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

Michael Bell¹, Philip Moody², Michael Thompson³, Christopher Guppy⁴, Antonio P Mallarino³, Keith Goulding⁵.

¹School of Agriculture and Food Sciences, University of Queensland, Australia.
²Queensland Department of Science, Information Technology and Innovation, Australia.
³Department of Agronomy, Iowa State University, USA.
⁴University of New England, Armidale, NSW, Australia.
⁵Rothamsted Research, Harpenden, Hertfordshire, United Kingdom.
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
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.

Bell et al. 2009
THESE WERE THE POOLS AS DEFINED IN THE HAWAII WORKSHOP

K loss

Non-harvested K

Plant K

Soil solution K

Exchangeable K

Interlayer K

Harvested K

Added K

Soil surface

Erosion

Runoff

Plant-available K

Dissolution

Primary minerals (feldspars, micas)

Time scale: a cropping season
Spatial scale: cumulative rhizosphere volume for a crop (rooting zone)

Depth of bioavailable K

Leached K

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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 ...but 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.

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Bell and Moody, unpublished

![Graph showing the relationship between CEC and $BC_K$.](image)

![Graph showing the relationship between AR$_K$ and exchangeable K.](image)

Bell et al. 2009

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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!
• 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.
FERTILIZER REACTION PRODUCTS MAY CONTRIBUTE TO A 2° 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 2º MINERALS

- Held between phyllosilicate sheets in 2:1 clay minerals, often in high affinity positions.
- Release 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)
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 reversible fixation.
- Unlike release, fixation can occur throughout the fertilized soil volume.
- Soils with the capacity to fix and release K increase the uncertainty of a fertilizer decision.

Sites for K fixation

- Randomly interstratified mica-smectite in the fine clay (<0.2 μm) dispersed from Typic Argiudoll in Iowa.
- Clay mica particle dispersed from a fine, smectitic, Quaternary paleosol in Iowa.

Note frayed, vermiculitic edges where monovalent cations such as K⁺ or NH₄⁺ 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.

Moody & Bell, unpub.
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.

Moody & Bell, unpub.

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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
SO AT A HIGHER LEVEL, CLEAR AS MUD!

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

Bell, unpub. data
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.
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.
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• 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.