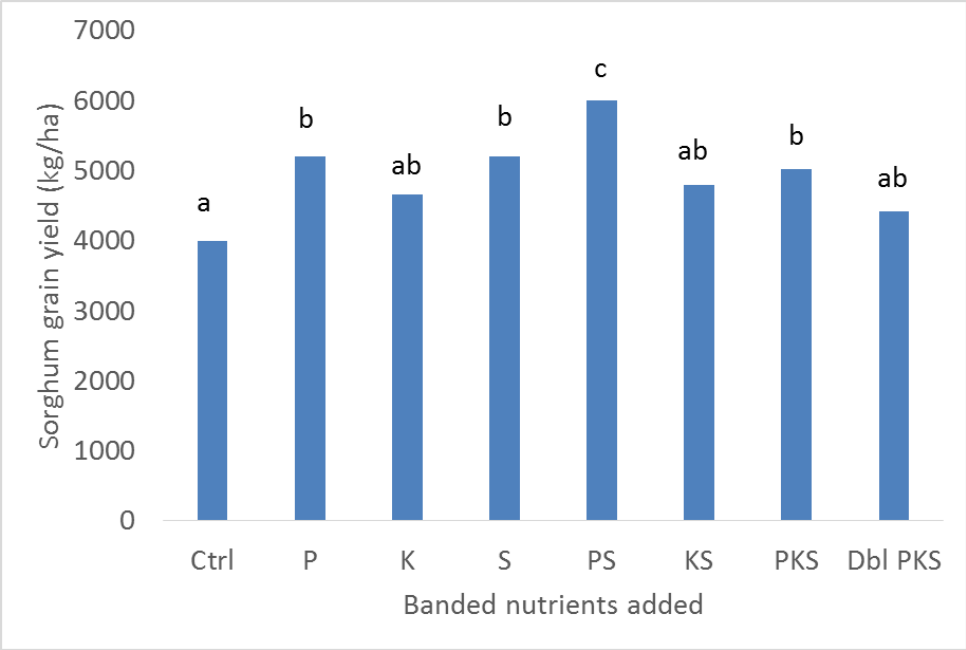
Images by ML Thompson



Increasing hydration, specific surface area and CEC (after Fotyma et al. 2013)

FERTILIZER REACTION PRODUCTS MAY CONTRIBUTE TO A 2^{O} MINERAL K POOL

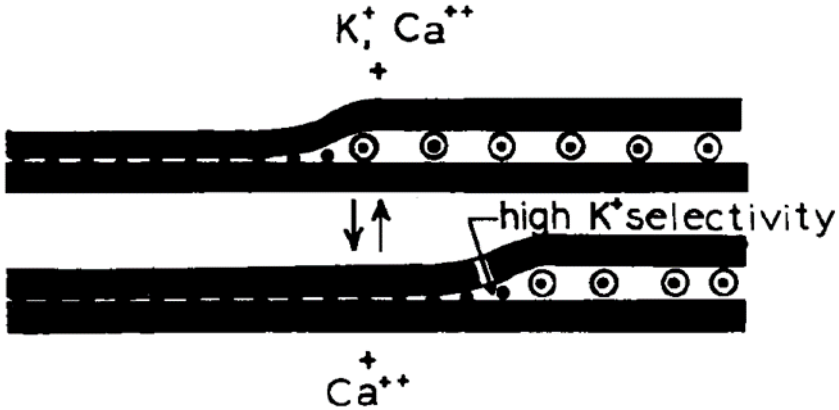
- Reported by Du et al. (2006) in acidic soils when MAP and KCl collocated.
- Circumstantial evidence of reduced P/K availability in sorghum grown on alkaline Vertosols with high in-band concentrations
- May reduce the efficacy of banding applications
- More research needed on in-band interactions, especially for row crops



(Bell and Lester, unpub. data)

INTERLAYER K IN 2° MINERALS

- Held between phyllosilicate sheets in 2:1 clay minerals, often in high affinity positions.
- <u>Release</u> is typically slow, facilitated by expansion of interlayer spaces when K is replaced by ions with larger hydrated radii. It is favoured by –
  - Wet soils
  - Low solution K concentration
  - High H^+ ion concentrations
- *Not surprisingly, release mainly occurs in the rhizosphere* (<2.5% of the soil volume)



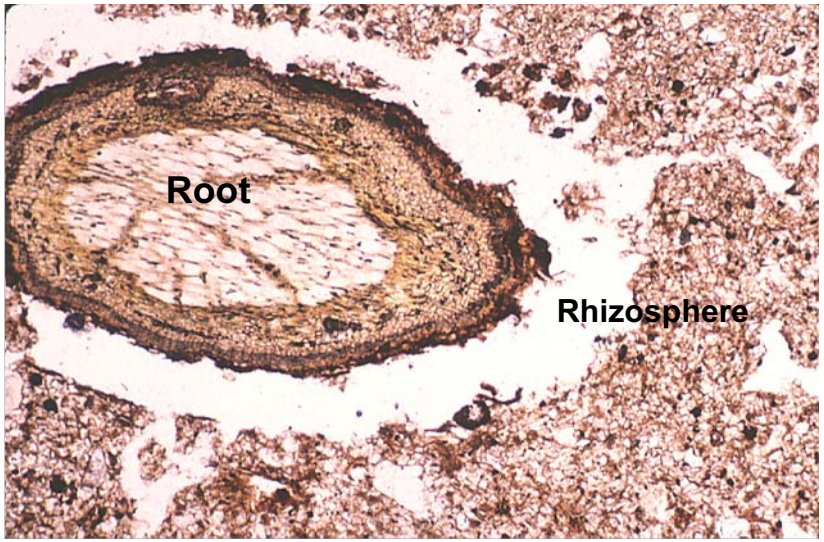
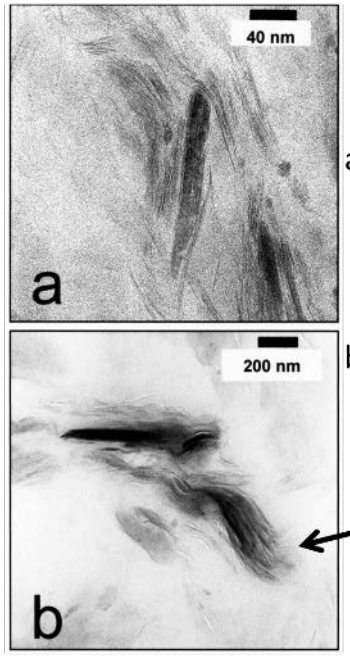


Image by ML Thompson

INTERLAYER K – THE DOWNSIDE!

- K exchange between interlayer positions and the soil solution is a two way process, driven by solution concentrations of K and competing cations.
- When fertilizer K is applied, K can re-enter the interlayer positions through <u>reversible fixation</u>.
- Unlike release, fixation can occur <u>throughout the fertilized soil volume</u>.
- Soils with the capacity to fix and release K increase the uncertainty of a fertilizer decision.



Images by ML Thompson

Sites for K fixation

a) Randomly interstratified mica-smectite in the fine clay (<0.2 µm) dispersed from Typic Argiudoll in Iowa.

b) Clay mica particle dispersed from a fine, smectitic, Quaternary paleosol in Iowa.

Note frayed, vermiculitic edges where monovalent cations such as K^+ or NH_4^+ might be fixed.

Fixed K

Edge sites: Di-vermiculite
Redox sites: Tri-verm and HC smectite
Interlayer sites: HIV and HIS

↑↓ **Redox processes, pH**

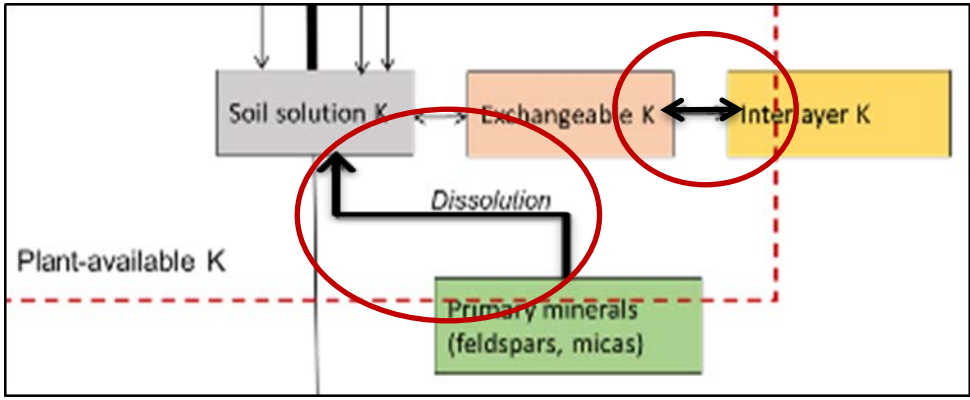
Exchangeable K

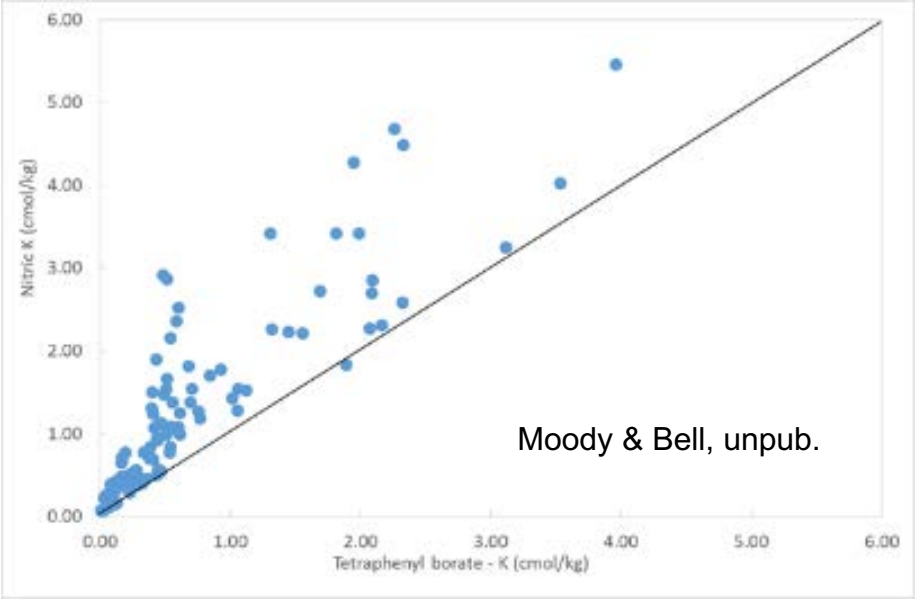
in clay minerals

(smectite, vermiculite)

DIAGNOSTIC TESTS FOR PRIMARY MINERAL AND INTERLAYER K POOLS

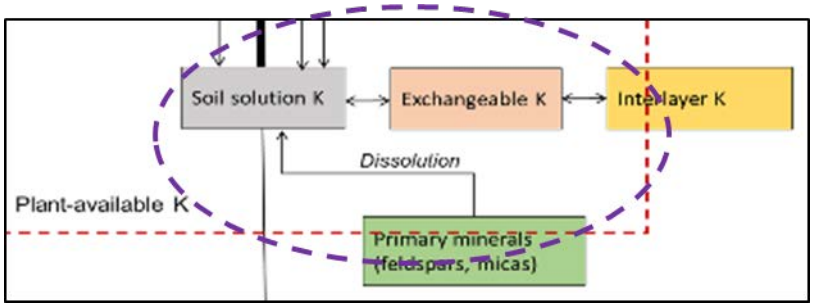
- Both pools can be a source for soil solution and exchangeable K, but…..
- Release of K from primary mineral pool is irreversible, while that from interlayer K is reversible.
- The widely used diagnostic tests do not discriminate, and by their modes of action (acidification versus lowering soil solution K) are not measuring the same things.
- Unsurprisingly they do not typically correlate with each other.

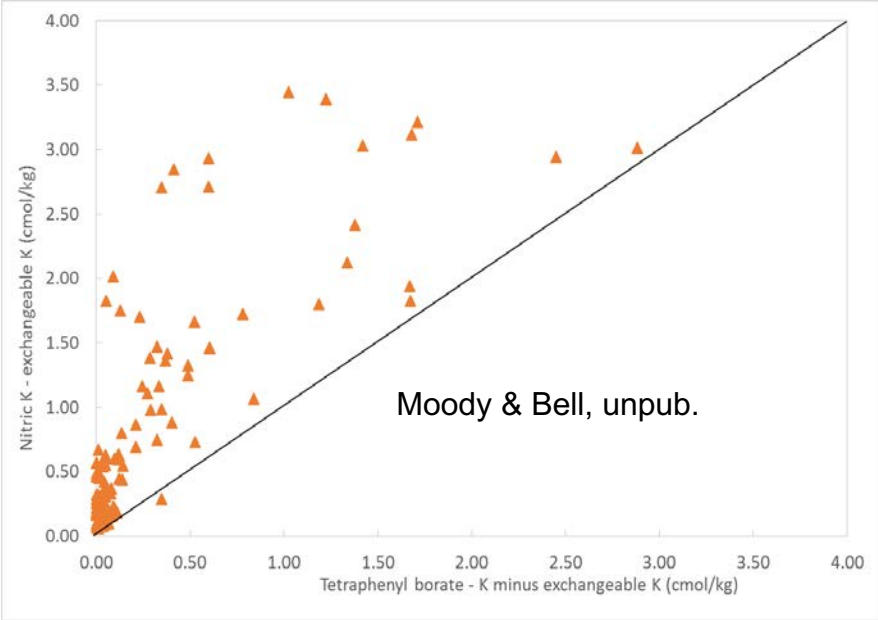




WILL USE OF TWO DIAGNOSTIC TESTS HELP?

- Both TB-K and Nitric K tests measure exchangeable K plus a proportion of either interlayer or primary mineral K or both
- Combining an exchangeable K test with TB-K or Nitric K can separate the 'readily available' and 'less available' K, but will measure different things in different soils
- Industries are therefore dealing with a diagnostic K 'pool' that could be termed 'slowly available', or after Hinsinger (2006), 'non-exchangeable K'. The constituents will change with soil type.
- Site specific soil test interpretation will be with us for some time.





UNDERSTANDING K RELEASE DYNAMICS ARE HARD ENOUGH, AND THEN WE ADD A PLANT..

- Plant roots modify the rhizosphere in different ways
  - Longer root hairs may deplete soil solutions further from the roots, as will those with more active high affinity K transporters.
  - Plant species will differentially acidify rhizospheres
  - Other plant species can release exudates involved in ligand-promoted dissolution of primary minerals
- Soil analysis will never deal with such complexity

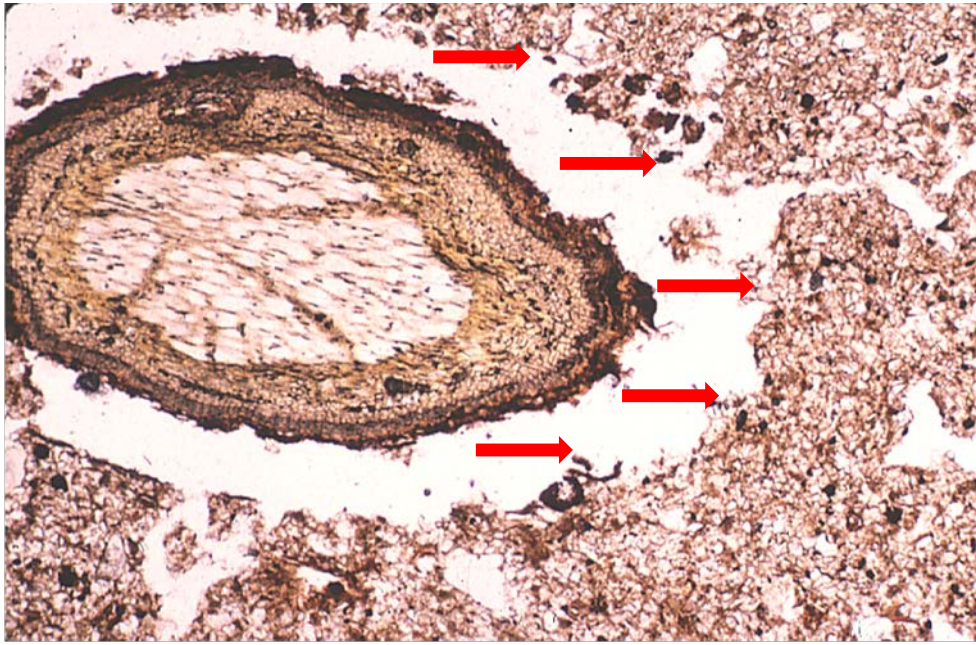


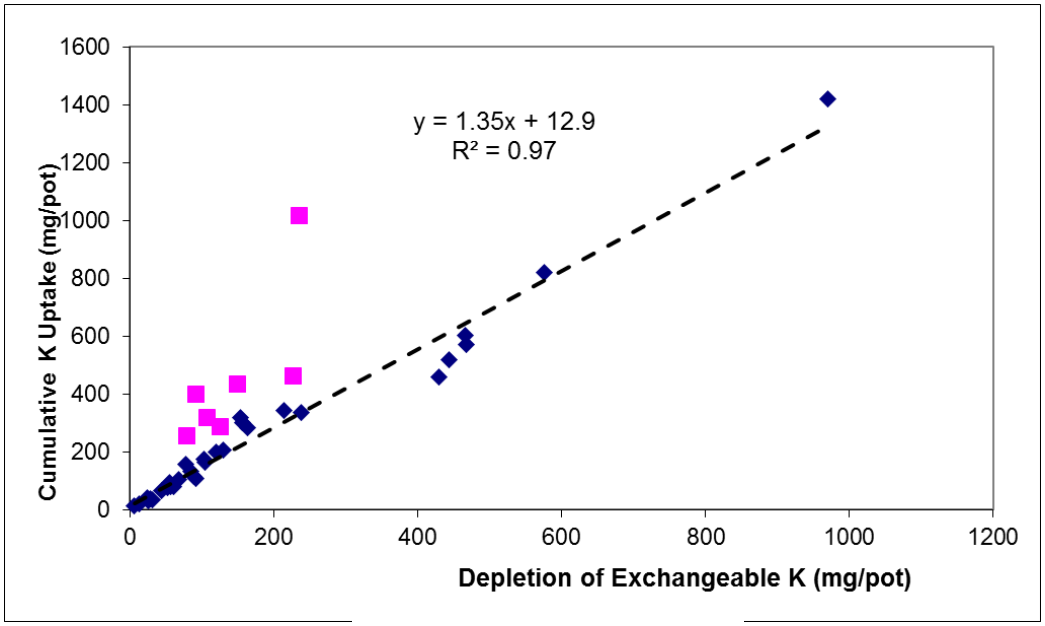
Image by ML Thompson

SO AT A HIGHER LEVEL, CLEAR AS MUD!

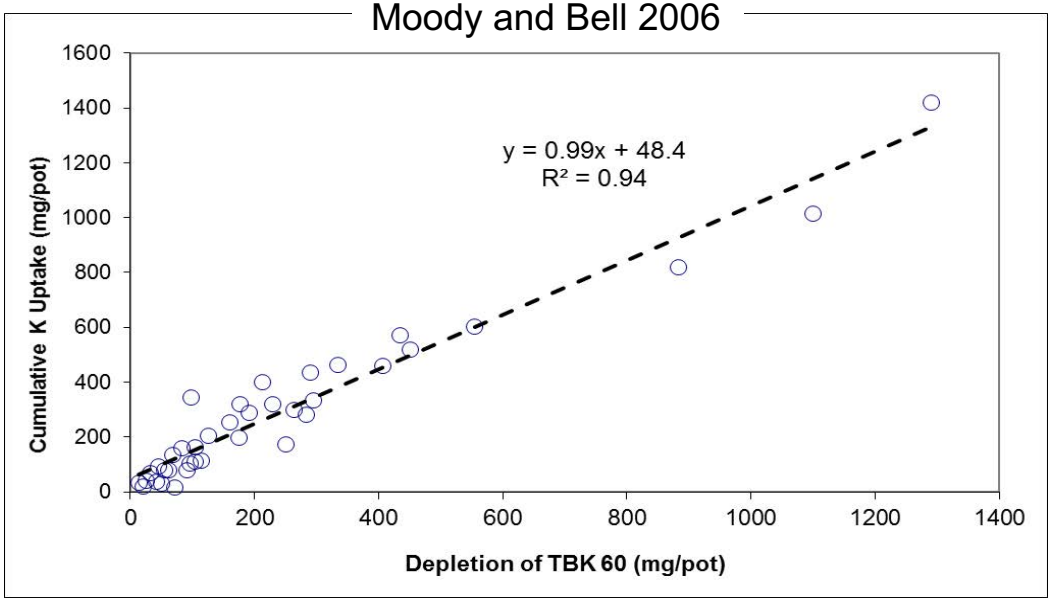
But what if we come back to a local scale – soil type and location??

KNOWING MORE ABOUT K POOLS IS NB FOR SOIL-SPECIFIC K ADVICE

- The first step is determining if there is any significant amount of non-exchangeable K, and that it is bioavailable.
- Correlating soil tests with K depletion assays is a good first step



Moody and Bell 2006

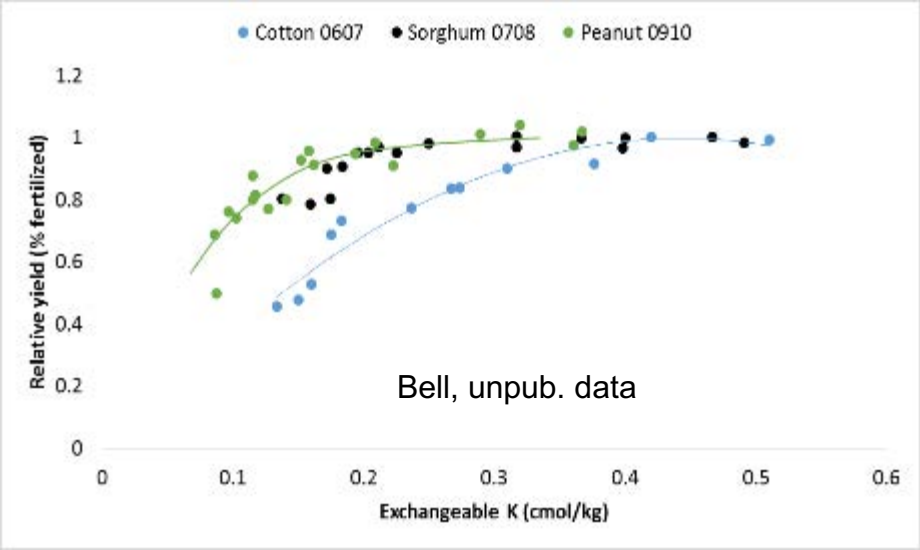


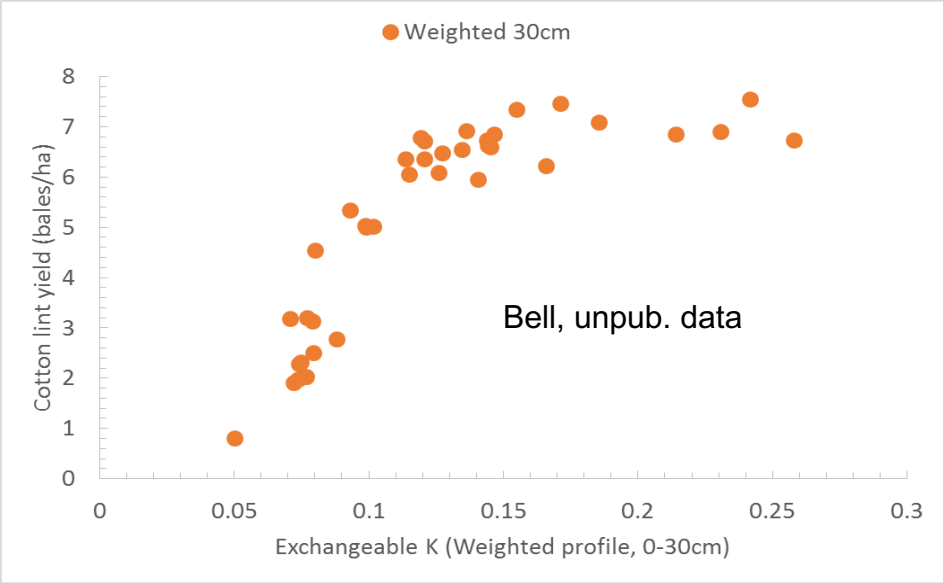
IN THE ABSENCE OF 'SLOWLY EXCHANGEABLE' K, THINGS ARE (RELATIVELY) SIMPLE

You will still have..

- Likely stratified reserves;
- Variable moisture conditions in crop; and
- Different crop species with different root systems in a rotation…..

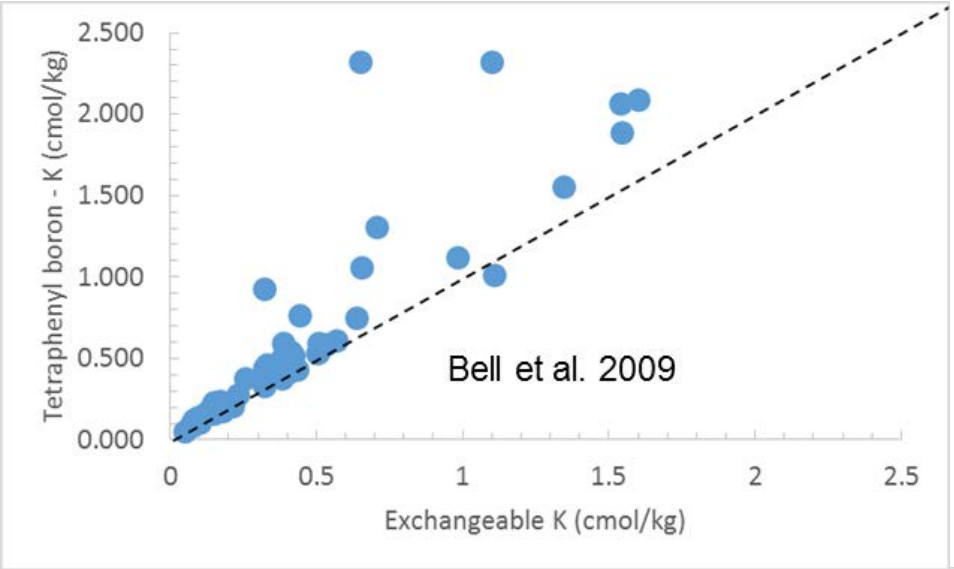
- BUT…well calibrated soil test-crop response relationships can be developed.
- Weighted profile samples can account for variation in access to different soil layers

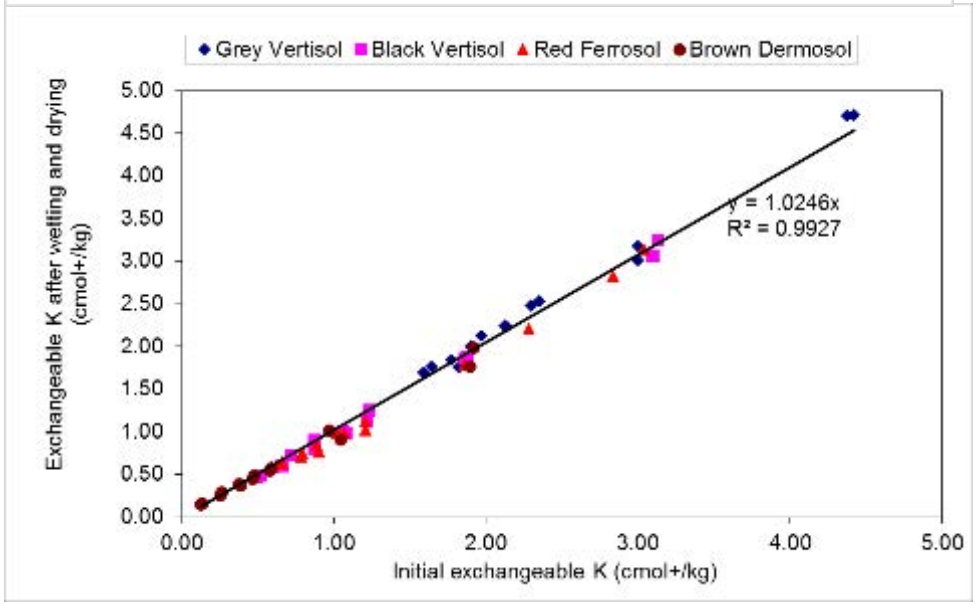




WITH 'SLOWLY-EXCHANGEABLE K', DETERMINE IF THERE IS INTERLAYER K

- The difference between exchangeable and TB-K/Nitric K will provide an indication of the 'pool' size.
- Correlation with plant removal will indicate bioavailability, while graded TB-K extraction times may indicate release rates
- Tracking the fate of applied K, especially in K-depleted soils, will indicate capacity for fixation.





INTERLAYER K REPRESENTS THE GREATEST CHALLENGE

- How much do you have, especially relative to primary mineral and exchangeable pools?
- How rapidly does fixation and release occur, relative to critical stages in the growing season?
- Can a simple laboratory test, analogous to the single point P buffer index, be useful in this regard?
- These would be fruitful areas for further research

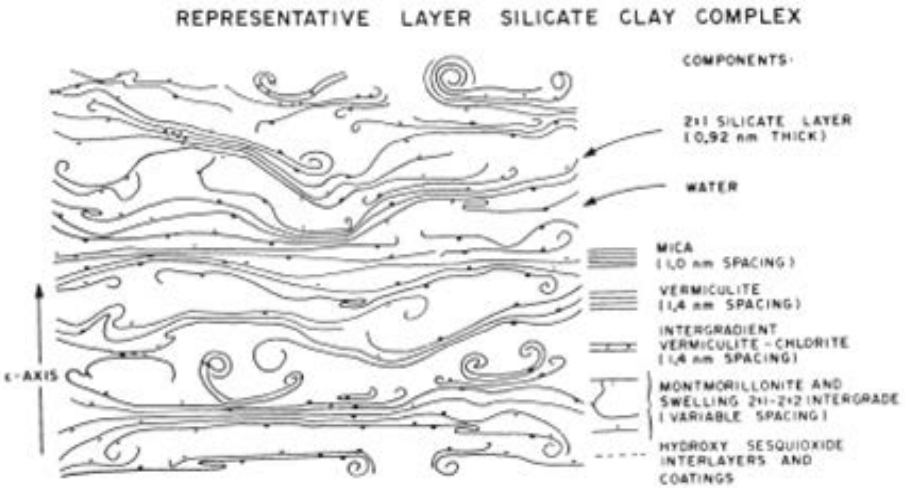


Fig. 4–5. Principal features of a dominantly montmorillonite layer silicate clay complex formed by weathering of mica. Different proportions of the various components occur in mica-derived layer-silicate clays of different soils and other sediments (Jackson, 1964) (illustration by G.A. Borchardt).

CONCLUSIONS

- We need to better understand the size of different K pools and their relative bioavailability to improve fertilizer decisions.
- Exchangeable K will remain the benchmark for the coming crop season. Interpretation will improve if combined with a measure of non-exchangeable K and its bioavailability.
- The variability in mineralogy and impact of soil and plant factors on K release will likely mean understanding of non-exchangeable K dynamics will remain more qualitative than quantitative in the context of a crop fertilizer budget.
- There is a need to develop commercially adoptable refinements to soil K testing (e.g. a KBI) that will help predict the fate of applied K fertilizer.
- Soil test – crop response relationships for K will likely remain site and soil type specific unless more quantitative diagnostic assays for bioavailable, non-exchangeable K pools are developed.

ACKNOWLEDGEMENTS

- We would like to thank IPNI for their role in promoting this international K initiative, and for supporting this conference and subsequent activity.
- We acknowledge the support of our respective host organizations, and the funding support of the agricultural industries in our respective home countries.
- We look forward to a resurgence in interest in K nutrition, and to opportunities to collaborate with participants internationally to advance the cause of efficient and effective K management in sustainable agricultural systems.

ROTHAMSTED RESEARCH

THE UNIVERSITY OF QUEENSLAND AUSTRALIA | Queensland Alliance for Agriculture & Food Innovation | Queensland Government | une University of New England | IOWA STATE UNIVERSITY Department of Agronomy